Strategies for Sustainable Land Management in the East African Highlands

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Edited by John Pender, Frank Place, and Simeon Ehui

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Foreword

Land degradation is a severe problem in the densely populated highlands of East Africa and elsewhere on the African continent. Soil erosion resulting from cultivation on steeply sloping terrain, mining of soil fertility due to continuous cultivation with limited application of inorganic or organic sources of soil nutrients, and deforestation and overgrazing of rangelands are among the key factors causing low agricultural productivity, widespread poverty, and food insecurity in the region. Finding ways to achieve more sustainable and productive land management is an urgent need, requiring policy, institutional, and technological strategies that are well targeted to the heterogeneous landscapes and diverse biophysical and socioeconomic contexts found in the East African highlands. This volume helps to address this information need.

The book is based on papers originally presented at the conference "Policies for Sustainable Land Management in the East African Highlands," held at the headquarters of the United Nations Economic Commission for Africa (UNECA) in Addis Ababa in April 2002. That conference was sponsored by the International Food Policy Research Institute (IFPRI); the International Livestock Research Institute (ILRI); the World Agroforestry Centre (formerly ICRAF); the East and Central Africa Program for Agricultural Policy Analysis (ECAPAPA); the African Highlands Initiative (AHI); the Soil, Water and Nutrient Management Program (SWNM) of the CGIAR; the United Nations Economic Commission for Africa (UNECA); and the Regional Land Management Unit (RELMA) of the Swedish International Development Cooperation Agency (Sida). The material focuses on land management issues in Ethiopia, Kenya, and Uganda, which include most of the people and area of the East African highlands.

The book reports the results of a large number of careful empirical studies of livelihoods and land management, showing that different strategies are needed for different contexts in the East African highlands and illustrating promising options for major development domains based on the theory of comparative advantage. In *areas of high agricultural potential and favorable market access,* a virtuous circle is possible, in which promotion of high-value commodities and nonfarm activities can facilitate improved land management, as observed in central Kenya. Investments in infrastructure and market institutions, a supportive policy environment, and efforts to address pest and disease problems are keys to success in such areas. In *areas of high agricultural potential but less favorable market access,* less perishable agricultural commodities—such as coffee and cereals—have comparative advantage. The development of market infrastructure and institutions for these commodities is particularly important, along with land management options, such as the promotion of inorganic fertilizer and improved seeds. In *areas of lower agricultural potential,* the comparative advantage is less in high-value crops or intensive cereal production, except where irrigation is available, and more targeted use of costly inputs is needed. Investments in livestock, tree planting, beekeeping, and other livelihoods often yield higher returns in such environments, but they depend on effective institutions to manage common property resources, such as grazing lands, forests, and community woodlots, as well as community and household investments in soil and water conservation.

Beyond the need to consider different long-run comparative advantages, the studies in the book also demonstrate the importance of farmer-centered approaches to agricultural technical assistance and credit, giving adequate attention to the near-term profitability and risks of alternative approaches. Even well-intentioned interventions can have negative impacts on smallholders where they are not well suited to the needs and constraints of farmers.

The findings and implications of this book should be useful to policymakers and practitioners seeking to address problems of natural resource degradation and poverty in East Africa and elsewhere. Given the wide array of circumstances in the East African highlands, the situations studied are representative of a much broader set of circumstances. We hope that this study will contribute to productive policy change to achieve more sustainable and poverty-reducing land management in developing countries in general.

Joachim von Braun
Director General, IFPRI

Acknowledgments

Many individuals and organizations contributed to the realization of this book. First we thank all the authors who contributed chapters to the volume (see the list of contributors). We particularly appreciate their patience since they first presented their papers in April 2002 at the Addis Ababa conference "Policies for Sustainable Land Management in the East African Highlands," which led to the publication of the book. We also thank the reviewers of the manuscript. Their detailed and constructive comments greatly enhanced the quality of the chapters in the book.

The April 2002 conference was made possible with the sponsorship of several organizations, including the International Food Policy Research Institute (IFPRI); the International Livestock Research Institute (ILRI); the World Agroforestry Centre (formerly ICRAF); the East and Central Africa Program for Agricultural Policy Analysis (ECAPAPA); the African Highlands Initiative (AHI); the Soil, Water and Nutrient Management Program (SWNM) of the CGIAR; the United Nations Economic Commission for Africa (UNECA); and the Regional Land Management Unit (RELMA) of the Swedish International Development Cooperation Agency (Sida). We thank all of these organizations for their support of the conference and the research that led to it.

Many of the chapters in the book report results of a long-term research project carried out in Ethiopia by collaborators from IFPRI, ILRI, the Agricultural University of Norway (NLH), Wageningen University and Research Centre (WUR), Mekelle University (MU), the Tigray National Region Bureau of Agriculture and Natural Resources (TBANR), the Tigray Bureau of Planning and Economic Development (TBOPED), the Amhara National Region Bureau of Agriculture and Natural Resources (ANRBANR), the Oromiya Agricultural Development Bureau

(OADB), and the Ethiopian Agricultural Research Organization (EARO). The support provided to the research by the management and staff of these institutions is greatly appreciated. In addition, we are grateful to the members of our national advisory committee in Ethiopia—chaired by the vice minister of agriculture and including representatives of bureaus of agriculture and bureaus of planning from each of the three study regions and from the prime minister's office—who provided valuable guidance to the research. Funding for the research in Ethiopia was made possible through the generous financial support of the Swiss Agency for Development and Cooperation (SDC), the Norwegian Ministry of Foreign Affairs (NoMFA), the Netherlands Ministry of Foreign Affairs (DGIC), the Department for International Development (DfID) of the United Kingdom, the Government of Japan, the Italian Development Cooperation (IDC), and the U.S. Agency for International Development (USAID).

The research in Uganda was carried out by collaborators from IFPRI, the Center for Development Research of the University of Bonn (ZEF), the Makerere University Faculty of Agriculture (MUFA), the National Agricultural Research Organization (NARO), and the Agricultural Policy Secretariat (APSEC). It was made possible through the generous financial support of NoMFA, the German Federal Ministry of Technical Cooperation (BMZ), USAID, and DfID. We are especially grateful to MUFA, NARO, and APSEC for their collaboration in and support of the research in Uganda, and to the members of our national advisory committee, which was chaired by the dean of MUFA and included senior officials representing the Ministry of Agriculture; NARO; APSEC; the National Environmental Management Authority; the Ministry of Lands, Water and Environment; the Uganda Soil Fertility Initiative; the Uganda Local Authorities Association; and the Uganda National Farmers Association. We are also grateful to the International Center for Tropical Agriculture (CIAT) and the African Highlands Initiative (AHI), which collaborated with the IFPRI research team in their study sites in Iganga and Kabale Districts, respectively.

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Most of all, we are grateful to the many smallholder farmers and community leaders who patiently participated in our surveys and group interviews. We hope that this book will help policymakers and other decisionmakers in East Africa and beyond identify and implement more effective strategies to help rural people in the highlands find effective and sustainable pathways out of poverty and natural resource degradation. This book is dedicated to them.

The findings, interpretations, and conclusions expressed in this report do not necessarily reflect those of the World Bank, the members of its Board of Executive Directors, or the countries they represent, or those of IFPRI, ILRI, ICRAF, and their Boards and supporting organizations.

John Pender, IFPRI
Frank Place, World Agroforestry Centre
Simeon Ehui, World Bank (formerly of ILRI)

Chapter 1

Key Issues for the Sustainable Development of Smallholder Agriculture in the East African Highlands

Frank Place, John Pender, and Simeon Ehui

This book includes a series of studies of income strategies, land use, and agricultural dynamics and their impacts on welfare and natural resources in the highlands of Ethiopia, Kenya, and Uganda. There are several reasons for focusing on the highlands. First, the complex problems of severe poverty, low productivity, and poor natural resource management seem to be the rule rather than the exception. This is critical because the highlands support the majority of rural populations in the region. Second, within the highlands are some of the most densely populated areas in all of Africa. Thus, what happens in the highlands may provide pertinent insights for what is likely to happen as population density increases and agriculture intensifies in the rest of Africa in the future. Third, the highlands also contain a wide variety of agro-climatic conditions, from the semi-arid Tigray landscape to the lush humid highlands of Mt. Kenya, and vastly different market opportunities. The varying population density, agricultural potential, and market access conditions are representative of the variation found elsewhere in Africa. And finally, within the highlands are not only many areas beset by problems of poverty and low productivity but some real successes where farmers invest in agriculture and improved resource management and generate significant profits. Therefore, it is possible to understand how different conditions tend to lead to different evolution or intensification processes as well as which factors have been most critical in enabling some communities and farmers to prosper.

Despite the favorable climate and natural resource base that describes a sizable portion of the land area in East Africa, the region continues to languish with low rates of economic growth and high rates of poverty. The World Bank estimates per capita national income to be $100 in Ethiopia, $360 in Kenya, and $250 in Uganda in 2002 (World Bank 2003). Relative to other countries, that places Ethiopia among the most impoverished nations in the world. Similarly, the percentage of population undernourished in 1995 was 50 percent in Ethiopia, 40 percent in Kenya, and about 28 percent in Uganda (FAO 1999). For Kenya, this current situation reflects a stagnation or even deterioration during the late 1990s and early 2000s. Kenya's macroeconomy was hampered by a withdrawal of International Monetary Fund (IMF) support and complete lack of foreign direct investment. Overall, the Ethiopian economy has grown at a pace of 6 percent per annum over the past decade (Federal Democratic Republic of Ethiopia 2002), but this is tempered by periodic droughts and investment resources being diverted to the Eritrean war in the late 1990s. Moreover, the per capita income and poverty figures remind us just how far the economy has to go to bring forth significant poverty reduction. Noticeable improvements have taken place in Uganda, with average GDP growth rates of around 6 percent during the 1990s. However, this has not led to widespread employment generation or agricultural growth, and rural poverty rates are estimated to have increased from 37 to 42 percent from 1999 to 2002, after falling from 1992 to 1999 (Republic of Uganda 2003).

Agriculture continues to be the main livelihood for the populations of these countries. It is most important in Ethiopia, where 85 percent of the work force is engaged in agriculture and produces about 45 percent of the total gross domestic product (Demeke and Abebe 2003). In Uganda and Kenya, the percentage of agricultural labor to total labor is 80 percent and 75 percent, respectively (FAO 2004). In these two countries, however, the industrial and service sectors are relatively more developed and account for more than two-thirds of the value added in the economy. As in the rest of Africa, the poor of East Africa are overwhelmingly rural.

Although the highland areas of these countries include the most favorable agricultural production areas, they are also characterized by disappointingly high rates of poverty. Most of Ethiopia's population resides in the highlands, and, as will be seen below, much of the highland areas are not of high agricultural potential. In Kenya, there are stark contrasts in terms of poverty severity across the highlands. Rates are relatively low in the central highlands, near Nairobi, but the western Kenya highland districts (e.g., Vihiga, Kakamega, Kisii) are among the worst in terms of percentage of the population in poverty and incidence of disease (Republic of Kenya 2003). Already high poverty has been exacerbated by civil strife in parts of the Ethiopian and Ugandan highlands. One of the reasons for high rates of poverty is the extreme population density. The East African highlands contain the most densely populated rural areas in Africa, resulting in small landholdings. Another reason has to do with difficulties of transportation and communication because the rugged and difficult terrain in highland areas greatly increases the costs of establishing a dense road network.

Sadly, nonagricultural employment opportunities are not growing rapidly enough (imperceptible change in some areas) to provide the engine for a viable poverty reduction strategy for the short to medium term. Growth in the agricultural sector where most of the work force is located is a must for poverty reduction. For the countries as a whole, and for the highlands in particular, agricultural growth must be through intensification of production because there are no additional productive lands to be brought under cultivation. But intensification is not an easy task, as witnessed by the recent trends in smallholder communities of shrinking average farm sizes, low investment in agriculture, stagnant crop productivity, and visible signs of degrading resources. In fact, there are signs that the opposite is occurring in large areas of the highlands, where high rates of soil erosion and nutrient mining in many locations and farming systems have been reported (Bagoora 1988; Hurni 1988; Stoorvogel and Smaling 1990; Böjo and Cassells 1995; Tukahirwa 1996; Braun et al. 1997; Smaling, Nandwa, and Janssen 1997; Elias, Morse, and Belshaw 1998; Van den Bosch et al. 1998; Wortmann and Kaizzi 1998; Shepherd and Walsh 2002; Lesschen, Stoorvogel, and Smaling 2003; Nkonya et al. 2004, 2005b). Yet there is enormous potential for the highlands to be the food baskets for the region and beyond.

There are some successes to be sure, such as smallholder dairy and cash crop production in the central Kenya highlands (Minot and Ngigi 2004; Ngigi 2004). There, relatively high levels of investment in agriculture take place, a large number of profitable agricultural enterprises are adopted, a vibrant nonfarm economy has developed, natural resource management has improved, and poverty rates are low by regional standards. It is important to better understand the nature and causes of the nexus of problems that characterize the highlands as well as the ways in which successes have occurred. As will be seen throughout this book, there is no single type of problem or solution that dominates across the highlands. Rather there are different combinations of problems that result from numerous localized differences in terms of physical, climatic, ethnic, demographic, and economic factors. This means the identification of effective poverty reduction strategies requires attention to the prevailing circumstances, problems, and opportunities.

Key Objectives and Contributions of the Book

Objectives of This Book

The main objectives of the book are:

1. to identify different development pathways[1] that may be attractive for communities under different economic, political, agro-ecological, market, and demographic contexts;

2. to identify promising technological options that can catalyze or propel these development pathways; and

3. to identify the supporting policies and institutions that can lead to more effective management of community and household resources directly and through technological change.

Contributions of This Book

In support of the objectives, the chapters undertake empirical analysis of the following main research issues:

1. the factors determining comparative advantages of different income strategies, such as agricultural potential, access to markets and roads, and population pressure, and the impacts of these factors on agriculture, land management, and outcomes such as agricultural production, household income, and land degradation;

2. the impacts of income strategies on farmers' agricultural and land management practices and outcomes;

3. the impacts of agricultural and land management practices on outcomes; and

4. the impacts of numerous policy relevant factors—such as technical assistance programs, credit, education, local organizations, and land tenure arrangements—on agricultural and land management practices and outcomes.

This is not the first book to address these issues. Previous books have looked at agricultural intensification processes (Vosti and Reardon 1997; Lee and Barrett 2000), natural resource management, and agricultural technology (Sanders, Ramaswamy, and Shapiro 1995; Barrett, Place, and Aboud 2002). In general, the relevant existing literature comprises case studies that focus on analyses of household behavior in a small number of villages. When synthesized, they are able to provide insights into the importance of meso- and macro-level variables in shaping agricultural processes, but because they were not designed to do so, their comparative strength remains in assessing the importance of household-level factors. Even here, there are some gaps in that the case studies have often emphasized a subset of decisions undertaken by households, for example, technology adoption or soil management. There have been some recent studies focusing on specific factors affecting natural resource management, such as property rights and land tenure (e.g., Otsuka and Place 2001b) and the ability to attain collective action (e.g., Meinzen-Dick et al. 2002), but these have tended to have a more narrow focus.

This book provides evidence about how the different problems of poverty, low productivity, and natural resource degradation are linked to one another at household and community (or meso) scales. It also shows how the particular set of local problems and other conditions will lead to distinct comparative advantages. Such comparative advantages further tend to influence the types of income strategies and development pathways pursued by communities and the households within them. The studies attempt to show how decisions on income strategies, land management, and technology adoption are linked as well as how they impact on welfare and natural resources.

The book also recognizes that important conditioning factors or driving forces manifest themselves at the landscape or community level as well as at the household or individual level. That is, some communities, by virtue of their remoteness, may be poorer and have fewer growth opportunities than other more favorably located communities. But even in favorable communities, some households will lack sufficient skills or resources with which to seize available opportunities. Likewise, there are some households in unfavorable areas that are able to invest in agriculture and break out of poverty cycles. Attention to these distinctions permeates throughout the problem and intervention analyses in the book.

The studies in the book are designed to tackle these issues. They cover wide areas of the highlands with both meso- and micro-level data. Hence, important variations in climate, market access, population pressure, land tenure systems, and cultural practices have been purposefully included in data sets and analyzed. In addition, quantitative analyses have been applied to assess the strength of tendencies across varied sites as well as within sites sharing particular conditions. Within the context of agriculture and natural resource management interventions, the studies in this book also look broadly at a range of technical, institutional, and policy interventions. Indeed, other strengths of the book are its focus on exploring synergies and tradeoffs among different interventions in order to address complex problems as well as the need to alter sets of interventions to tackle diverse problem domains in different parts of the highlands.

Description of the East African Highlands

In this section, we describe some of the important features of the highlands and the national economic and political context in which highland households operate. These correspond first to conditioning factors, that is, those factors that are beyond the control of households, communities, and other decisionmakers and are largely fixed over time, such as altitude, rainfall, and soil type. A second set corresponds to what we call "driving forces," which are those variables that do change over time and may be influenced by decisionmakers. These include population growth and density, market access, and a host of government institutions and policies. We also provide brief descriptions of the distinguishing features of the agricultural and natural resource sectors. At the end, a few remarks are made about what we consider to be the key lessons from the description—some similarities, key differences, and what are likely to be the important variables that drive different income strategies and development pathways in the highlands that are to be explored in more detail in the following chapters. Chapter 2 will then examine these same factors in the framework of a conceptual model from which key hypotheses on cause–effect relationships may be formulated.

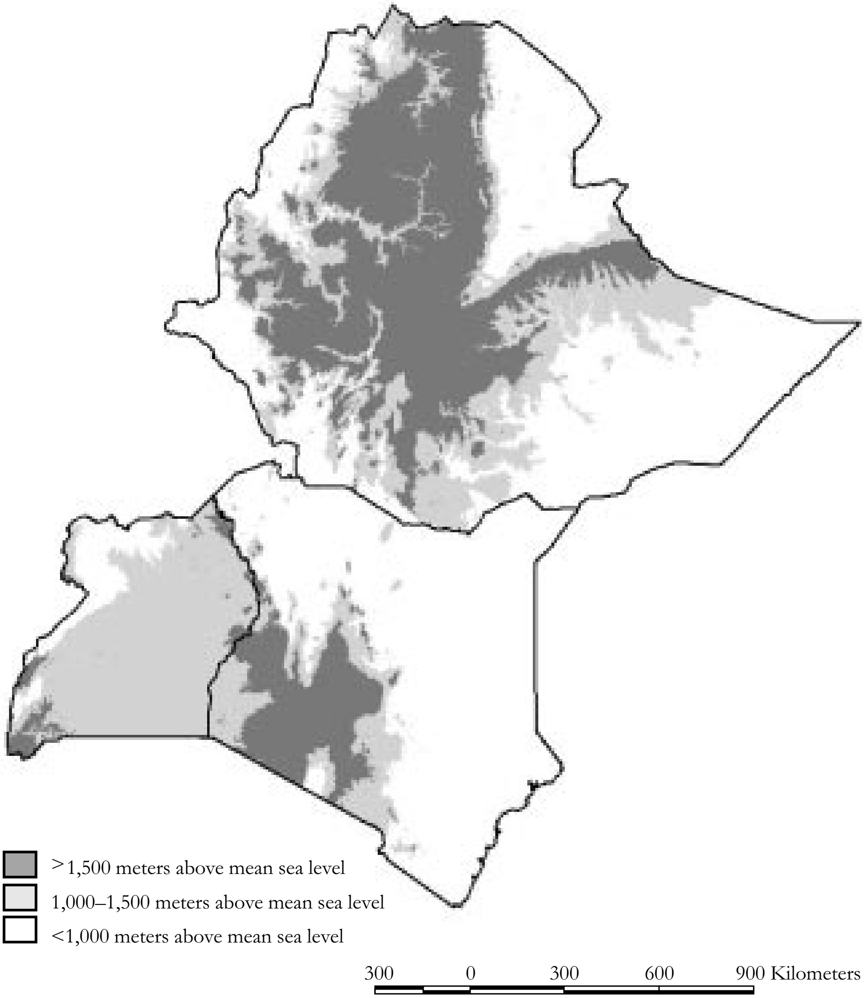
The Geography of the East African Highlands

Altitude and topography. The highlands constitute a large share of land in East Africa (consisting of Ethiopia, Kenya, Uganda, Rwanda, Burundi, and Northern Tanzania). Defined at 1,200 meters above sea level, the highlands comprise about 23 percent of the land area but are home to an even larger share of the population, 53 percent. The highlands are particularly important in Ethiopia, where they comprise 40 percent of the land area and as much as 81 percent of the population (Hoekstra and Corbett 1995; Alumira and Awiti 2000). In Kenya over half of the population resides in highland areas. Figure 1.1 shows the areas of Ethiopia, Kenya, and Uganda that are above 1,000 and 1,500 meters, respectively.

Another feature of the highlands is the wide variation in topography, often within small geographic areas. Common landscapes include hilltops, steep and moderately sloping land, relatively flat plateaus, and valley bottoms, both narrow and wide. Sloping areas represent the most fragile lands in the highlands, as they are highly susceptible to erosion, especially because intense rainfall events are common.

The topography leads to two important characteristics for farming. The first is that the climate can change dramatically within several kilometers as a result of the

Figure 1.1 Elevation map of the highlands of Ethiopia, Kenya, and Uganda



Source: Prepared by Meshack Nyabenge, World Agroforestry Centre.

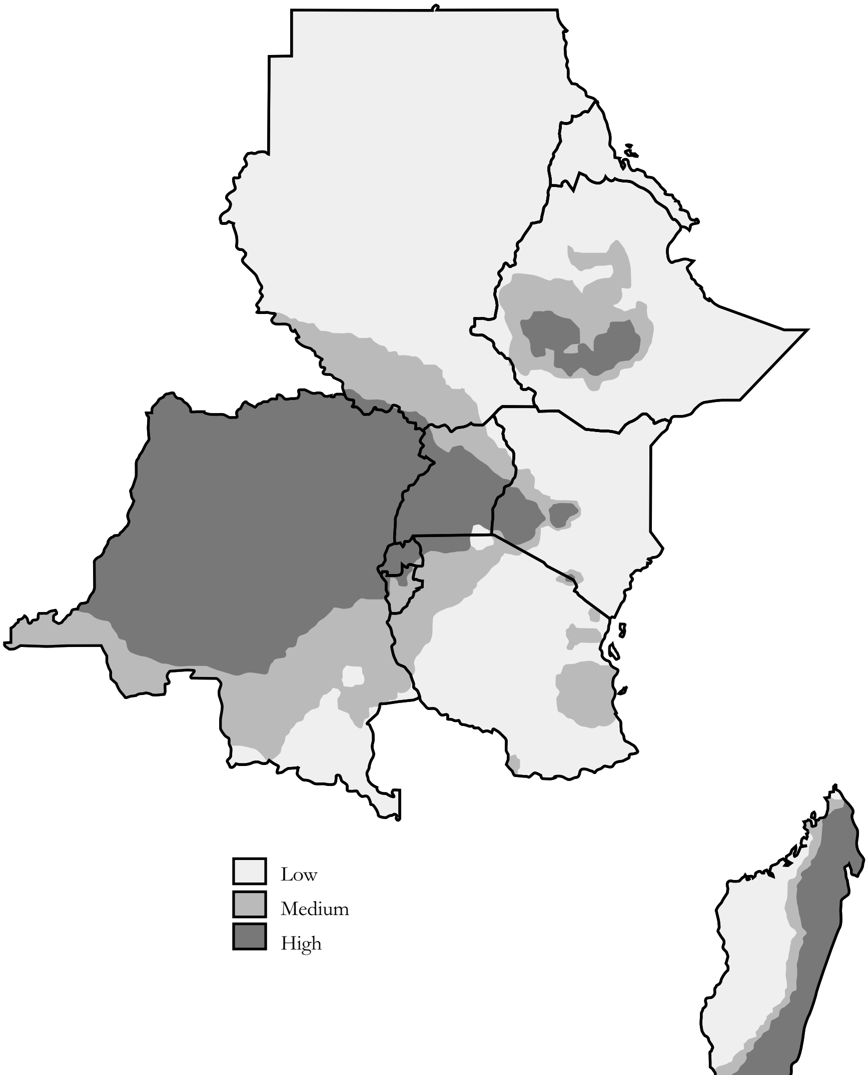
effects of mountains on wind and rainfall patterns. This is observed near Mt. Kenya, where the western slopes are dry compared to the humid southern and eastern slopes. It is also commonly observed in Ethiopia, where pockets of lush vegetation can be found within relatively dry zones (and vice versa). The second implication is that because of the microvariations caused by slope and toposequence, villages and even individual farmers are able to produce a range of crops.

Climate. There is considerable variation in the agricultural potential of highland areas. Some are characterized by high rainfall, two rainy seasons, and fertile volcanic soils, whereas others have low and erratic rainfall with poor inherent soil quality. The highlands for the most part have rainfall totals and patterns that compare very favorably with the rest of Africa. Most of the highlands have average rains of over 1,000 millimeters per year, and for many such sites, rainfall is distributed in a way that allows two growing seasons. In the Ugandan and Kenyan highlands, rainfall is generally 1,200 millimeters or more, rising to averages as high as 1,600 millimeters per year. There are some pockets of the Ugandan and Kenyan highlands that receive significantly less rainfall because of wind currents and mountain effects (e.g., the west of Mt. Kenya, some portions of the Rift Valley in Kenya, and the southeastern highlands in Uganda). Ethiopia is a different case. Its vast highland areas include a significant proportion of semiarid areas with rainfall as low as 400 millimeters per year in the northern and eastern parts of the region, whereas parts of the southern and western highlands received more than 2,000 millimeters per year. The rainfall patterns correspond well to variations in the length of the growing period, and these are displayed in Figure 1.2 for all of East Africa. All areas are prone to drought spells and torrential rains, both creating risks for agriculture. In addition, hailstorms are a feature of some highland areas, and western Kenya is particularly prone to such events (Place et al. 2004).

Temperatures in the highlands are moderated and do not normally exceed 30°C. Low temperatures may reach below 10°C at night, but frosts do not occur except at very high elevations.

Land use. Much of the highlands is under agriculture because of its suitability for cultivation and was settled by people early because it had a lower incidence of human diseases such as malaria. In general, there has been substantial conversion of forests and other natural habitats to agriculture. In both Kenya and Ethiopia, between 80 and 85 percent of original forest cover has been removed to make way for largely agricultural land uses (Earthtrends 2004). In Uganda, only 4 percent of the original forest cover remains, and the converted areas include much of the highlands. A study in medium-elevation central Uganda found that between 1960 and 1990, the share of woodland, forest, and bushland fell from 32 percent to 20 percent to make way for agricultural expansion (Place, Ssenteza, and Otsuka 2001). Nonetheless, the highlands continue to host tropical closed forests that remain important habitats for biodiversity and hosts of headwaters of major rivers, although these are much smaller than previously. These areas represent only 4.0 percent of total land in Ethiopia, 1.9 percent in Kenya, and 3.8 percent in Uganda (FAO 1995). In the drier portions of the highlands, such as in northern and eastern

Figure 1.2 Agroclimatic potential in eastern and central Africa, based on length of growing period



Source: Adapted from Fischer et al. (2001).

Ethiopia or the Rift Valley of Kenya, some of the highlands are covered with low dense woodland or bushland. In Ethiopia, because of the importance of livestock, communities have kept a portion of land under rangeland. In summary, a large proportion of the highlands is under agriculture, and cultivation in particular. Nonetheless, management of natural resources in the highlands is concerned not only with soil and water for agriculture but also with forest, woodland, and rangeland resources that can be vitally important locally.

Soils. There are a variety of soil types found in the highlands, such as nitosols, cambisols, ferralsols, and lithosols, with none being dominant. In Kenya and Uganda, most are relatively high in clay content and are deep. In fact, some mountainous areas have nutrient-rich volcanic soils. As a consequence, most of the highlands of Kenya and Uganda are considered to be medium- to high-potential areas and are expected to be major breadbasket regions. This is not the case in Ethiopia, where, because of its extensive highland area, soils of both inherently high and low potential can be found, including the difficult vertisols, hardpans, and sandy soils. Some of the major problems at the national level (i.e., not necessarily unique features of the highlands) are erosive soils in Ethiopia (31 percent of soils), Kenya (22 percent), and Uganda (16 percent); shallow soils in Ethiopia (30 percent) and Kenya (22 percent); and aluminum toxicity in Uganda (47 percent) (FAO 2000). These national estimates are supported by a number of site-level studies throughout the region that demonstrate high levels of soil erosion in the highlands of Ethiopia (Wright and Adamseged 1984; Hurni 1988), Kenya (van den Bosch et al. 1998; Angima et al. 2003), and Uganda (Bagoora 1988; Tukahirwa 1996).

Even in relatively intact soils, soil nutrient deficiencies are also common. Irrespective of the inherent or parent soil conditions, because of high population density, a large proportion of the highlands has been cultivated on a nearly continuous basis for many decades if not centuries. All the while, few inputs have been applied and conservation measures have been inadequate in most places (there are some exceptions of course, such as central Kenya). At the outset of the twenty-first century, widespread nutrient deficiencies are reported in the soils, nitrogen deficiency being common throughout the highlands, and phosphorus especially in western Kenya (Sanchez et al. 1997). In addition to assessments of stocks, nutrient flow studies in the highlands have shown large negative balances for major nutrients in many locations and farming systems (Stoorvogel and Smaling 1990; Smaling, Nandwa, and Janssen 1997; Elias, Morse, and Belshaw 1998; Van den Bosch et al. 1998; Wortmann and Kaizzi 1998; Soule and Shepherd 2000; Shepherd and Walsh 2002; Lesschen, Stoorvogel, and Smaling 2003; Nkonya et al. 2004, 2005b).

The land degradation debate. The issue of land degradation in East Africa, and elsewhere in Africa, has been the subject of increasing debate in recent years. That land has degraded physically, chemically, or biologically in many places in Africa is not challenged. However, the extent, severity, and the underlying causes and effects of the degradation and what should be done about it are debated. Several studies question the extent of land degradation, providing examples of particular cases where land conditions have improved in recent history (Tiffen, Mortimore, and Gichuki 1994; Fairhead and Leach 1996; Leach and Mearns 1996; McCann 1999) or evidence that earlier land conditions (e.g., forest cover) were not as favorable as previously thought (McCann 1999). Some studies argue that land degradation is highly context specific, acknowledging that land degradation is a problem for some farmers in some places and times but arguing that the problem is not as universal as sometimes claimed (e.g., Elias and Scoones 1999). Some studies critique the methods used by agronomists and others to estimate land degradation as being conceptually flawed, subject to large errors, and driven by political motives (e.g., Stocking 1996; Keeley and Scoones 2000; Bassett and Crummey 2003; Fairhead and Scoones 2005). Many studies deconstruct and critique the "Malthusian narrative," which predicts that land degradation is the inevitable result of population pressure and poverty and that drastic action by governments is required to address it (Hoben 1995; Leach and Mearns 1996; Keeley and Scoones 2000; Bassett and Crummey 2003). Most of the authors in this tradition argue that greater appreciation of farmers' knowledge and ability to adapt and innovate is needed, as well as greater understanding of the local historical, political, and sociocultural context.

Some of these criticisms are well founded (Koning and Smaling 2005). Land degradation is certainly not an inevitable consequence of population growth or of poverty; the relationships among these and other factors are complex and context-dependent, and there are many examples of sound land management being practiced by small farmers in many parts of Africa. Nevertheless, there are many studies that document serious degradation, and some of the studies questioning the importance of land degradation also suffer from methodological flaws such as ignoring sources of soil nutrient outflows that are difficult to quantify (Koning and Smaling 2005). Although there are few long-term experimental studies of land degradation in Sub-Saharan Africa (Braun et al. 1997), those that are available show that under continuous cultivation using low external inputs, soil fertility rapidly decreases, yields decline, and a combination of inorganic and organic sources of soil fertility is necessary to sustain crop production (Juo and Kang 1989; Vlek 1990; Swift et al. 1994; Bationo, Lompo, and Koala 1998). This experimental evidence is supported by reports from numerous participatory rural appraisals and surveys in Africa, in which low or declining soil fertility is often cited as a major constraint to agricultural production (e.g., Scherr 1999; Deininger and Okidi 2001; Pender et al. 2004a).

Much of the evidence on land degradation is synthesized in the recently completed Millennium Ecosystem Assessment (MEA 2005). The MEA is a compilation, analysis, and synthesis of the widest body of research available on various topics of interest relating to ecosystems. The preponderance of evidence from Africa indicates that land productivity has stagnated or decreased across large areas and that in many instances land degradation can be cited as a major cause. Across Africa and for most staple crops, yields have stagnated or worsened over the past 30 years (FAO 2004) despite increased use of improved varieties of maize and other crops (Smale and Jayne 2003) and factoring out variations in rainfall. In addition, fertilizer input use per hectare and per capita remains extremely low in Africa and in several countries has fallen in recent decades (Jayne, Kelly, and Crawford 2003), contributing to soil nutrient depletion. This may be somewhat compensated for by increased organic inputs, but available evidence would suggest that these too are very limited (Place et al. 2002c).

There is also direct evidence of land degradation on the continent. Although earlier estimates of large-area degradation were based either on expert opinion (Oldeman, Hakkeling, and Sombroek 1991) or on assumptions and relatively few plot-level trials (Stoorvogel and Smaling 1990), recent advances in remote sensing and ground survey methods have substantiated the existence of significant land degradation at landscape scale. Recent use of near-infrared spectrometry to assess soil quality and land degradation over wide areas has been able to provide evidence of the extent of degradation in the Nyando River Basin of Kenya. Cohen, Shepherd, and Walsh (2005) found that about 56 percent of the land was moderately to severely degraded. Further research combining measured soil degradation with estimated effects on crop yields (Cohen, Brown, and Shepherd 2005) calculate the costs of soil erosion at the national scale in Kenya to be equivalent to 3.8 percent of GDP. Estimates of the costs of land degradation in Ethiopia from different methods also indicate large impacts, although there are debates about the methods used and the exact magnitudes of the impacts (Sutcliffe 1993; Böjo and Cassells 1995; Kappel 1996; Sonneveld 2002). Evidence from laboratory analysis of changes in soil properties in plantation agriculture in Tanzania (Hartemink 2003) and from sample plots in small farmers' fields in Uganda that were resampled 40 years after an earlier soil survey (Ssali 2003) also support the view that soil fertility has declined in East Africa. There are also studies showing high costs of siltation resulting from high levels of soil erosion in the East African highlands. In Sudan, for example, the total capacity of the Roseires Reservoir, which supports 80 percent of the country's electricity, has fallen by 40 percent in 30 years as a result of siltation of the Blue Nile (UNEP 2002).

We conclude, based on the available evidence, that land degradation is a serious problem in many parts of the East African highlands, though it is context-dependent, as farmers in many places are responding to the problem with improved land management practices. As noted earlier, improving understanding of the widespread variation in the causes and extent of land degradation and farmers' land management practices is a major objective of the studies included in this book.

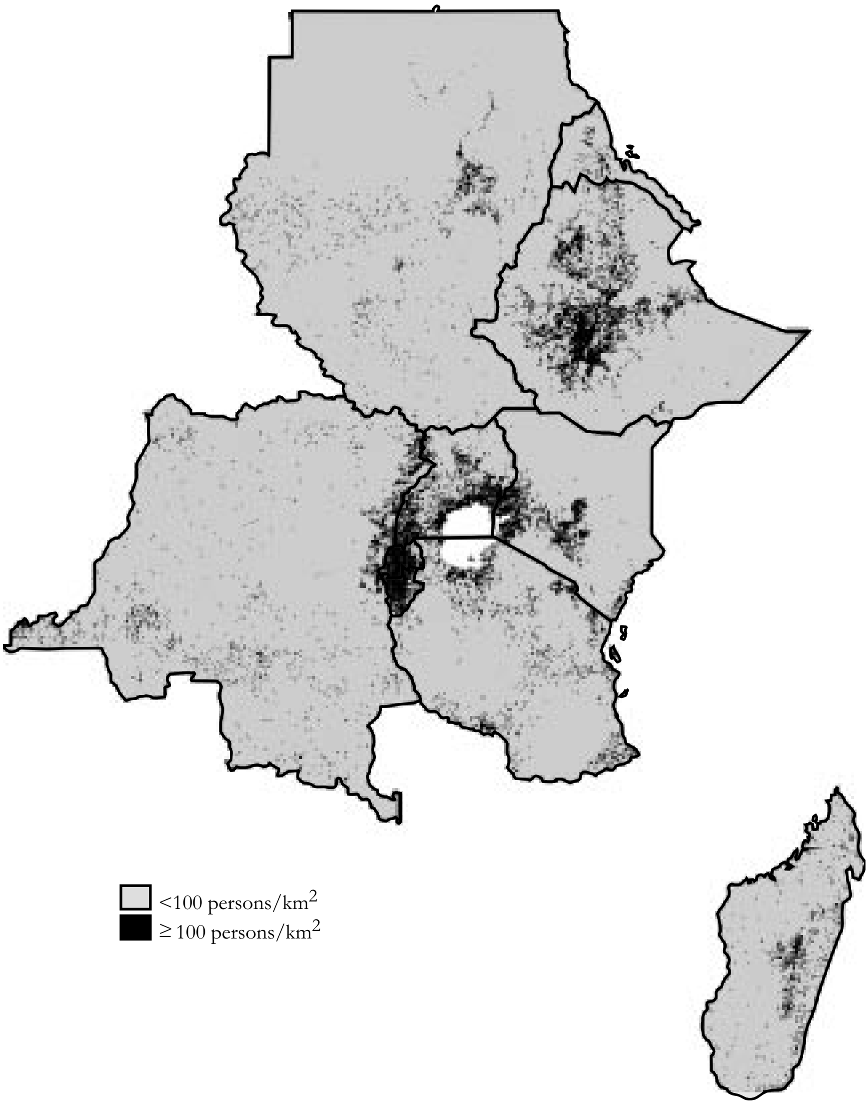
The Social, Economic, and Political Context

Population. The highlands of East Africa are home to the highest rural population densities in Africa because of the attraction of the relatively cool climates, low risks of disease (e.g., malaria), as well as the potential for high agricultural productivity. The Kenyan highlands average between 170 and 190 persons per square kilometer, which is both higher and less variable than rates for Ethiopia (51–130) and Uganda (102–155) (Diechmann 1994). This pattern is represented in Figure 1.3. But densities can reach far above these levels, especially when land unsuitable for agriculture is factored out. Most studies from the highlands indicate an average farm size of about one hectare or less and, with six persons per household, suggesting a population density of around 600 persons per square kilometer of cultivated land. The western Kenyan highlands are the most densely populated, with over 1,000 people per square kilometer in some locations (Republic of Kenya 2002).

Rural population growth rates have slowed recently as a result of urban migration and higher death rates from AIDS (and the ever-persistent malaria). There are no specific figures for the highlands, but rates of HIV/AIDS incidence among adult populations are estimated to be 15.0 percent in Kenya, 6.4 percent in Ethiopia, and 5.0 percent in Uganda (Earthtrends 2004), though there is some dispute about the accuracy of these numbers. The existence of AIDS and continued persistence of other fatal diseases such as malaria and tuberculosis have prevented significant rises in human longevity. Wars and population displacement have not been a prominent feature of the highlands, but the Tutsi–Hutu conflict has periodically spread into the Rwenzori highlands in southwestern Uganda, and the Ethiopia–Eritrea war affected some areas of northern Ethiopia. All of these factors have continued to impinge on life expectancy, which ranges only between 43 and 49 years in the three countries.

Nonetheless, total population annual growth averaged 3.3, 2.9, and 2.2 percent between 1995 and 2002 in Uganda, Ethiopia, and Kenya, respectively (FAO 2004). Although urban areas are growing more than twice as fast as rural areas

Figure 1.3 Population density in eastern and central Africa



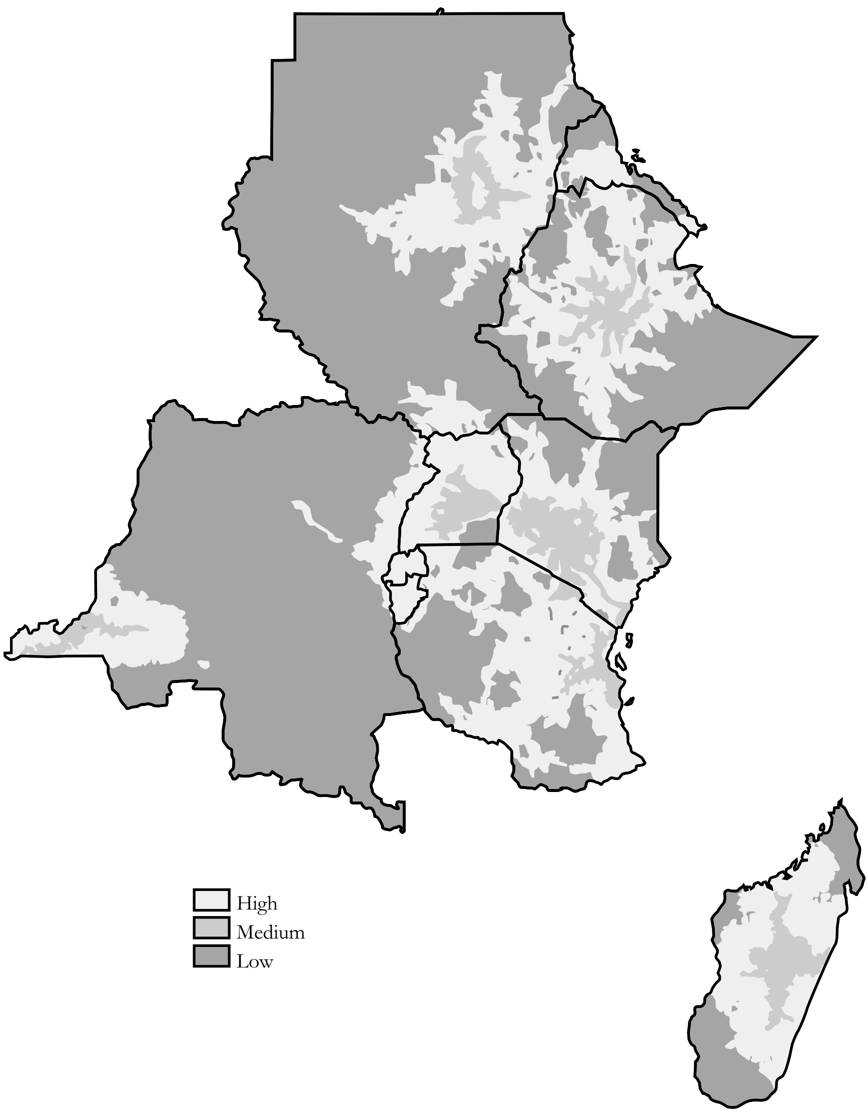
Source: CIESEN/IFPRI/ World Bank/CIAT (2005).

(e.g., urban growth in Kenya was over 6 percent per year in the late 1900s; United Nations 2001), rural population continues to rise. The rate of population growth in the highlands is likely less than those in other rural areas because of their already high densities and the implications this has on emigration to urban or other rural areas. This pattern of emigration also suggests that the highland communities are typically better connected with cities and towns (many of which are growing rapidly within farming landscapes) than other rural communities. The result is that highland-based households may have very complex economic structures with labor and capital moving between rural and urban settings.

Settlements and land tenure. As a consequence of high population densities, farm sizes are small throughout the highlands, with average sizes at or below 2 hectares almost everywhere. In the western Kenya highlands, average farm size is less than 1 hectare in most areas and even as low as 0.5 hectares in many parts (Wangila, de Wolf, and Rommelse 1999). A national study in Ethiopia found average farm size to be 1 hectare (Ethiopian Economics Association 2002). In Uganda, the 1991 agricultural census found that more than 1.2 million of the 1.7 million rural holdings were 1 hectare or less (Republic of Uganda 1992). Most farms consist of a single holding, and fragmentation of holdings is most common in the highlands of southwest Uganda. Land in the Kenyan highlands had been demarcated and registered in the name of the owner beginning in the 1960s. Most farmers in the central highlands have updated their titles, but many in western Kenya have not. Highland smallholder farmers in Uganda do not have formal titles but normally are secure in their tenure, and rights of land alienation are common throughout Kenya and Uganda. The de facto individualization of tenure in Uganda (especially in the highlands) has led to legal recognition of private rights in the 1998 Land Act. However, regional differences still persist, as exemplified by the parallel *mailo* tenure system in central Uganda (Baland et al. 2003). Ethiopia is distinct from Kenya and Uganda in that land tenure rights have been formally held by the state, and land sales and mortgages are forbidden. However, land reforms have been announced and implemented by regional governments in Ethiopia, including the halting of land redistributions and the issues of land certificates to households. One consequence has been an emerging land rental market (Holden, Shiferaw, and Pender 2001; Pender and Fafchamps 2005). Thus, there is a rich diversity of tenure systems and arrangements across the study countries.

Markets. Road densities and quality are low throughout East Africa, as is the case in Sub-Saharan Africa as a whole. The proportion of paved roads to total road length is on the order of 10 to 15 percent for all the countries. However, in terms of total road densities most of the Kenya highlands are well served compared to Ethiopia. There are only 26 kilometers of road per 1,000 square kilometers in Ethiopia, one of the lowest road densities in the world (Demeke and Abebe 2003). Figure 1.4 shows how market access, in terms of travel time, varies in East Africa.

Figure 1.4 Market access in eastern and central Africa, based on travel time to nearest five markets, weighted by population of markets



Source: Constructed by Jordan Chamberlin, IFPRI.

Note: Based on cities with a population of 1 million people or more.

Growth in telecommunications was dormant for decades until the advent of mobile phones and the privatization of cell phone providers. Growth in Uganda has been staggering. In 1999, it became the first country in the world where the number of mobile telephone users exceeded that of fixed-line users. Kenya shortly followed suit and is experiencing similarly high growth rates. Ethiopia lags the others because of its continued reliance on the government-owned telecommunications corporation. It should be emphasized that the rapid growth rates are applied to very low levels of telephone lines. By 2000, the numbers of fixed and mobile lines per 100 persons were only 1.05 and 0.42, respectively, in Kenya. In Ethiopia, the comparable figures were only 0.37 and 0.03 (International Telecommunications Union 2004). The economic impact of the recent improvement in telecommunications has not yet been documented.

Markets for inputs are much more developed in the Kenya highlands than in the highlands of Uganda or Ethiopia. On the input side, there were as many as 12 fertilizer importers in Kenya and 500 wholesalers in the mid-1990s (Allgood and Kilungo 1996). These are underdeveloped in Uganda and Ethiopia, as is the retail sector. In fact, fewer than 10 percent of Ugandan farmers use any chemical fertilizer (Pender et al. 2004a), and the average fertilizer application rate in Uganda (about 1 kg/ha) is much less than even the low average in Sub-Saharan Africa as a whole (Republic of Uganda and FAO 1999). In Ethiopia, fertilizer use is significantly higher than in Uganda as a result of heavy promotion by the government extension and credit program. The Ethiopian market for fertilizer is controlled by two holding companies supported by government tenders (Jayne, Kelly, and Crawford 2003). Despite rhetoric from the Government of Ethiopia extolling the intention to strengthen the private sector's involvement in agricultural inputs, there is relatively little movement in this direction.

Credit is practically absent for smallholders in East Africa with three notable exceptions. First, cooperatives (i.e., mainly government parastatals) operating in export crops have traditionally maintained credit programs. This was a key contributing factor in building up the coffee and tea sectors as well as ensuring adequate use of inputs, at least in the case of Kenya. A second source is through private firms under contract farming. This is less common but occurs for vegetables and some other horticultural crops. A third way is through the occasional government support program such as that in Ethiopia, where the government is promoting the adoption of modern cereal varieties and accompanying inputs (especially fertilizer). Aside from these formal opportunities, there are very few opportunities for farmers to borrow through formal banks, and they are left with small and uncertain loans from small traders or in revolving credit schemes.

There have been few restrictions on labor markets after the fall of the Derg regime in Ethiopia, which had prohibited the hiring of labor along with restrictions on land transactions. There are examples of migrant labor working on a fixed-term basis (e.g., for tea) and local labor markets (e.g., casual labor tasks) in many highland areas. The quantity of hired labor is strongly linked to the presence of high-value agricultural enterprises, such as coffee and tea, in all countries. In areas where low-value cereal production dominates, relatively little labor is hired except by the wealthier households.

Markets for outputs are heavily influenced by road densities, export opportunities, processing industries, and, of course, general prosperity levels of the country. From the 1960s to the 1990s, Kenya was far advanced in these indicators as compared to Uganda and Ethiopia. However, its advantage has slipped after about a decade of very poor economic growth. Nonetheless, export markets remain relatively strong in Kenya, and high urban growth (6.75 percent annually in the late 1900s) has boosted domestic food demand. Government parastatals, processors, contractors, export buyers, national buyers, and local buyers actively purchase many highland agricultural goods, including crops, milk, meat, and tree products. Uganda has experienced improved market conditions since 1990 in both export and food crops, with significant investment in food processing having taken place. The government has facilitated market linkages to rural communities through major development of road and communications infrastructure. The result is that certain crops enjoy good market channels, notably bananas, the main food crop, tea, coffee, and selected horticultural crops. However, other crops are not as easily sold, and there are reports of rapid gluts in rural markets (Raussen et al. 2002). Ethiopia is clearly lagging in output market growth. Many communities remain disconnected from urban output markets. When production increases do occur, such as with maize in 2001 and 2002, there is no capacity to handle excess supplies, and prices collapse (Gabre-Madhin and Amha 2003).

Political Structure and Policies

International relations and macro policies. There have been quite different political histories in Uganda, Kenya, and Ethiopia in terms of relationships with international organizations. For the entire decade of the 1990s and continuing into the early twenty-first century, Uganda has been a favored recipient of donor funding. This is partly because of the desperate economic and social conditions in Uganda following the long periods of dictatorship under Amin and Obote. Further, the Western countries viewed Uganda's far-reaching macroeconomic stabilization, structural adjustment, market liberalization, and decentralization policies, discussed below, as favorable (World Bank 1996). Following from active IMF and World

Bank programs, and those of numerous other donors, private foreign direct investment was also noticeable, attracting over $100 million per year in the late 1990s (UNCTAD 2003), and its overall balance of payments was 20 times that of Kenya (an economy that is twice the size of Uganda's). This was fostered by encouragement of expelled Asian property and business owners to return to the country and to reclaim their assets.

Kenya has been on the opposite side of the spectrum. The IMF closed down its Kenya facility in the mid-1990s and resumed it only in 2004. The main reason for this was government corruption, and that signal affected donor funds from other countries profoundly. It also had an effect on private capital inflows, which virtually dried up by the late 1990s and were just $5 million in 2001. Certain government programs, such as health, education, and agricultural research and extension, continued to receive support, but there was no general budget support to the government. In 2003, a new government was elected following the formation of a political coalition to oust the long-standing ruling party. The government made an immediate impact with a change to free primary education and has made well-publicized strides to fight corruption. As a result, there has been renewed interest in Kenya on the part of the IMF, the World Bank, and several other donors.

Ethiopia lies somewhere between these cases. It is widely recognized that Ethiopia is one of the world's poorest countries. In addition, the Ethiopian government is not considered to be very corrupt, relative to many other African countries, including Uganda and Kenya (Transparency International 2004). So there are strong interests on the part of the international community to assist the government to mitigate periodic famines and to develop the country. However, the international community became incensed at the diversion of resources to fight a war with Eritrea. This proved to be quite a setback for the continuation of a number of development projects. Finally, because of the low state of development, foreign direct investment has been low, ranging between only $10 million and $20 million per year during the 1990s. Data on external remittances to East African countries are very poor, and estimates vary widely. The IMF (cited in Harrison 2003) estimates that in 2000, the remittances into Ethiopia were $53 million (with the rest of East Africa receiving about $300 million altogether). Farm level surveys from Ethiopia and Uganda (results discussed in Chapters 5, 7, and 9 of this book) do not show remittances (whether from domestic or external sources) to be a major component of farm households' incomes in the regions studied in those countries. In the highlands of Kenya, remittances are probably more important to rural households (as are other sources of nonfarm income as shown in Chapter 8), though evidence on this is limited.

Uganda was the first of the East African countries to liberalize exchange rates (in 1990) and to relax restrictions on capital flows. This enabled, among other things, Asian capital to return. Kenya followed suit shortly after (in 1993), and Ethiopia has likewise moved largely in that direction. As a result, Uganda's currency has depreciated the most against the hard currencies since the early 1990s, followed by the Kenya shilling and then the Ethiopian birr, which had been closely managed to create a stable exchange rate with the dollar until a 240 percent rise in the exchange rate in 1992. By 1997, the parallel currency market rates were very close to official rates. Trade and commodity market liberalization accompanied the exchange rate policy changes. However, by 2004, the countries still maintain import tariffs, and discussions continue to remove these over time, first among Kenya, Uganda, and Tanzania and then with a broader set of eastern and southern African countries.

All governments have sought to control inflation in recent years and in fact have done well in this respect, apart from some bouts of high inflation in Uganda in the early 1990s and in Kenya around elections in 1992 and 1997. Ethiopia has kept inflation under control except during the severe drought years of the mid 1980s and 1990s, when it reached between 15 and 20 percent. On the other hand, government spending has been difficult to balance against revenues in all countries. This has increased tensions between donors/lenders and the governments of these countries, especially because of their large defense budgets.

Decentralization of governance. The three countries also differ in terms of the degree of internal decentralization of political decisionmaking. In the 1990s, Uganda embarked on a broad program to decentralize much decisionmaking to local levels. This program included the direct election of local officials, granting of numerous powers to local authorities, and the ability for local governments to raise and retain their own revenues. This has been done within a single-party framework. Contrary to this movement, Kenya remained, as of 2003, on the other end of the spectrum with a rather centralized political system. To its credit, the Moi government allowed the multiparty system to develop, but it retained key powers in the executive branch at the national level. For instance, all local administrators, from sublocation up to province level, are appointed by the executive branch. Some planning is done at local levels, but the planners are not accountable to the local populations. Ethiopia lies between the two cases. In fact, it has recently increased the powers of its seven regional state governments across a range of decisionmaking areas, including agriculture and the environment, and is also increasing authority and capacity of district (*woreda*) governments. Some fiscal autonomy has also been granted to the regional governments.

Natural resource and tenure policy. As indicated above, the past decades have witnessed substantial conversion of natural habitats to other uses. This includes a large amount of gazetted land supposedly protected by law. Yet, in many cases, exemptions were granted by one office (e.g., lands) in defiance of the rules set by another (forests). In other cases, clearing of land was allowed to proceed because of local corruption or inability to enforce policies. A number of environmental regulations and bylaws are on the books but are routinely flaunted. These include the observance of easements along riverbanks and restrictions on cultivation on hills and steep slopes, the cutting of indigenous trees, and the harvesting of water resources. In most cases, agricultural imperatives, especially those of cultivators, have won out over the implementation of environmental policies where the two were in conflict.

Property rights policies and enforcement play a key role in the management of natural resources. It is necessary to discuss tenure on agricultural land country by country because of distinct differences. But there are many common features of property rights on noncultivated lands in the three countries. Although indigenous populations have enacted management rules over land resources that they cultivate, wide areas of noncultivated lands have been subjected to various claims and uses by an array of users: migrant cultivators, new pastoral communities, charcoal burners, tree cutters, and land-grabbing elites (Deininger and Castagnini 2004). In many of these lands, the degree to which sovereign or traditional rules take precedence is not clear. There are often no mechanisms by which different claimants of rights to the same resources can resolve conflicts or can join together to prevent illegal claimants from using the resources. The lack of clarity of property rights over forests, woodlands, grasslands, and wetlands has only increased under decentralization processes that have devolved more control over natural resources to local levels. Moreover, capacity to manage natural resources at local levels is very poor.

On cultivated lands, Kenya embarked on a freehold system to grant individual titles to farmers operating in all medium- to high-potential areas. This exercise began in the 1960s and was largely completed by the 1980s. Under this system, exclusive rights to household heads, mainly male, were granted. But there remained many secondary rights arrangements that survived this, and land boards were also established to prevent the dispossession of landholdings without full consent of family members. Forty years later, the privatization program continues to flourish in some areas where new recipients of parcels update the land registry. In other areas, however, the land registries are moribund because new recipients of land do not find it worthwhile to invest the time and costs in acquiring a title deed in their name.

Uganda passed a new land law in 1998 that affirmed the importance of private tenure on agricultural land but did not deal uniformly with the different tenure systems that operated previously. Customary tenure is supposed to be converted into a fully private system in which the legitimate occupant of land rights is now formally recognized as the owner under the law, though the law has not been fully implemented. The *mailo* tenure system, which covers a wide area in central Uganda, developed into one of overlapping rights between owners and long-term occupants. The law has not decided in favor of one over the other but has set forth the process to resolve these competing claims and methods for determining due compensation. The law also establishes a streamlined mechanism by which smallholders can obtain title deed on their property. Although very few Ugandan farmers have a title deed, the buying and selling of rural land is as common in Uganda as anywhere in Africa (Place 2002).

In Ethiopia, the government remains the owner of all land. That is enshrined in the constitution, and all regional governments must adhere to that article when devising land reforms. The national government had, through the 1975 land reform, introduced mechanisms for state and cooperative farms along with redistributions of land to promote equitable distribution of land (through peasant associations). State farms were discontinued after 1991 with land reverting back to communities and households. The extent of commercial farming is limited in the Ethiopian highlands, relative to Kenya and Uganda. Also, sale and mortgage of land were barred and remain prohibited today. But there is some relaxing of other restrictions, and land renting is now allowed, subject to restrictions imposed by regional governments. Importantly, many regional governments have stated that they will no longer redistribute land, and the Amhara and Tigray regions have strengthened this new policy by issuing land certificates to households.

Agricultural sector policies. Government involvement in agriculture has roots from precolonial days and continues today in some form in each country. In Kenya, the major areas of government involvement remain in export crops such as coffee and tea, in the national staple, maize, as well as in a few other areas such as irrigation. There is no doubt that public cooperatives helped develop the Kenya highlands. At the turn of the twenty-first century, Kenya boasted as many as 600,000 smallholder dairy farmers, 500,000 smallholder coffee growers, and 300,000 smallholder tea producers. Many of the parastatals, however, were mismanaged and corrupt and may have even had a negative effect on smallholder production and income in the 1990s. As of 2002, the Ministry of Agriculture managed 40 parastatals, many of which required significant budget support in return for dubious benefits. Coffee is widely held up as an example of a poorly run cooperative in which farmers had little voice in the management of the sector. Tea producers, on the other hand, appear to be reasonably well served by the Kenya Tea Development

Authority (Argwings-Kodhek et al. 1999). The liberalization of the dairy sector had enormous impact, with the number of dairy products increasing by perhaps 30 times and retail shortages becoming a thing of the past. Kenya also long ago liberalized the fertilizer industry and removed subsidies. As noted above, this has resulted in competitive import and wholesaling in fertilizer. Fertilizer is available in retail shops throughout the country. The major problem is with costs. Because of the poor road conditions, poor transport means, and lack of competition in the transportation sector, transport costs more than double the price from Mombasa to the farm. Liberalization has not worked in all cases, however, and there remains a concern about input delivery to remote areas, output processing of meats from the pastoral areas, the prices paid to maize farmers, and the incentives to ensure a domestic sugar industry, to name just a few. Credit remains problematic. The government's solution to rural credit was the Agricultural Finance Corporation, but that institution has concentrated almost exclusively on medium- to large-scale farmers in selected high-potential areas (Argwings-Kodhek et al. 1999).

In Uganda, the Museveni government acted quickly in concert with foreign donors to reform the ways in which the government was to be involved in the agricultural sector. After a period of discussion, the Produce Marketing Board, the Coffee Marketing Board, and the Lint Marketing Board lost their monopoly status in 1989, 1991, and 1993, respectively. Consequently, participation of the private sector in agricultural input and output trading increased significantly (Balihuta and Sen 2001; Nkonya 2002), and the farmers' share of the international price of major traditional export crops increased substantially, for example, from 30 percent to nearly 80 percent for coffee (Balihuta and Sen 2001). In 2000 the government initiated the Plan for the Modernization of Agriculture, which sought to enhance the intensification and commercialization of the agricultural sector through agricultural research and advisory services, support to agricultural processing, and promoting the use of high-value enterprises and inputs. There have been successes, for example, in responding to a global shortage of vanilla. However, Ugandan farmers continue to apply few soil inputs as compared to farmers elsewhere in Africa for many reasons, including the high costs of inputs delivery. The Uganda government is also supporting the development of microcredit and has established a high-level government department in this area.

The Ethiopian government has historically been heavily involved in agriculture, especially during the Marxist/socialist regime that lost power in 1991. The policy statements of the current government have been to promote the private sector, but their actual practices are not always reflective of this. For instance, the government has become heavily involved in credit for fertilizer and seed to the extent that private fertilizer dealers have closed down. This has been targeted to cereal-producing areas, chiefly maize and wheat. It has been successful in raising yields, especially in higher-rainfall areas, sometimes so successful that surpluses could not be handled by either the market or the government, leading to price collapses. The government has been less successful in promoting productivity increases for other commodities and in the drier regions.

All three countries have had functioning agricultural research systems, with Kenya's arguably the strongest in terms of length of uninterrupted research, its decentralized structure, and its successful delivery of improved technologies. Uganda and Ethiopia have recently moved to decentralize their research systems. Both the Kenyan and Ugandan research institutions rely heavily on World Bank and other donor funds, whereas the Ethiopian national and regional governments provide a large share of research capital and operational funds. Extension systems have faced serious deficiencies in all three of the countries, and thus, they all have recently undergone major overhaul. Kenya moved away from a training and visit approach to a focal area approach in which teams of staff concentrate efforts in selected communities each year. Uganda is in the process of transforming its public system into a farmer-led system (Uganda National Agricultural Advisory Services), but this will take considerable time to fully implement (if indeed the system is found to be effective). Ethiopia is investing heavily in increasing the number of extension agents (to three per community), developing a large number of farmer-training centers, and broadening its Participatory Demonstration and Training Extension System to promote a wider variety of commodities and technologies that have market potential.

Livelihoods and Agricultural Systems

Major crops. In Kenya, almost all the highlands are considered to be medium to high potential. As a result, a variety of crops can be found throughout the highlands. The main factor in explaining differences is not agricultural potential, therefore, but rather market access and cultural factors such as the commercial mindset of the population. In central Kenya, the practice of growing commercial products and buying food items is well entrenched. Therefore, the notion of a subsistence farmer is practically unheard of. Farmers integrate a wide range of food and nonfood crops on their farms. On the other hand, there are a large number of farmers in the western Kenya highlands who produce mainly food crops and sell a small portion of their output, those being mainly distress sales (i.e., out of the need to pay for another critical household need). The key staple food crops in the Kenya highlands are maize, beans, potatoes, and bananas, followed by sorghum, cassava, and rice. Maize accounts for 80 percent of all cereal value and occupies about 1.5 million hectares of land. Vegetable production of kale, peas, onions, carrots, and tomatoes is also common. Nonconsumed cash crops include coffee, tea, sugar cane, and French beans.

In Uganda, banana is the main staple and, at 1.5 million hectares, accounted for the largest share of acreage under cultivation (FAO and World Food Programme 1997). Several important crops follow, including beans, maize, and sweet potato, with maize production experiencing good growth with markets in Kenya. Uganda is one of the largest growers of coffee in Africa, with 90 percent of production being robusta. It can be found in many districts, including all lakeshore, southwest, and western districts. A number of specialty crops are also produced; the more commercially traded include vanilla, passion fruit, and pineapples.

In Ethiopia, teff is the main staple food and, at 2.7 million hectares, occupies the largest share of cultivated land, especially in the central and northern regions (FAO and World Food Programme 2000). Maize, wheat, and barley are also produced on over 1 million hectares each, with the maize area expanding at high rates. Pulses as a group also occupy about 1.5 million hectares of land. Coffee is the major cash crop, found mainly in the southwest of the country. Almost all coffee is grown by over 700,000 smallholder farmers and together accounts for 60 percent of Ethiopia's export earnings. Also important as a food crop in more humid areas is enset (a root crop), and chat (a mild narcotic) is increasingly important as a cash crop in many such areas, particularly in the wake of low world coffee prices in recent years.

Livestock. There are about 12 million head of cattle in Kenya and 20 million sheep and goats. The sector contributes about 42 percent of total agricultural income (Argwings-Kodhek et al. 1999). Although many of these animals are located in pastoral areas, a large number are in the highlands, and over 3 million dairy cattle can be found in the highlands (Aklilu 2002). Livestock systems in the Kenya highlands are intensive and productive. Most cattle in Central and Rift Valley Provinces are high-grade animals and are raised in zero grazing units. Indigenous cattle breeds raised in tethered or guarded grazing systems are more common in the western highlands. Poultry keeping is also very common at small and medium scales. Goats are also common; the Kenya highlands host the largest number of improved dairy goats in Africa.

Ethiopia has the largest livestock herd in Sub-Saharan Africa. There are over 35 million head of cattle, 30 million sheep, and 21 million goats. About 80 percent of cattle and 75 percent of sheep are found in the highlands, whereas most of the goats are raised in the lower elevations (Demeke and Abebe 2003). The livestock sector contributes 20 percent of gross domestic product.

In Uganda, there are about 5.9 million head of cattle and 7.3 million sheep and goats (Mwebaze 2002). Poultry are the most common of all, numbering about

22 million. Most of the cattle are under extensive feeding systems in the drier zones. There is a growing dairy industry, estimated to produce about 511,000 metric tons of milk annually (Mwebaze 2002), but the number of high-grade animals is small in comparison to Kenya. The major pockets of modern dairy production systems are in the western and eastern highlands, the southwestern districts of Mbarara and Bushenyi, and in periurban areas near Kampala and Jinja.

Trees and other agricultural products. Another notable agricultural product in Ethiopia is eucalyptus poles, which comprise nearly all the trees planted by farmers. The demand for poles is high because of construction booms in the cities and towns and for poles for making plow beams. Eucalyptus is also a major source of fuelwood. Some fruit trees are also found but are not extensively commercialized. A final important product is honey production, which is produced in the drier parts of the highlands. In Kenya, there are a variety of valuable trees, including macadamia and avocado fruit trees and grevillea timber trees in central Kenya and eucalyptus woodlots in western Kenya. For example, avocados generate about $6.5–7.0 million in export revenue each year, the third largest export among fruits and vegetables (FBAK Feld Consulting 2001). In Uganda, eucalyptus is also a common timber/pole tree, mainly found in woodlots. Fruit trees such as avocado, jackfruit, and mango are common in the highlands of Uganda but in small numbers per farm.

Agricultural Productivity and Growth

The three countries have experienced significantly different trends in per capita agricultural production in recent years. As indicated in Table 1.1, Ethiopia has exhibited the highest growth rates in agricultural production between 1995 and 2003 (5.5 percent), fueled by impressive increases in cereal production. This has come about because of three factors: the very low baseline yields, characteristic of the military regime; slight expansion of cultivated land (mostly outside of the highlands); and improved yields from intensified use of inputs, especially fertilizer. Kenya attained modest growth in per capita agricultural production (1.8 percent) over the same period but actually experienced a large drop in per capita cereal production. This indicates a shift toward higher-value production systems, such as tea, dairy, and horticulture. In Uganda, trends in both indicators have been negative. Part of the reason for this is the rapid agricultural growth that occurred in the 1986–95 period, especially in terms of cultivated areas. Further increases are going to be difficult to realize unless input use (especially of organic or inorganic sources of soil nutrients) increases from its extremely low level.

Table 1.1 Some indicators of agricultural performance in Ethiopia, Kenya, and Uganda

Indicator	Ethiopia	Kenya	Uganda
Per capita agricultural production 2003 (1990 = 100)	103.9	94.0	94.1
Growth in per capita agricultural production 1995–2003	5.5	1.8	–1.8
Per capita cereal production 2003 (1990 = 100)	155.0	70.1	95.2
Growth in per capita cereal production 1995–2003	9.5	–28.0	–11.5

Source: FAO (2004).

The Critical Variables

Here are some of the critical variables that take various patterns across the landscape of the highlands and that are expected to have large effects on the development pathways of communities and the households within them.

Climate. The more humid portions of the highlands receive a high and relatively well-distributed rainfall, perhaps the most favorable for agriculture in all of Africa. In such areas, the highlands host a wide variety of perennials, annuals, livestock, and trees that is unparalleled in Africa and perhaps the world. In such places (e.g., central Kenya, western Uganda, southwest Ethiopia), there are very few supply constraints impeding the choice of agricultural options. It is rather the markets, entrepreneurial expertise, and access to productive factors that become critical. The drier areas are quite different, and production possibilities are much more limited. Perennials tend to disappear from the landscape, and the low-moisture annuals such as sorghum, millet, barley, and wheat predominate. Because of the lack of vegetation, zero grazing units of improved breeds give way to free-grazing native breeds.

Population. Virtually all of the highlands are densely populated, implying that land is scarce in almost all regions. Indeed, farm sizes average no more than 2 hectares anywhere in the study sites (apart from some larger commercial areas in Kenya). This will of course limit opportunities for mechanization, which indeed is not found to a significant extent anywhere in the highlands. There are some subtle differences in population pressure in that some areas have been reduced to farm sizes of 0.5 hectare or smaller. In those cases, off-farm income has become so important as to render further on-farm innovation problematic.

Markets. Especially within the high-potential areas, market opportunities and infrastructural investment play a significant role in agricultural enterprise selection and farm investment production. Casual observation suggests that sites where significant investment has taken place (e.g., all-year roads or tea factories) or that are close to the capital cities have become relatively commercialized and prosperous. Farmers are often innovative and tend to make investments where returns are high. In contrast, farmers in remote locations do not adopt the same types of enterprises as will others and will tend to focus on food crops and other subsistence commodities.

Land tenure. There are several significant tenure arrangements that operate in the highlands of East Africa, and they have been uniquely shaped by differences in national policies. Kenya has for a long time promoted individual freeholds, especially in the highlands; Uganda is home to a variety of legal and customary systems; and Ethiopian farmers have been uniformly subjected to strong state ownership rules with emerging transfers of some land rights to households. Ethiopian farmers had further been subjected to periodic land redistributions that have likely inhibited long-term fixed investments such as trees, fences, livestock-feeding units, and the complementary enterprises that they promote. Only in Kenya have a large number of households had access to titles and theoretically to commercial credit.

Government programs. Irrespective of climatic, physical, and market conditions, government programs and policies can have significant effects on rural communities. Ethiopia has been proactive in cereal production promotion, which led to large increases in production and consequent marketing problems in high-potential areas almost overnight. In Kenya, government investment in tea and coffee factories in the 1960s and 1970s had a tremendous effect in creating smallholder commercial farmers. More recently, it has been the move toward liberalization that has tended to improve incentives in many sectors, especially dairy. In Uganda, by most accounts, the liberalization policies adopted have been praiseworthy. This has had some impacts, albeit of a limited nature because of inherently weak public and private systems for disseminating information and for transporting inputs.

Overview of the Book Chapters

The next chapter presents a broad conceptual framework and the key hypotheses that are explored in the empirical chapters. Chapters 3 through 5 form the second part of the book, which focuses on development domains and pathways in the East African highlands. These relate to livelihood strategies emphasized by different communities and, in particular, their agricultural and natural resource management strategies. Chapter 3 focuses on the central and western Kenya highlands, and Chapters 4 and 5 pertain to Ethiopia.[2] All chapters go beyond descriptive analysis to investigate relationships among development domains and pathways, biophysical conditions, and driving forces of change.

The third part of the book includes six studies of the determinants of land management practices by households and communities in the East African highlands. Chapters 6, 7, and 8 focus on household-level land management in Ethiopia, Uganda, and Kenya, respectively. The Ethiopian and Ugandan studies draw on recent household surveys that were coordinated and are thus able to test a wide range of similar hypotheses. The Kenyan chapter is a synthesis of several recent studies that have individually focused on discrete segments of the conceptual framework. Chapter 9 focuses on the land management impacts of land policy in the case of Ethiopia. Land policy is particularly important in Ethiopia where there is concern that the nationalization of all land has inhibited agricultural development. The chapter will investigate the effects of recent easing in restrictions on individual rights. Chapters 10 and 11 focus on the role of collective action and organizations in particular on natural resource management at the community and household levels in Ethiopia and Uganda, respectively.

The fourth part of the book builds on the analyses of the context and the determinants of land management to examine possible technological and policy options to address land degradation, low agricultural productivity, and poverty in the East African highlands. Chapters 12 and 13 analyze the potential for selected land management technical options to be effective, be adopted, and have an effect on smallholder farmers in the three countries. Chapters 14 and 15 emphasize policy options for Ethiopia and Uganda. Both chapters evaluate the influences of alternative policy options with the aid of bioeconomic models in order to address the potential trade-offs among economic, social, and environmental effects.

Last, Chapter 16 includes a summary of key results, some conclusions based on a synthesis of findings, and implications for policy. The chapter devotes considerable space to reviewing the main findings of the preceding chapters because they are numerous and some readers will not have had the time to read all the empirical chapters. The conclusions are organized around the variables emphasized in the Chapter 1 description and in the hypotheses developed in Chapter 2. The principal implications pay attention to important distinctions among the widely different contexts existing in the East African highlands.

Notes

1. We define a development pathway as a common pattern of change in households' livelihood or income strategies (Pender et al. 2004a). We define income strategies as the set of activities that households pursue to produce or acquire income and consumption goods, such as subsistence

production of food crops, production of perishable cash crops, livestock production, forestry, and nonfarm activities (Nkonya et al. 2004). We use the term "income strategies" rather than "livelihood strategies" for clarity because the latter has been defined by some authors in a very expansive way. See endnote 2 of Chapter 2 for more discussion.

2. Development domains and pathways in Uganda are already described in published work (e.g., Pender et al. 2004a).

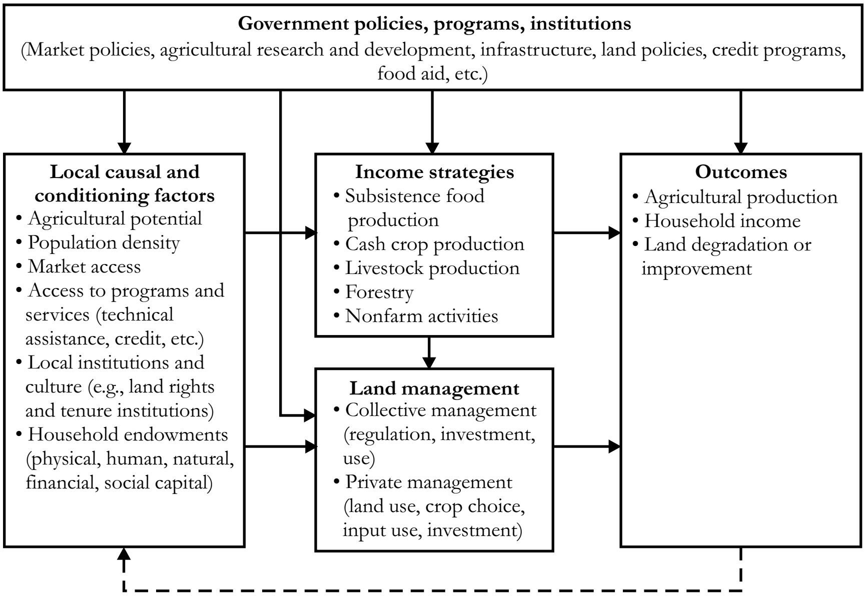
Chapter 2

Conceptual Framework and Hypotheses

John Pender, Simeon Ehui, and Frank Place

In this chapter we introduce the conceptual framework that underlies the case studies presented in this book and discuss hypotheses about the effects of key factors on community and household decisions concerning income strategies and land management. We also discuss the influence of such decisions on outcomes such as agricultural production, household income, and land degradation (or improvement). This chapter is adapted from Scherr et al. (1996); Pender, Place, and Ehui (1999); Pender, Scherr, and Durón (2001); and Nkonya et al. (2004). The conceptual framework considers the effects of dynamic driving forces of change, such as population growth and changes in access to technology, markets, infrastructure, and services, as well as of more slowly changing conditioning factors such as agricultural potential, local institutions, and culture. We also consider the influence of government policies, programs, and institutions, which may influence income strategies, land management, and outcomes in many ways at different levels by affecting the driving forces and conditioning factors at the local level, by directly promoting or inhibiting different income strategies and land management practices, or by directly affecting outcomes (e.g., through food aid). We argue that the impacts of many factors are likely to be context-dependent, emphasizing the importance of empirical research in specific contexts, though some unambiguous hypotheses are derived. In general, policy and program interventions are likely to involve trade-offs among the objectives of increasing agricultural productivity, increasing household income, and reducing land degradation.

Figure 2.1 Factors affecting income strategies, land management, and their implications



Conceptual Framework

To address the objectives and the research issues identified in the preceding chapter, we developed a conceptual framework, illustrated in Figure 2.1, that served as a guide for developing hypotheses tested during the various research activities reported in this book. The conceptual framework for this research on sustainable land management draws from theories of induced technical and institutional innovation in agriculture that explain changing management systems in terms of changing microeconomic incentives facing farmers as a result of changing relative factor endowments (Boserup 1965; Hayami and Ruttan 1985; Binswanger and McIntire 1987; Pingali, Bigot, and Binswanger 1987). Additional variables that are also important determinants of resource management have been included, inspired by theories of collective action (Olson 1965; Ostrom 1990; Baland and Platteau 1996), market and institutional development (North 1990), and agricultural household models (Singh, Squire, and Strauss 1986; de Janvry, Fafchamps, and Sadoulet 1991).

Outcomes

The key outcomes of interest to policy makers include outcomes such as agricultural productivity, household income and household welfare indicators, and changes in natural resource conditions, particularly land degradation or improvement. Our interest in this framework is to assess the ultimate impacts of policies, programs, and institutions on these outcomes and the extent to which there may be trade-offs or complementarities among outcomes. For example, government policies that prevent sales or exchanges of lands may be effective in preventing the dispossession of lands from poor smallholders but be ineffective in improving the welfare of the poor because of their inability to put the land to productive alternative use. Another example is that a strict regulatory approach (such as preventing farmers from planting annual crops on sloping lands) may be effective in reducing soil erosion but may also have severe implications for agricultural production, food insecurity, and poverty. On the other hand, there may be "win-win-win" strategies such as promotion of improved technologies or markets that promote greater production and incomes as well as improved resource conditions.

These outcomes not only are important for people at present but also affect households' endowments and opportunities in the future (indicated by the arrow from outcomes to the factors affecting income strategies and land management in Figure 2.1). For example, increases in agricultural production and income can facilitate greater investment in different types of capital, whether physical (e.g., purchase of livestock or equipment), financial (e.g., monetary savings), or human capital (e.g., investments in education), and improvements in land quality that represent an investment in natural capital. Interventions or other changes that lead to improved agricultural productivity, household income, and natural resource conditions may foster a "virtuous circle" or "upward spiral" out of low productivity, poverty, and land degradation; conversely, negative outcomes may contribute to a "downward spiral" (Durning 1989; Leonard 1989; Cleaver and Schreiber 1994; Pinstrup-Andersen and Pandya-Lorch 1994).

Whether such upward or downward spirals occur depends critically on how livelihood and land management decisions are affected by asset poverty, broadly defined to include limited endowments of all types of capital (Pender et al. 2004c). If increasing poverty causes poorer land management, then downward or upward spirals may occur, whereas if poor people manage their land as well as or better than wealthier ones, then such spirals are less likely (Pender et al. 2004c). Upward or downward spirals of land degradation are examples of path-dependent processes that are caused by positive reinforcement mechanisms (Arthur 1988). If such positive reinforcement does not occur (e.g., if poor people manage land as well as or better than wealthier ones), or if other factors outweigh any positive reinforcement that occurs (e.g., if improvements in technologies or access to markets lead to reduced poverty and land degradation), then downward spirals may not occur. Thus, it is necessary to assess the impacts of asset poverty and other factors on livelihoods and land management in order to assess whether such downward spirals can occur and how they can be prevented or reversed.

The empirical studies in this book are mostly based on cross-sectional data and thus are limited in their ability to assess such dynamic issues as whether downward spirals of land degradation and poverty are occurring and what can be done about them. But by investigating the factors influencing households' livelihood and land management decisions at a given time, including various dimensions of poverty, these studies shed light on some of the issues influencing such dynamic processes. Furthermore, the databases and findings of this research provide a foundation on which future studies of the dynamics of poverty and land degradation can be built.

Income Strategies

Many factors affect outcomes such as agricultural productivity, household income, and land degradation. The central focus of this book is on the determinants and results of people's decisions about income strategies and land management practices. We define *income strategies* as the set of activities that households pursue to produce or acquire income and consumption goods, such as subsistence production of food crops, production of perishable cash crops, livestock production, forestry, and nonfarm activities.[1]

We hypothesize that such strategies have important direct implications for the outcomes of interest, and also affect them indirectly by influencing technology adoption and land management decisions. For example, production of high-value horticultural crops or other cash crops may lead to higher household incomes than production of food crops simply because the profitability of such crops may be greater than that from food crops. But they may also promote greater productivity, land improvement, and increased income indirectly by promoting greater use of purchased inputs, labor, or adoption of labor or capital intensive land improvements because higher value production increases the value of these inputs and the ability to finance them (e.g., Tiffen, Mortimore, and Gichuki 1994; Barrett, Place, and Aboud 2002).

Land Management

Agricultural production and land conditions are affected by land management practices, including both private decisions made by farm households and collective decisions made by groups of farmers and communities. For example, farm households make decisions about land use (whether, for example, cropland or grazing land), the crop types to plant, the amount of labor to use, and the types and amounts of inputs, investments, and agronomic practices to use to conserve soil and water, improve soil fertility, reduce pest losses, and so on. Communities also can influence land management through their collective decisions. They may make investments on communal land areas (e.g., erosion controls on degraded lands, tree planting) or private lands (e.g., drainage investments as part of watershed conservation and development efforts) or regulate use of communal land (e.g., restrictions on use of grazing areas) or private lands (e.g., bylaws limiting burning or cutting of trees). As argued above, these household and collective decisions affect current agricultural production and income and affect the condition of land resources, thus influencing potential future agricultural production and income.

Determinants of Income Strategies and Land Management

Income strategies and land management decisions are affected by many different factors operating at different scales. These include factors that influence the relative profitability and hence comparative advantage of different income strategies and land management practices in a particular location, such as biophysical factors determining agricultural potential, population density, and access to markets and infrastructure (Pender, Place, and Ehui 1999; Pender, Scherr, and Durón 2001). These factors largely determine the comparative advantage of a location by affecting the costs and risks of producing different commodities, the costs and constraints to marketing, local commodity and factor prices, and the opportunities and returns to alternative activities, such as farming versus nonfarm employment. These factors may have generalized effects at the village or higher level on income strategies and land management, such as through their influence on local prices of commodities or inputs, or they may affect household-level factors such as average farm size.

Another important factor influencing income strategies and land management is access to programs and services, such as government or nongovernmental organization (NGO) technical assistance and micro–finance institutions, education and health services, and so on. Some of these programs and services, such as access to technical assistance and education, can affect local comparative advantages by increasing access to technologies and information, thus expanding households' available production and marketing possibilities. These and other programs and services also influence household constraints that affect income strategies and land management, such as limited access to finance and production inputs or labor constraints related to the health status of individuals.

Local institutions also have important influences on income strategies and land management. In much of the East African highlands, customary land tenure institutions determine what land use rights and land management obligations farmers have, how secure those rights are, whether those rights may be transferred or used as collateral, how conflicts are resolved, and other questions. Such institutions can have substantial effects on land management by regulating land use and land management decisions, by facilitating or inhibiting collective action, and by affecting households' incentive and ability to invest in land management practices (Feder et al. 1988; Place and Hazell 1993; Platteau 1996; Otsuka and Place 2001a; Meinzen-Dick et al. 2002; Nkonya et al. 2005a). They may also influence (and be influenced by) households' income strategies. For example, local institutions may limit certain types of extractive activities such as timber cutting in forests, brick making in wetlands, or extensive livestock grazing. But these institutions may also change in response to new income-earning opportunities and relative factor scarcities (Boserup 1965; Hayami and Ruttan 1985; North 1990; Platteau 1996).

Although local institutions can evolve in response to changes in economic opportunities and scarcities, they are also largely affected by history and cultural factors and preferences; thus, institutional change may be path-dependent and resistant to change in many circumstances (North 1990). For example, historical changes in property rights in Ethiopia and Eritrea have not always occurred according to the predictions of the economic theory of property rights (Joireman 2001). In some cases changes were driven by outside influences (e.g., by feudal lords in southern Ethiopia and Italian colonists in Eritrea) rather than being endogenous responses to changing factor scarcities, whereas in other regions of Ethiopia (e.g., in Shoa province) the property rights system was resilient against change despite large changes in land scarcity. Besides differences in cultural factors, the power and interests of local political elites are also important determinants of whether and how changes in such local institutions occur (Joireman 2001). Platteau (1996) documents numerous cases throughout Africa in which the evolutionary theory of property rights fails to explain the nature of change in property rights systems.

Culture is also an important determinant of local consumption preferences and uses of factors of production. If markets are imperfect, production decisions are not separable from consumption preferences (Singh, Squire, and Strauss 1986; de Janvry, Fafchamps, and Sadoulet 1991); as a result, preference of a particular community for a certain type of staple food (e.g., *teff* in the Ethiopian highlands or *matooke* in central Uganda) may greatly affect the agricultural production system. For example, the prevalence of religious fasting periods in Ethiopia, during which individuals do not consume meat or dairy products, greatly influences the prospects for commercial livestock production for the domestic market. Similarly, religious prohibitions against consumption of pork by Muslims and Orthodox Christians limits the opportunities for pig production, and the large number of religious holidays celebrated by Orthodox Christians in Ethiopia (e.g., more than 100 days per year when agricultural work is prohibited; REST 1995), together with requirements that adults contribute 20 days of labor per year to mass mobilization labor campaigns, may have a large influence on households' income strategies and land management decisions.

Household-level factors such as households' endowments of physical assets (e.g., livestock and equipment), "human capital" (assets embodied in people's knowledge and abilities, such as education, experience, and training), "social capital" (assets embodied in social relationships, such as through participation in organizations or informal networks), "financial capital" (access to liquid assets, including credit and savings), and natural capital (assets embodied in natural resources, including the quantity and quality of land, access to other resources) may also determine the income strategy and land management practices pursued by particular households. For example, education and access to financial and social capital may be critical in determining households' ability to take advantage of remunerative nonfarm opportunities (Barrett, Reardon, and Webb 2001), although these advantages may have mixed impacts on farmers' land management decisions, facilitating use of capital inputs but possibly undermining use of labor inputs by increasing the opportunity cost of labor (Reardon, Crawford, and Kelly 1994; Clay, Reardon, and Kangasniemi 1998; Pender and Kerr 1998). We discuss these and other hypotheses about impacts of specific factors further in the next section.

Government Policies, Programs, and Institutions

Government policies, programs, and institutions at many levels may influence income strategies and land management and their implications for production, resource conditions, and household income. Macroeconomic, trade, and market-liberalization policies will affect the relative prices of commodities and inputs in general throughout a nation. Agricultural research policies affect the types of technologies that are available and suitable to farmers in a particular agro-ecological region. Infrastructure development, agricultural extension, conservation technical assistance programs, land tenure policies, and rural credit and savings programs affect awareness, opportunities, and constraints at the village or household level. Policies or programs may seek to promote particular income strategies (e.g., nontraditional export cash crop production) or may seek to address constraints arising within a given income strategy (e.g., credit needs arising in cash crop production). Programs may attempt to address land management approaches directly, for example, by promoting particular soil fertility management practices. Policies and programs may also be designed to affect development outcomes directly, for example, through direct management of land by the government, or through nutrition or cash-transfer programs.

The opportunities and constraints for changes in policies are of course influenced by the political context, which can vary greatly from one location or temporal context to another. The examples of the different policy environments and approaches cited in Chapter 1 illustrate this point, but different political contexts can lead to different policy "spaces" even within the same country and time frame. For example, decentralization policies in Ethiopia have provided differential autonomy for regional governments to respond to local perspectives in designing and implementing environmental policies and agricultural programs, with greater autonomy allowed in the Tigray Region than in the Southern Nations, Nationalities and People's Region (SNNPR) (Keeley and Scoones 2003). As with other contextual factors, such as culture and local histories, the local political context may lead to different responses and outcomes, even in areas that are otherwise similar in terms of natural endowments, access to markets, population pressure, and other socioeconomic conditions.

Currently available information does not provide policy makers with much guidance as to which of these intervention points will be most effective in achieving better land management, increasing agricultural production, ensuring sustainable use of resources, and increasing incomes and welfare. Much public action aimed at improving land management focuses on influencing household adoption of particular technologies. Yet this may be ineffective if the technologies are not suited to the income strategies that have potential in a given location, or it may miss opportunities for achieving larger impacts by focusing on other areas of intervention. Furthermore, the trade-offs or complementarities of different interventions in their impacts on development outcomes need to be assessed. This conceptual framework serves as a basis for addressing these information gaps through the studies in this book.

Hypotheses

The central hypothesis of the research reported in this book is that appropriate strategies for sustainable rural development and land management depend on the comparative advantages that exist for people in a particular location.[2] For example, opportunities for development of high-value perishable commodities, such as horticultural crops or dairy, are likely to be greatest in areas with relatively high market access and favorable agricultural potential. In such areas, investments in appropriate forms of market infrastructure and institutions may yield high social returns and facilitate a process of sustainable development. In areas more remote from markets or having lower agricultural potential, alternative income strategies, such as extensive livestock production or forestry, may have a greater comparative advantage, and development strategies addressing these livelihoods (e.g., promotion of improved institutions of common property resource management) are more likely to be effective.

We hypothesize that different income strategies and land management practices are affected by differences in comparative advantage and that these are largely determined by differences in agricultural potential, access to markets, infrastructure (e.g., roads, electricity, communication), and population density. Population density indicates the relative endowment of land and labor (the two primary factors determining production of agriculture in the East African highlands), and these, together with the agricultural potential in a particular location and available technology, determine the agricultural production possibilities. Access to markets and infrastructure, together with factor endowments and agricultural potential, largely determines the local relative prices of inputs and outputs, which determine farmers' comparative advantages in choice of outputs and inputs, as explained in further detail below. The comparative advantage of pursuing nonagricultural versus agricultural livelihoods is also largely affected by households' access to markets and potential for agricultural production. Other factors, such as access to new technologies via technical assistance, access to credit, education, land tenure, household wealth, and others, can also influence livelihoods and land management practices by affecting the information that farmers have access to and the constraints that they face, irrespective of local comparative advantages.

Agricultural Potential

Agricultural potential is an abstraction of many factors, including rainfall, altitude, soil type and depth, topography, access to irrigation, presence of pests and diseases, and others, that influence the absolute (as opposed to comparative) advantage of producing agricultural commodities in a particular place. There are, of course, variations in potential depending on which commodities are being considered. Furthermore, agricultural potential is not a static concept but changes over time in response to changing natural conditions (such as climate change) as well as human-induced conditions (such as land degradation). Throughout this section, we discuss agricultural potential and other multidimensional concepts such as market access in a simplified heuristic fashion to help define the generic set of hypotheses for empirical research, recognizing that there can be complex implications of variations in the component dimensions of these concepts that we will not be able to fully illuminate.

If all markets were perfect and transactions were costless, farmers' production choices would be based on maximizing profits from current production and on maximizing the net present value of investments (Singh, Squire, and Strauss 1986; de Janvry, Fafchamps, and Sadoulet 1991). In such a scenario (unrealistic as it is), choices about agricultural production and land management would depend only on exogenous prices and biophysical factors determining agricultural potential, which together would determine the profitability of alternative agricultural decisions. Other factors would be important in determining prices, but these would not vary across households in the context of perfect markets. Thus, variations in agro-ecological conditions would be the primary determinant of variations across households and locations in agricultural decisions.

In the perfect markets case, one would expect all land to be allocated to its most profitable uses. Because different agro-ecological conditions are suitable for different types of commodities, we would expect different income strategies to be favored in different conditions. For example, perennial crops such as coffee and bananas generally grow better in higher bimodal rainfall areas. On the other hand, some annual crops, such as many cereals and cotton, grow better in less humid environments with a single long growing period. This suggests that perennial crops are likely to be found in the more humid bimodal rainfall zones and that many annual crops would be found in drier unimodal rainfall zones. However, these choices also depend on prices: if prices of cereals were high enough, they might be grown throughout East Africa.

In areas of generally higher agricultural potential, such as in highland areas having favorable rainfall and fertile volcanic soils, we would expect the highest-value commodities, such as horticultural crops, tea, and coffee, to be produced. Lower-value commodities such as cereals are more likely to be grown in areas of lower potential, along with complementary livestock production (McIntire, Bourzat, and Pingali 1992). Extensive livestock grazing is likely to be found in lower-rainfall areas not well suited to continuous crop production. In a more realistic market context, production of some of these high-value commodities, particularly perishable vegetables and fruits, may be inhibited by limited access to markets and infrastructure, and food crops may need to be grown in areas of low market access to satisfy subsistence requirements regardless of profitability (Omamo 1998).

If insurance markets are missing or imperfect, agro-ecological conditions may also influence income strategies by affecting risks (Binswanger and McIntire 1987). For example, households may seek to diversify their income sources and crops as a means of coping with production or price uncertainty (Binswanger and McIntire 1987; Ellis 2000; Barrett, Reardon, and Webb 2001). Such considerations may lead to greater diversification or to adoption of less profitable but less risky crops in areas where rainfall is more uncertain, as in drought-prone areas. Risks of pests and diseases also could lead to similar risk-management strategies.

Agro-ecological conditions also influence labor intensity and land management practices. In general, higher agricultural potential is expected to be associated with higher labor intensity and adoption of more labor and input-intensive practices, by increasing the marginal return and/or reducing the risks of these inputs (Barrett et al. 2002). For example, fertilizer use is likely to be less profitable and more risky in low-rainfall areas because nutrient uptake may be limited by inadequate soil moisture. Higher-rainfall areas may be associated with greater adoption of vegetative land management practices such as use of agroforestry, live barriers, and mulching because of higher biomass productivity in such areas. By contrast, adoption of some soil and water conservation measures may be more profitable and less risky in low-rainfall areas because they may have a larger impact on yields in the short run by conserving scarce soil moisture and may be less prone to harboring pests and weeds than in high-rainfall environments (Herweg 1993a,b).

The impacts of more favorable agro-ecological conditions on crop production and incomes are expected to be positive. Higher agricultural potential is expected to promote more intensive and productive use of inputs and production of higher-value crops as noted above, leading to higher value of crop production and income. Livestock incomes may be higher in such areas because of greater availability of feed sources. On the other hand, farmers in high-potential areas may have less comparative advantage in livestock production because of higher profitability of crop production and because problems of animal pests and diseases are generally greater in more humid environments. Nonfarm opportunities linked to agricultural production are likely to be greater in higher-potential areas (Haggblade, Hazell, and Brown 1989; Reardon 1997; Barrett, Reardon, and Webb 2001), although households may be less prone to pursue such opportunities given the higher profitability of farming in these areas. Overall, we expect household incomes to be higher in higher-potential environments, controlling for differences in access to land and other resources.

The expected impacts of agricultural potential on land degradation are mixed. In higher-potential areas, there is likely to be more planting of perennial crops and more vegetative cover of the soil in general, which helps to limit soil erosion. However, the higher rainfall in such areas may be more erosive, especially in steeply sloping areas such as in the highlands. Soil nutrient depletion may be higher in such areas as a result of greater offtake of biomass from fields, especially if use of fertilizer or other means of soil fertility restoration is limited. Thus, some aspects of land degradation may be worse in higher-potential zones, even if other aspects are better.

Access to Markets and Infrastructure

Access to markets and infrastructure is critical for determining the comparative advantage of a given location, given its agricultural potential. For example, a community with an absolute advantage in producing perishable vegetables (i.e., total factor productivity in vegetable production is higher there than anywhere else) may have little or no comparative advantage (low profitability) in vegetable production if it is far from roads and urban markets. As with agricultural potential, market access is also a multidimensional and dynamic concept (e.g., distance to roads, condition of roads, distance to urban centers, access to foreign markets, degree of competition, access to transport facilities).

Because of the substantial transaction costs of storing, transporting, and marketing commodities, access to markets and roads is critical for determining the comparative advantage of a particular location, given its agricultural potential. Following von Thünen (1826), we postulate that land will be allocated to its highest-rent use, which in areas close to urban markets is more likely to be in production of intensive high-value commodities that involve substantial transport costs (such as vegetables and dairy products) or used for industrial purposes than in production of lower-value and more transportable food grains or livestock using extensive methods or natural forest (Chomitz and Gray 1996).[3] Even if high-value crops are more profitable than food commodities further from markets, farmers faced with high transport costs may need to produce low-value crops for their subsistence purposes rather than higher-value cash crops (Omamo 1998; Key, Saudolet, and de Janvry 2000).

In areas of high market and road access, production of perishable high-value crops such as horticultural crops is likely to be profitable if agro-ecological conditions are suitable. These may displace other, less perishable and profitable cash crops such as coffee to areas somewhat more remote from markets because such crops can be transported over greater distances at lower costs than perishable commodities. Other bulky food crops may also have a comparative advantage close to urban areas, given their high transport costs, or be grown for subsistence purposes in more remote areas. More storable and transportable crops, such as cereals and legumes, are likely to have a comparative advantage further from markets and roads because they can be stored and transported over longer distances than other commodities.

Dairy production and other intensive livestock operations are also more likely to be found close to urban areas because of economies of scale in production and marketing, high transport costs, perishability of the products (e.g., limited viability of milk), and the need for market access to purchased compound feeds. Extensive production of livestock that are relatively easy to transport, such as cattle and small ruminants, can occur in areas far from markets and is likely to have a comparative advantage in areas that are low in potential for crop production.

Opportunities for rural nonfarm activities are also likely to be greater closer to urban markets and roads (Haggblade, Hazell, and Brown 1989; Reardon 1997; Barrett, Reardon, and Webb 2001). This includes activities linked to agriculture, such as processing agricultural commodities, commodity trading, and provision of agricultural inputs as well as other activities stimulated by higher demand resulting from higher incomes in areas of better access. Employment opportunities in urban industries are also likely to be greater for people who live closer to urban centers.

Better access to markets and roads is expected to increase the use of purchased inputs and the capital intensity of agriculture by increasing the profitability and availability of such inputs and increasing farmers' access to credit (Binswanger and McIntire 1987). However, the effects of market and road access on labor intensity and land management are ambiguous. For example, the level of commodity prices has a theoretically ambiguous influence on soil conservation investments (LaFrance 1992; Pagiola 1996). Higher access implies that the marginal return from labor invested in crop production and land management is higher (because output and land prices are increased) (Binswanger and McIntire 1987), but the opportunity costs of labor are also likely to be higher. The net result depends on which effect is stronger (Barbier and Bergeron 2001). The positive effect of market and road access on input use may have further influences on use of labor-intensive practices, depending on whether capital- and labor-intensive practices are complements or substitutes.

The effects of market and road access on the value of crop production are also ambiguous. To the extent that better access promotes production of higher-value crops, increases the local prices of crops, and promotes more intensive use of inputs, it tends to increase the value of crop production. However, as mentioned above, better access also may reduce the labor intensity of crop production and thus could reduce the value of output.

Given the ambiguous effects of market and road access on land management, the effects on land degradation are also, not surprisingly, ambiguous. By increasing the profitability of agricultural production, greater market access will promote expansion of production into forest areas or other fragile lands if the costs of productive factors and output prices are unaffected by market access (Angelsen 1999), which will increase land degradation in such areas. However, if the costs of factors rise because of constrained supply or prices fall as a result of inelastic demand, a reduction in agricultural area (and hence the pressure on forests and other fragile lands) is possible as productive factors are concentrated on the most profitable lands (Angelsen 1999). Market-driven intensification may also contribute to land degradation by leading to reduced fallowing (Binswanger and McIntire 1987), which will contribute to declining soil fertility and increased erosion (from reduced vegetative cover) unless sufficiently offset by adoption of more intensive soil fertility management and soil conservation practices. Improved market access may contribute to increased use of animal draft power for tillage (Binswanger and McIntire 1987), which may contribute to soil erosion on sloping lands. Commercialization of agricultural commodities also can contribute to depletion of soil nutrients if the nutrients being exported from the farming system in the form of commodity sales are not adequately replenished by fertilizers or other nutrient sources (de Jager, Nandwa, and Okoth 1998). On the other hand, market-driven intensification may lead to reduced erosion and improved soil fertility management as a result of the increased incentive to invest in land improvements, given the rising value of land relative to labor (Tiffen, Mortimore, and Gichuki 1994).

Regardless of its net influence on crop production, better market and road access is expected to have a positive effect on income because access increases households' income earning opportunities, whether through increased agricultural production or through nonfarm activities.

Irrigation

Irrigation is a form of infrastructure that directly affects agricultural potential. As with improvements in market access, irrigation investment can enable production of higher-value crops such as horticultural crops. It likely contributes to labor intensity by enabling multiple crops per year to be produced and by increasing the return and/or reducing the risk of labor invested in crop production. If this intensification increases the costs of productive factors (e.g., if wages rise as a result of increased labor demand), irrigation may limit expansion of agricultural production, as in the case of improved market access. Irrigation may promote investments in complementary soil and water conservation investments and practices, such as investments in soil bunds and drainage (Pender and Kerr 1998). It may also encourage farmers to adopt complementary productive inputs such as fertilizer, particularly where soil moisture constraints limit farmers' willingness to use fertilizer (Pender, Place, and Ehui 1999). As a result of these effects, irrigation is likely to contribute to increased value of crop production and incomes.

The effects of irrigation on land degradation may be mixed. Irrigation increases the incentive to invest in land improvement and soil fertility management by increasing the value of such investments. On the other hand, irrigation may contribute to problems of soil erosion or salinity if runoff and drainage are not managed adequately. Irrigation can also contribute to increased soil nutrient mining by increasing production and commercialization of crops unless adequate efforts are made to replenish such nutrients. Irrigation also may have negative effects on people downstream as a result of reduced access to water or increased use of agrochemicals.

Population Pressure

Population pressure (indicated by higher population density) affects the expansion of agriculture and the labor intensity of agriculture by affecting the land/labor ratio. It may cause households to expand agricultural production into areas less suited to agriculture, contributing to lower agricultural productivity and natural resource degradation, as argued two centuries ago by Thomas Malthus and more recently by his modern followers (e.g., World Commission on Environment and Development 1987). But population pressure may cause households to intensify their use of labor and other inputs on the land and may also induce innovations in technology, markets, and institutions or investments in infrastructure, thus possibly mitigating or outweighing such negative Malthusian effects (Boserup 1965; Ruthenberg 1980; Hayami and Ruttan 1985; Binswanger and McIntire 1987; Tiffen, Mortimore, and Gichuki 1994).

Population pressure is expected to increase labor intensity in agriculture by increasing the availability (hence reducing the costs) of labor relative to land (Boserup 1965). Higher labor intensity of agriculture can take the form of production on more marginal lands, less use of fallow, adoption of more labor-intensive methods of cultivation, labor-intensive investments in land improvement, and/or adoption of more labor-intensive commodities (e.g., horticultural crops and intensive livestock production) (Pender 2001). Income strategies that are land and resource intensive, such as forestry and extensive livestock production, are likely to be less viable in more densely populated settings. There may be greater opportunities for rural nonfarm activities in more densely populated settings because of larger markets and lower transaction costs, which will facilitate diversification of economic activities (Tiffen, Mortimore, and Gichuki 1994).

Population pressure may also induce increases in the capital intensity of agriculture if capital is complementary to labor (e.g., use of draft animals; McIntire, Bourzat, and Pingali 1992) or increase the "knowledge intensity" of agriculture through adoption or adaptation of technologies (e.g., improved seeds, integrated pest or soil nutrient management). It may also have more indirect (but still important) effects by stimulating migration, investments in infrastructure, or technical or institutional change (Pender 2001).

Population-induced intensification is likely to lead to higher yields and higher value of crop production per hectare unless greater intensity is offset by land degradation (Salehi-Isfahani 1988; Pender 2001). However, labor intensification may lead to lower labor productivity and per capita income (as a result of diminishing returns to labor) unless offset by technical change, improvement in infrastructure and market access, or other improvements in opportunities (Binswanger and McIntire 1987; Salehi-Isfahani 1988; Pender 2001).

The impacts of population pressure on land degradation may be mixed. Land degradation may increase as a result of cultivation on fragile lands, reduced use of fallow, increased tillage, mining of soil nutrients, and other potential results of agricultural expansion and intensification, consistent with Malthusian predictions. On the other hand, more labor-intensive investments in land improvements and soil fertility management practices as a consequence of lower wages relative to land values resulting from population pressure may improve land conditions, consistent with Boserup (Scherr and Hazell 1994; Tiffen, Mortimore, and Gichuki 1994; Pender 2001). Considering these issues, some have argued that there may be a U-shaped response of natural resource conditions as rural population increases, with initial degradation followed by improvement as population and resource degradation reach a point at which it becomes profitable to invest in conserving and improving resources (Scherr and Hazell 1994; Pender 1998; Otsuka and Place 2001a). However, such favorable responses may not be automatic (even if investments in resources become profitable), as they depend on the existence or development of a favorable institutional environment for investment (e.g., secure and individualized property rights) (Scherr and Hazell 1994; Pender 1998; Otsuka and Place 2001a).

Development Domains

These factors (agricultural potential, market access, and population pressure) interact with each other in complex ways. Population density tends to be higher where there is greater agricultural potential or greater market access because people have moved to such areas in search of better opportunities. On the other hand, population pressure may have contributed to land degradation, reducing agricultural potential from what it once was. Market access tends to be better where there is a higher population density because the per capita costs of building roads are lower and the benefits higher in such circumstances. Market access also tends to be better where agricultural potential is higher because the returns to developing infrastructure are greater.

Some of these relationships can contribute to self-reinforcing patterns of development. For example, population growth in a region increases the size of the local market and hence the profitability of local industry and agriculture (where economies of scale or transport advantages are involved), thus leading to increased local wages and further population growth through immigration (Krugman 1998). On the other hand, some of these relationships may cause offsetting tendencies. For example, population growth may lead to land degradation, which increases production costs and undermines the potential for intensifying agriculture, even as the demand for local agricultural production increases.

Despite these interrelationships, there is still substantial independent variation of these factors in the East African highlands. Given such variations, and the fact that most of these factors change relatively slowly over time, it is useful to consider different development domains represented by variations in these variables. Overlaying the indicators used in Figures 1.2, 1.3, and 1.4, we represent one possible classification of development domains in East Africa in Figure 2.2 (see color insert).

The potentials for different income strategies, land management practices, and the effects of policies influencing these decisions are likely to vary across such domains (Pender, Place, and Ehui 1999). For example, commercialization of high-value perishable crops such as fruits and vegetables may be highly profitable and feasible in areas of high agricultural potential and favorable market access (which are also usually densely populated), such as highland areas close to major urban centers in central Kenya and Ethiopia (Table 2.1). Dairy production and other intensive livestock production also are likely to be profitable in such regions because of the demand for milk and meat in urban areas, its high perishability and transport costs, and availability of feed supplies. High-value, but less perishable, crops such as coffee and tea and lower-value food crops also can be produced in areas of high potential and market access, though the profitability of many of these crops may be lower than that of high-value perishable commodities in these areas. Rural

Table 2.1 Hypotheses about income strategies in different development domains in the East African highlands

Agricultural potential	Market access: High	Market access: Medium/low
High	Central Kenya, Uganda, and Ethiopia near urban centers Perishable cash crops Dairy, intensive livestock Nonperishable cash crops Intensive food crop production Rural nonfarm development	Southwestern Ethiopia, western Kenya, southwestern and eastern Uganda Nonperishable cash crops Intensive food crop production Livestock production (especially in areas of moderate population density)
Low	Parts of northern/eastern Ethiopia near urban centers With irrigation investment: Intensive food crop production Perishable cash crops Dairy, intensive livestock Without irrigation investment: Low-external-input cereals Rural nonfarm development	Much of northern and eastern Ethiopia With irrigation investment: Intensive food crop production Without irrigation investment: Low-external-input cereals Extensive livestock production (in areas of low population density) Woodlots/forestry/beekeeping (especially in low-density areas) Emigration

Source: Adapted from Pender, Place, and Ehui (1999).

nonfarm development, linked to agricultural production through development of input supply and agricultural processing industries and demand linkages for rural services, also may have strong prospects in high-potential, high-access areas.

Areas with high agricultural potential but less favorable market access, such as significant parts of the highlands of southwestern Ethiopia, western Kenya, and eastern and southwestern Uganda, likely have a comparative advantage in producing high-value (relative to their volume) nonperishable commodities (such as coffee) that can be transported over relatively long distances. Given the high costs and risks of depending on imported food in such areas, farmers may continue producing most of their own food crops until improvements in roads and transportation services, as well as increased production of food crops in other regions, allow imported food to be more economical and less risky. At this stage of development, complementary linkages between crop and livestock production are important, with animals providing a source of draft power, manure, and food protein, and crop residues an important source of feed (McIntire, Bourzat, and Pingali 1992). Thus, opportunities for livestock production linked to crop production are also likely to be important, particularly in areas of low or moderate population density with sufficient available land to provide fodder. There is likely to be good potential for adoption of purchased inputs in such areas, financed by sales of cash crops or livestock, as a way to improve local food supplies as well as income.

In lower-potential areas, such as the moisture-stressed highlands of northern and eastern Ethiopia, adoption of input-intensive food crop production may be risky and of limited profitability in rainfed conditions. Where irrigation and good market access are available, intensive production of food and cash crops is likely to be profitable. Increased production of cereals and fodder in irrigated areas may also facilitate intensive dairy or other livestock production in areas close to cities. In nonirrigated low-potential areas, the agricultural options are more limited. Soil and water conservation investments may yield significant returns in moisture-stressed areas and may facilitate targeted and limited use of fertilizer and other inputs where soil moisture is adequate. Where population density is high and farms are very small, farmers in such low-potential environments may be unable to produce sufficient surplus to finance purchase of inputs. Thus, this will be most feasible closer to urban areas where nonfarm sources of income are available, where rural industries are developing, or where seasonal migration (or remittances from permanent migrants) is common.

In more remote low-potential areas with low population density, improvement of extensive livestock production may offer development potential. Achieving this potential may require the strengthening of collective action institutions to encourage investments in improvements of grazing lands, perhaps by planting and managing fodder grasses and trees. Tree planting and related activities, such as beekeeping, may also provide opportunities for significant incomes and welfare improvement, especially where market access is relatively good.

The most difficult cases in terms of viable income strategies are areas with low agricultural potential, without irrigation, that are far from markets and are densely populated (as in parts of the northern Ethiopian highlands). In some cases, particularly in less densely populated areas close to forests, forestry and beekeeping activities can be important. Where natural forests have been depleted or are protected, tree planting may be profitable. Small ruminants can be efficient users of available fodder resources and can be transported long distances to market, though intensification of their use will be limited by availability of fodder or grazing materials. Rehabilitation of degraded lands, investment in soil and water conservation structures, and low-external-input methods of soil fertility enhancement also may have significant potential to improve land productivity. Nevertheless, these seem unlikely to solve the long-term poverty problem facing such communities. Emigration (short or long term) is likely to be an important element of the livelihood strategy for many households in these areas.

Income Strategies

Income strategies influence land management and labor intensity. For example, production of high-value horticultural crops or other cash crops will promote greater use of purchased inputs, labor, and adoption of labor-intensive land improvements such as terraces because higher-value production increases the value of these inputs and the ability to finance them (e.g., Tiffen, Mortimore, and Gichuki 1994; Barrett et al. 2002). Mixed crop–livestock producers are more likely to apply manure to their crops because they have greater access to this bulky resource. When credit is constrained, households with greater access to off-farm income may be more prone to use inputs or make investments that require cash, such as fertilizer or hired labor (Reardon, Crawford, and Kelly 1994; Clay, Reardon, and Kangasniemi 1998; Pender and Kerr 1998; Reardon et al. 2001). On the other hand, households with greater off-farm opportunities may be less prone than others to invest labor in crop production or labor-intensive land management practices because their opportunity costs of labor may be higher (if labor markets are imperfect) (Scherr and Hazell 1994; Pender and Kerr 1998).

By influencing crop choice and the intensity of input use, income strategies affect the value of agricultural production. For example, the value of crop production is expected to be higher for producers of high-value crops than other producers. Income strategies may also affect the value of agricultural production by affecting the ability of households to produce and market their commodities. For example, households that specialize in production of certain crops may develop better ability to produce and market their crops than those that are more diversified. Livestock producers may obtain better crop production because of deposition of animal manure on their fields (even if they are not investing effort in collecting and applying manure). Households involved in nonfarm activities may have advantages in liquidity and risk management that enable them to obtain better prices for their crops (e.g., by not being forced to sell right at harvest).

Income strategies may also have impacts on land degradation. For example, households producing higher value crops or having nonfarm income may be more likely to replenish soil fertility by using fertilizer, or may invest more (or less) in soil and water conservation measures, as argued above. The impacts on land degradation will depend on the net effects of decisions affecting crop choice, input use, and land management practices.

Income strategies are also expected to affect household incomes and poverty. Households able to rely on high-value crops, intensive livestock systems, or remunerative nonfarm activities are likely to earn higher incomes than those confined to subsistence food crop production (Tiffen, Mortimore, and Gichuki 1994; Barrett, Reardon, and Webb 2001). On the other hand, households dependent on low-wage off-farm employment may be poorer than even subsistence farm households.

Access to Programs and Services

As noted earlier, access to programs and services can influence the income strategies and land management practices of communities and households by affecting their access to information about technologies, their capacities to effectively use technologies or to organize collective action, and their financial or other constraints. In this subsection, we consider three types of programs and organizations that are expected to have significant influence on income strategies and land management: technical assistance programs and organizations, credit and microfinance programs and organizations, and educational services.

Technical assistance programs and organizations. Because natural resource management (NRM) technologies are knowledge-intensive (Barrett et al. 2002), technical assistance is likely to be an important determinant of their adoption. Presence of programs and organizations is likely to improve delivery of NRM technologies (Swinkels and Franzel 1997). However, the effects of participation in programs and organizations will likely depend on their focus.

Credit. Credit programs may enable farmers to purchase inputs or acquire physical capital, thus contributing to technology adoption and increased capital and input intensity in agriculture (Feder, Just, and Zilberman 1985). This may promote increased production and marketing of high-value crops or intensification of livestock production and a reduction of subsistence food crop production. If credit availability helps to relax capital constraints, this can reduce the extent to which households discount the future (Pender 1996; Holden, Shiferaw, and Wik 1998), possibly leading to more investment in soil and water conservation (Pender and Kerr 1998). Credit may also facilitate labor hiring and thus promote labor intensification. On the other hand, credit availability may enable households to invest in nonfarm activities and may thus contribute to less intensive management of land and other agricultural resources. Also, by promoting intensification of capital and purchased inputs, credit may reduce labor-intensive land management practices that are substitutes for these (e.g., fertilizer use may reduce use of manure and compost). The net effects of credit on land management, crop production, and land degradation are thus ambiguous. The impact of credit availability on income is likely to be positive, provided households have profitable uses for it (otherwise the effect may be nil or even negative).

Education. Education is likely to increase households' opportunities for salary employment off farm and may increase their ability to start up various nonfarm activities (Barrett, Reardon, and Webb 2001; Deininger and Okidi 2001). Education may increase households' access to credit as well as their cash income, thus helping to finance purchases of physical capital and purchased inputs. This may help to promote production of high-value crops and intensive livestock production as well as promoting greater use of such capital and inputs in producing traditional food crops. Education may also promote changes in income strategies and technologies by increasing households' access to information about alternative market opportunities and technologies, and hence households' ability to adapt to new opportunities (Feder, Just, and Zilberman 1985). On the other hand, more educated households may be less likely to invest in inputs or labor-intensive land investments and management practices because the opportunity costs of their labor and capital may be increased by education. Thus, the net impacts of education on land management, crop production, and land degradation are ambiguous. The impact on household income is expected to be positive.

Property Rights and Land Tenure

Property rights and the form of land tenure can affect land management and productivity for several reasons. If there is insecurity of tenure, the household operating the plot may have less incentive to invest in land improvement (Feder et al.

1988). This is not necessarily the case, however, if the household can increase tenure security by investing in the land (Besley 1995; Otsuka and Place 2001b). In that case, there may be more investment on land having insecure tenure.

Perhaps more important for land management than security of tenure is the set of rights associated with the different tenure systems. Owners of freehold land have complete rights to use, lease, sell, bequeath, and mortgage their land. Owners or occupants of lands under other tenure systems may have more restricted rights, including restrictions on sales, leasing, and mortgaging. These restrictions may reduce farmers' access to credit, where land is (or could be) used as collateral for credit (Feder et al. 1988; Place and Hazell 1993). If so, farmers having more complete property rights (such as ownership under freehold tenure) may be more prone than other farmers to use cash inputs or make investments. The effects of this would be similar to the effects of increased access to credit discussed above. Also, to the extent that land sales or lease rights enable households to recoup the value of land improvements, owners with more complete transfer rights may be more likely to make investments in land improvement (Pender and Kerr 1999; Deininger et al. 2003).

Ownership of a formal title may amplify the impacts of greater tenure security and complete land rights associated with freehold by providing proof of freehold status. In particular, formal title may facilitate access to credit and help to prevent or resolve land disputes (Feder et al. 1988). However, whether land titles have the hypothesized positive impacts on tenure security, credit access, and investment in the African context has been much debated in the literature (Shipton 1988; Haugerud 1989; Atwood 1990; Barrows and Roth 1990; Migot-Adholla et al. 1991; Place and Hazell 1993; Bruce and Migot-Adholla 1994; Besley 1995; Platteau 1996; Sjaastad and Bromley 1997; Nkonya et al. 2004). Limited or adverse impacts of land titles on security and investment in Africa may be caused by many factors, including adequate security of customary tenure, rent-seeking opportunities created by titling efforts, limited availability of rural credit regardless of whether land is usable as collateral, limited ability to foreclose on mortgaged land, use of collateral substitutes by credit organizations, lack of updating of titles following sales or land subdivision because of high costs, or other factors.

In addition to tenure status and land title, the means of acquisition of land may also influence farmers' tenure security and incentives to invest in land management. For example, tenants on rented or borrowed land are unlikely to invest in soil and water conservation measures or in perennial crops if the lease or borrowing arrangement is relatively short term, regardless of the tenure system under which the landholder claims the land. Tenants on sharecropped plots may have less incentive to apply labor and other inputs than owner-operators or tenants using fixed rental (Shaban 1987; Otsuka and Hayami 1988). By contrast, owners of purchased land and tenants using cash rental may have more incentive than owners of inherited land to produce cash crops and apply inputs in order to be able to recoup the costs of their investment and repay any loans used to finance the investment. Land users who have encroached on public or communal lands may face substantial tenure insecurity; and this may prevent them from undertaking investments or fallowing unless such investments are perceived as increasing the land user's tenure security (Otsuka and Place 2001a).

Household Endowments

If factor markets (markets for land, labor, and capital) do not function efficiently, then there may be significant differences among households in their land management practices and agricultural productivity (de Janvry, Fafchamps, and Sadoulet 1991). In the context of imperfect labor and land markets, agricultural households with less land or a larger family labor endowment per unit of land can be expected to use labor more intensively in agricultural production (Feder, Just, and Zilberman 1985). Essentially, the impacts of smaller farm size, or larger household labor endowment controlling for farm size, will be similar to the effects of population density if imperfections in labor or land markets limit the extent to which differences in labor endowments can be overcome through labor or land transactions. Greater labor availability per unit of land may also induce households facing land constraints to pursue alternative off-farm income strategies, such as wage employment and various nonfarm activities. The effect of smaller farm size or larger family size on the value of crop production per hectare is likely to be positive if labor and land markets are imperfect, or zero if these markets function well. The impact of labor availability on household income is expected to be positive (as long as the marginal product of labor is positive), though the impact on income per capita may not be (if there are diminishing returns to labor). As with population pressure, the impact of labor availability on land degradation is ambiguous.

If credit is constrained, farmers who own more livestock, equipment, or other physical assets may be better able to finance the purchase of inputs or investments, either by liquidating assets or through better access to credit. The impacts on crop choice, land management, and labor intensity are thus qualitatively similar to the impacts of access to credit discussed above and are ambiguous for the same reasons.

The impact of livestock on land degradation may be mixed and depends on the type of degradation as well as on interactions between crops and livestock. Livestock may contribute to soil compaction and erosion along animal walkways, and if draft animals are used for tillage, they also may contribute to erosion and compaction as a result of tillage operations. Livestock usually have a more positive role in plant nutrient cycling at the household level. If farmers apply animal manure to their crop plots, then it is likely that farmers with more animals would have higher nutrient balances than those with fewer animals. However, farmers may fail to apply manure or other organic materials to their crop plots for various reasons. Farmers often keep animals close to the homestead, which implies greater availability of manure close to the homestead. This, together with the difficulty of transporting manure because of its bulkiness, implies that plots further away from the homestead are less likely to receive manure and other bulky organic materials such as household wastes. Thus, we expect plots away from the residence to have lower nutrient balances than those closer.

Farm equipment may also have mixed effects on land degradation. Plows and other machinery may contribute to soil erosion through tillage, especially if used on sloping lands. On the other hand, equipment may be used to help construct soil and water conservation structures or to apply fertilizer or other inputs that help to prevent soil erosion, nutrient depletion, or other forms of degradation.

The effect of livestock and other physical assets on household income is expected to be positive, to the extent that such assets are accumulated for purposes of increasing income. However, there may be other reasons for accumulating assets. For example, livestock may be kept as a store of relatively liquid wealth and as an insurance substitute, where financial and insurance markets are poorly developed because of problems of covariate risk (Binswanger and McIntire 1987). Livestock, jewelry, or other assets also may be accumulated for dowry or bequest purposes. Thus, the impacts of some physical assets on income may be limited.

Summary of Hypotheses

The hypotheses are summarized in Table 2.2. In general, most factors have theoretically ambiguous impacts on agricultural production, land management, and land degradation. Many factors have more unambiguous expected impacts on household incomes. These hypotheses suggest that the impacts of policy and program interventions on agricultural production and land degradation may be very context specific, and may often involve trade-offs among the objectives of increasing agricultural production, reducing land degradation and increasing household incomes. Empirical research is essential to understand these impacts and trade-offs, given the theoretically ambiguous nature of most of these relationships.

In the remainder of this book, we present 13 case studies from Ethiopia, Kenya, and Uganda that investigate many of these empirical relationships using a variety of data sources and analytical methods. Many studies use econometric approaches to investigate the effects of different factors on land management and outcomes, controlling for confounding influences. Some of these studies are based on community

Table 2.2 Summary of hypotheses

Impacts of	Livelihood strategy	Labor intensity	Land management practices	Value of agricultural production	Land degradation	Income
Higher agricultural potential	+ Higher-value crops – Lower-value crops – Extensive livestock +/– Intensive livestock +/– Nonfarm activities	+	+ Labor- or capital-intensive practices + Agroforestry, vegetative methods – Some SWC measures	+	+/–	+
Higher market/road access	+ Perishable cash crops – Storable crops – Subsistence food crops + Intensive livestock – Extensive livestock + Nonfarm activities	+/–	+ Capital- and input-intensive practices +/– Labor-intensive practices	+/–	+/–	+/0
Higher population density	+ Labor-intensive activities (food crops, horticulture, intensive livestock) – Land-intensive activities (extensive livestock, forestry) + Nonfarm activities	+	– Land-intensive practices (fallow, slash and burn) + Labor-intensive practices +/– Capital- and input-intensive practices	+/0	+/–	0/–
Livelihood strategy (cf. subsistence food crops)	NA					
– High-value crops		+	+ Labor- and capital-intensive practices	+	+/–	+
– Livestock		+/–	+ Use of manure	+/–	+/–	+
– Nonfarm activities		+/–	+ Purchased inputs, hired labor	+/–	+/–	+/–
Irrigation	+ Horticultural crops	+	+ Practices complementary to irrigation and horticultural crops (e.g., fertilizer use)	+	+/–	+

(*continued*)

Table 2.2 (continued)

Impacts of	Livelihood strategy	Labor intensity	Land management practices	Value of agricultural production	Land degradation	Income
Programs and organizations	? Depends on focus	?	?	?	?	?
Credit	+ Capital- and input-intensive strategies (high-value crops, intensive livestock, nonfarm) – Subsistence food crops	+/–	+ Purchased inputs and capital (if credit used for agriculture) +/– Labor-intensive practices	+/– (depends on whether used for agriculture)	+/–	+/0
Education	+ Salary employment + Nonfarm activities +/0 High-value crops and intensive livestock	+/–	+ New technologies + Capital- and input-intensive practices +/– Labor-intensive practices	+/–	+/–	+
Larger household labor endowment or smaller farm size	+/0 Labor-intensive activities (food crops, horticulture, intensive livestock) –/0 Land-intensive activities (extensive livestock, forestry) +/0 Nonfarm activities	+/0	–/0 Land-intensive practices (fallow, slash and burn) +/0 Labor-intensive practices +/– Capital- and input-intensive practices	+/0	+/–	0/+ (labor) – (smaller farm size)
Livestock ownership	+ Livestock activities + Complementary cropping activities (e.g., cereals)	+/–	+ Capital-intensive practices +/– Labor-intensive practices	+/–	+/–	+/0
Farm equipment ownership	+ Capital-intensive agricultural activities	+/–	+ Capital-intensive practices +/– Labor-intensive practices	+/–	+/–	+
Land tenure security/more complete land rights (e.g., freehold versus others, titled versus not, owner versus not)	+/– Perennial crops +/0 Capital- and input-intensive commodities	+/–	+/– Land investments +/0 Capital- and input-intensive practices +/– Labor-intensive practices	+/–	+/–	+/–

or other meso-level data, whereas others use household and plot survey data. As mentioned previously, most of the studies are based on cross-sectional data, limiting their ability to draw conclusions about dynamic processes of change, although a few of the case studies address dynamic issues using historical recall information. In the fourth part of the book, reviews of results of experimental studies and farm level work in the three study countries are used to assess the influences of land management on agricultural productivity and other outcomes, and two other studies use bioeconomic models to enhance understanding of the driving forces and dynamics of changes in land management and outcomes and the potentials for improvement in land management and incomes as a result of policy and program options. In the final chapter, we draw conclusions and policy implications from this wide ranging set of empirical studies.

Notes

1. This definition is similar to the concept used by Reardon and Vosti (1995). Ellis (2000, p. 40) defined livelihood strategies similarly as the "activities that generate the means of household survival." According to Ellis, this definition includes natural resource–based activities, such as collection of natural resource products (e.g., forestry or fishing), cultivation of food or nonfood commodities, livestock rearing, and nonfarm natural resource–based activities (e.g., mining); and non–natural resource–based activities and sources of income (e.g., rural trade, services, manufacturing, remittances, and other transfers) (Ellis 2000). Other authors have provided somewhat broader definitions of livelihood strategies. For example, Adato and Meinzen-Dick (2002, p. 10) define people's livelihood strategies as "the choices they employ in pursuit of income, security, well-being, and other productive and reproductive goals." Although land management decisions could be seen as part of households' livelihood strategies, we wish to investigate the relationships between the major decisions that households make about how to earn their income (such as in agriculture vs. nonfarm activities) and land management decisions. Thus, we use the narrower term *income strategies* to distinguish this concept from the concept of land management.

2. Comparative advantage refers to the profitability of the economic activities that a group of people may pursue, relative to other activities that could be pursued by that group (Stiglitz 1993, p. 61). Having a comparative advantage in a given activity does not imply that the group earns more profit from the activity than could other groups (that would be absolute advantage); rather, it means that the group profits more by pursuing that activity than other activities and by trading with others who have comparative advantage in pursuing other activities. Comparative advantage can be defined for groups of different sizes at different scales (e.g., nation, region, community, household, individual), though it is most commonly discussed at a national scale in discussions of trade theory and policy.

3. As did von Thünen, we take the location of urban markets as predetermined. Recent theoretical developments in economic geography have sought to explain the location and growth of cities based on consideration of plant-level economies of scale, transport costs, positive externalities, or other sources of economies of agglomeration (e.g., Krugman 1998). Consideration of these theories and their implications is beyond the scope of this book.

Chapter 3

Development Pathways in Medium- to High-Potential Kenya: A Meso-Level Analysis of Agricultural Patterns and Determinants

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The highlands of East Africa have been endowed with a combination of moderate temperatures, adequate rainfall (falling in two distinct seasons for much of the highlands), and productive soils that make the region one of the best suited for agricultural development in all of Africa. As a consequence, the area has a long history of human habitation and supports some of the highest rural population densities in Africa (Hoekstra and Corbett 1995; Pender, Place, and Ehui 1999).

The good news is that in some areas in the highlands, it is clear that land use change has been part of a productive and sustainable pattern of agricultural development. Two examples of successful agricultural intensification are found in the central highlands of Kenya. The Mt. Kenya highlands have been the home for many studies (see Chapter 8) that have found improvements in living conditions and land quality. Similarly, the nearby Machakos District had a high prevalence of soil erosion, pasture degradation, and deforestation with very low agricultural productivity and income in the 1930s and was considered to be overpopulated (Tiffen, Mortimore, and Gichuki 1994). By 1990, however, the population had increased fivefold. Surprisingly, not only was there less resource degradation, but the value of agricultural output per head was estimated to be three times larger than 60 years earlier. A recent Government of Kenya study also suggests that most of the districts that comprise the central highlands of Kenya (Nyeri, Kiambu, Kirinyaga, and Meru) have much lower levels of poverty than other rural areas of Kenya (Ministry of Planning and Finance, Government of Kenya 2000). This is corroborated by a recent study by Tegemeo Institute and Michigan State University showing agricultural productivity, value of production, and incomes per hectare to be significantly higher in central Kenya than elsewhere (Argwings-Kodhek et al. 1999).

The bad news is that the trend in the majority of the highlands appears to be a downward spiral of increasing population pressure and land degradation, stagnant or declining agricultural production, and entrenched poverty (Cleaver and Schreiber 1994). In many parts of the highlands people are now living in abject poverty. Over 50 percent of the rural population in western Kenya lies below the poverty line (Ministry of Planning and Finance, Government of Kenya 2000). In many of these same areas, poverty has been accompanied by resource degradation. Reductions in woody vegetation, declines in soil fertility, and increases in soil erosion appear to be the norm in much of western Kenya, where recent studies in the Nyando River Basin have found a high proportion of physically degraded land as a result of poor land management practices (Shepherd and Walsh 2001).

The success stories are few and far between. Poverty and land degradation characterize most of the highlands. Why is this so? Nonfarm employment opportunities are growing slowly in East Africa, continuing to place pressure on agriculture to support roughly 80 percent of workers (World Bank 2002b). The road to sustainable livelihoods for rural households is difficult. The agricultural options available to communities are conditioned to some, perhaps a large, extent by physical and climatic conditions. But the policy environment plays a key role in the structure and performance of supporting systems to agriculture (e.g., extension) as well as in the promotion of markets for agricultural goods and services.

The key development challenge this chapter addresses is how the cases of successful intensification can be replicated or adapted in the wider highlands to overcome widespread poverty and land degradation in a manner that leads to sustainable improvement in livelihoods. What are successful land uses and management strategies, and are they feasible only in certain physical and climatic environments, or can they be catalyzed in diverse areas given proper market development?

In particular, we examine the following hypotheses:

- The prominence of high-value agricultural enterprises is not only predicated by climatic conditions; market development plays a significant role.

- Market development has a greater influence on higher-value agricultural enterprises in more favorable zones.

- Higher-value agricultural enterprises (cash crops, dairy, and tree growing) are associated with greater wealth.

- Higher-value agricultural enterprises (cash crops, dairy, and tree growing) are supportive of improved natural resource management.

The remainder of the chapter is as follows. Section 2 describes the methodology involved in the collection and analysis of the data. Section 3 identifies different development domains for rural Kenya based on population pressure, agricultural potential, and market access. Section 4 describes different types of land use strategies pursued by rural communities in Kenya. An analysis of the major underlying factors associated with observed land uses is found in Section 5. Section 6 evaluates the effects of different agricultural enterprises on wealth and natural resource management. Finally, Section 7 summarizes the key findings and discusses ways forward for policy.

Methodology and Data Sources

In this section, we first present the empirical models tested, followed by a description of the specific variables available. The final subsection then provides more detail on the types of statistical tests undertaken to test the hypotheses.

Developing Econometric Models

The first step is to better understand the types of agricultural strategies adopted by farming communities in the arable areas of Kenya. Our unit of analysis is the community or landscape scale, and thus we are interested in the choice of the scale of cereal production or its proportion of area versus cash crops versus woodland, for example. Decisions for land use are taken at the household level for the most part. Household decisions are determined strongly by the profitability or, more generally, provision of utility of different land uses (e.g., Chomitz and Gray 1996; Place and Otsuka 2000; Nelson and Geoghegan 2002). Farm-level profitability depends on the prices of inputs and outputs faced by the farmer and, in the case of imperfect markets, her endowment of resources, including management skills. If these concepts are projected to a larger scale, agricultural profitability depends critically on production possibilities that are in turn dependent on agro-ecological conditions. Data on prices of inputs and outputs would be ideal to include in a model. In their absence, factors hypothesized to determine prices may be market access and factor ratios (e.g., captured by population density).

One may therefore posit a model of land use at the community level as follows:

$$\text{Land use} = f(\text{conditioning factors, driving forces}) \qquad (1)$$

where conditioning factors are the exogenous physical and climatic factors such as soil type, rainfall, altitude, and temperature, and driving forces are the more dynamic drivers of landscapes such as population density and market access.

If the conditioning factors explain an overwhelming proportion of the variation, this implies traditional development and transfer of agricultural technologies appropriate to specific agro-ecological zones may well be a sufficient strategy for agricultural development. The interpretation of the coefficients for the driving forces may be made difficult if the driving forces are related to the conditioning factors. For instance, Chomitz and Gray (1996) discuss the likelihood of endogeneity of road development in the case of Belize. Thus, in order to understand the importance of individual variables, it would be appropriate to account for such relationships among the explanatory variables. As will be explained below, the availability of variables at a meso level (i.e., the middle levels roughly from village to district) is poor. This turns out to be the key constraint to ideal causal analysis because many of the key variables related to land use, such as climate, land tenure, population pressure, and market access, vary significantly at this meso scale.

If effects between conditioning factors and driving forces can be isolated, results from equation (1) will enable the confirmation of the importance of population density (through effects on factor ratios) and market access on agricultural strategies. Of particular importance will be the market variables because these are more clearly related to policy decisions. Another challenge for modeling land use is that there are several possible land use outcomes. This suggests that a system-of-equations approach is appropriate. The practical difficulty of implementing this is the lack of variables to identify the different land use equations. Indeed, as will be shown below, the major limitation of analyses covering wide geographic areas is lack of available variables.

Analysis of the land use model would provide some insights into what types of land uses are observable or attainable under various conditions and, to some extent, how such systems can be promoted. However, it does not provide evidence of why certain land uses should be promoted over others. For this, it would be important to evaluate the land use systems in regard to their impacts on productivity, poverty, or resource management variables, which are of importance to individuals and society. For instance, are cereal-dominated systems more productive than others? Are they linked to lower poverty rates, or do they lead to better-managed soils? Such an analysis is shown in equations (2a) and (2b), which use poverty as an example:

$$\text{Poverty} = f(\text{conditioning factors, driving forces}) \quad (2a)$$

$$\text{Poverty} = f(\text{conditioning factors, driving forces, land use}) \quad (2b)$$

The effects of land use on poverty (or other indicators of utility) may not be straightforward because the nonfarm sector may play a vital role in providing incomes to families. Of particular interest will be to identify the specific types of land use systems that are found to generate high levels of wealth. This question may be difficult to disentangle because the direction of causality between land use and poverty levels is ambiguous from a theoretical point of view. In other words, it is conceivable that more wealth leads to different choices as to which crops to sow or livestock to buy, but which crops or livestock products you produce may also influence how well off you are.

We present findings regarding the relationship among different land uses, wealth, and the percentage of tree cover. However, reliable meso-level data for other indicators of degradation, production, or productivity do not exist beyond small geographic areas. The regression results from equation (1) may be interpreted as identifying relationships from the explanatory variables to the land use variable because the explanatory variables are exogenous, and some of them are not modifiable at all. However, we are unable to disentangle the direction of causality between land use (and implied enterprise choice) on the one hand and poverty and environmental indicators on the other hand. In that case, we merely attempt to describe associated patterns that merit further attention.

The Data Set

The data used in the analysis reflect different spatial units and are drawn from different sources. Many of the variables, including the land use variables, are generated from aerial photos of 45-hectare-sized areas. Because all the land use data are generated from the aerial photos, this 45-hectare area is the basis for almost all the statistical analysis and is what we refer to as the "site." Others may relate to square kilometer resolution or data collected at divisional level (administrative unit below a district). These are described in more detail. In all cases, variables are geo-referenced, allowing them to be scaled up or down to link with other data. The aerial photos are geo-referenced in a crude way. The center point for the photo is identified before the flight, but the actual photo may deviate slightly from this as a result of human error in flying and taking the photo.

Available data on physical and climatic conditioning factors include altitude, slope, rainfall, length of growing season, temperature, and the precipitation to potential evapotranspiration ratio (Corbett et al. 1999). These variables are available for all of Kenya and have been catalogued by ILRI (2003). These variables constitute the most relevant variables for agriculture, with the possible exception of soil type. However, there is no reliable, recent, and high-resolution information on soil types for Kenya.

There are potentially many important driving forces behind land use decisions. At the national level, these include peace and security, economic stability, exchange rates, financial liquidity, urban growth, and facilitation of agroprocessing. Such factors would be critical in a dynamic model of land use change or intensification. However, because our land use data are from a single year, these national variables become constant across all our sites. Thus, we focus on driving forces that differ across sites within Kenya. Among these are population density and growth, market access and growth, rural nonfarm growth, presence of development projects, ethnicity, and effectiveness of extension programs. However, our data set includes population density and various measures of market access only. There is insufficient data coverage for information on the other driving forces. Population density information pertains to 1989 (the last census that has been made available to the public) and is available at the sublocation level (lowest administrative unit) for all of Kenya. Market access surfaces have been generated by ILRI and ICRAF and include distances to different types of roads and urban markets as well as estimates of travel times to different urban areas. These variables are available for the medium- to high-potential areas of Kenya.

Land use variables were generated from interpretation of low-altitude aerial photographs (1,500 meters above ground level) that were taken toward the end of the long rainy season of 1997 (May–June). Each photo represented 45 hectares, and photos followed a grid pattern at 2.5-kilometer intervals along transects that were separated by 5 kilometers. So although there is a good density of coverage, it is not complete, and we cannot produce land use surfaces. Thus, the ability to generate ex situ spatial variables, such as land use in adjacent areas, is inhibited. The original flight coverage included all areas where maize might be grown, so this excluded the north of Kenya as well as the more arid areas of southern and eastern Kenya. The available photos number over 8,200, but because of financial constraints, 5,546 photos from 30 districts were interpreted. The excluded photos are largely from the drier, lower-elevation areas. Interpretation of land use variables was done by projecting the photos onto a 100-dot grid paper on a wall and counting the number of times a certain land use intersects with a dot.[1] Tree canopy cover was calculated by visual inspection over the entire photo. Finally, data on cattle density are from 1993–97 division-level reports of the Ministry of Agriculture and Livestock Development.

The low-altitude aerial photography allowed very detailed interpretation of land use, including specific type of crop, for example, maize, sorghum, or potato. A total of 97 land use or cover variables could potentially be distinguished, and these include not only different crops but nonagricultural land covers such as water bodies, roads, and man-made structures. Because the photos covered entire 45-hectare tracts, there is considerable noncultivated area in the resulting land use data. To make our analysis tractable, we aggregated land use into a handful of discrete cases: maize, other staples, legumes, cash and horticulture,[2] grazing and pasture land (including planted forages), wooded land, other land, water, and man-made structures. In our analyses, we focus mainly on explaining differences in maize, cash/horticultural production, and woodlots, as other land types were neither common nor sizable. These calculations are made for each of the 5,546 images. We also attempt to explain the current intensity of cattle and dairy cattle raising. These data are available from the International Livestock Research Institute (ILRI) at the divisional level (a district may be composed of 5–10 divisions).

High-resolution data on poverty, productivity, and natural resource management are not yet available for wide areas of Kenya. Thus, we again turned to the aerial photographs to generate such information. For poverty, we used the proportion of roofs that were high value (tile or tin) as opposed to thatch. Although there are certain cultural preferences as to roof type, this variable is widely considered to be associated with more robust poverty measures. As for natural resource management, the percentage of land under tree canopy cover is the only useful variable at our disposal for each of the 5,546 sites. We attempted to measure soil degradation by visual identification of gullies. However, this proved to be feasible only in the drier areas because sheet and gully erosion could be hidden under vegetation in the more humid areas.

Delineation of Kenya into Development Domains

In this section, we focus on the highlands of Kenya, defined as areas exceeding 1,200 meters above sea level. Most, but not all, medium- to high-potential land is found in the highland areas. Figure 3.1 (see color insert) shows that the highlands cover much of the southwest quarter of Kenya. The easternmost area is known as the central highlands, and the westernmost area is the western highlands. The western highlands extend almost all the way to Lake Victoria, which is at 1,100 meters above sea level. In between the two is the rift valley, which, although it lies below the enveloping higher hills, still falls into our definition of the highlands. In addition to this large contiguous area, there are fragmented highland areas extending to the southeast and to the northwest.

In order to define distinctive and meaningful development domains, the highlands were partitioned into zones according to agricultural potential, population density, and market access (defined in detail below). These three variables are selected because they are expected to have a significant influence on agricultural strategies or pathways (this has been shown in other studies, including Pender, Place, and Ehui 1999; Kristjanson et al. 2002). Agricultural potential has an obvious link to agricultural strategies in that it essentially defines what options are feasible from a technical point of view.[3] Market access influences the extent to which agricultural commodities can be marketed and inputs and services obtained and is expected to influence the degree of adoption of commercial enterprises. Because population density is a general proxy for average landholding size, it is expected that high population density will lead to the adoption of more labor-intensive strategies and, according to Boserup (1965) and Ruthenberg (1985), will lead to more intensified agriculture. Population density can also be seen as reflecting market demand for local goods and services.

The actual variables used in the delineation of Kenya's highland areas were:

1. Agricultural potential: total precipitation/potential evapotranspiration ratio (or P/PE, where the numerator and denominator are both measured in millimeters).[4]

2. Market access: travel time (by vehicle in minutes) to the nearest urban area of at least 2,500 people, using assumed mean travel speeds for the main road types.

3. Population density: population density from the 1989 census.

Identifying cutoffs for each of these variables is a bit subjective. We undertake two separate exercises, one that attempted to give a more realistic yet complex picture of the variation across highland sites and another to provide a more simplistic but manageable view. The first retained four categories of population density, four levels of market access, and four agricultural potential zones and in the end found 61 different development domains in the highlands, 28 of which represented at least 1,000 square kilometers. These are not discussed in detail but serve as a reminder that the highland landscape is complex and varying. The multivariate analyses that follow later in this chapter will take this into full account, though for descriptive purposes we now simplify the picture.

The simplified delineation of development domains assumes only two categories for each of the three variables (high and low), which in combination can yield a maximum of eight distinct outcomes. The cutoffs used were 0.75 for P/PE, 30 minutes in travel time to a small center of at least 2,500 persons, and 200 persons per square kilometer. All eight possible outcomes do in fact emerge, and these are depicted in Figure 3.2 (see color insert). The different green shades are areas with relatively good market access, while those with red shades have relatively poor market access. Figure 3.2 clearly shows that the highlands near Nairobi, as well as those in the densely populated western highlands, have good access to urban markets. Market access is worse on the northernmost and southernmost reaches of the highlands. Among the low-market-access areas, almost all have low population density and low agricultural potential. There is much more variation in population density and agricultural potential within the high-market-access zones.

This is borne out by the data in Table 3.1. Of the low-market-access areas, 81.5 percent are also characterized by low agricultural potential and low population density. On the other hand, the high-market-access areas have large areas with low agricultural potential combined with low population density, high agricultural potential combined with low population density, and high agricultural potential combined with high population density. Contrasting across population density class, the high-population zones are dominated by high agricultural potential and

Table 3.1 Description and importance of development domains in the Kenya highlands

Development domains			Importance of development domains		
Agricultural potential	Market access	Population density	Total area [km^2 (%)]	Total population (%)	Population density
Low	Low	Low	44,599 (32.9)	734,897 (4.6)	16
Low	Low	High	309 (0.2)	102,279 (0.6)	331
Low	High	Low	31,550 (23.3)	1,736,525 (10.8)	55
Low	High	High	5,691 (4.2)	3,453,481 (21.6)	607
High	Low	Low	9,481 (7.0)	372,802 (2.3)	39
High	Low	High	359 (0.3)	126,070 (0.8)	351
High	High	Low	25,728 (19.0)	2,312,963 (14.4)	90
High	High	High	17,848 (13.2)	7,177,320 (44.8)	402
Total			135,565	16,016,337	118

high market-access characteristics (73.7 percent), followed by low agricultural potential but high market-access features (23.5 percent). Conversely, the low-population-density zones are distributed across different levels of agricultural potential and market access. Finally, if one begins with agricultural potential, it is obvious that there are no dominant patterns between areas of high and low potential.

In terms of population size, four development domains stand out:

1. high agricultural potential, high market access, high population density (7.2 million people)

2. low agricultural potential, high market access, high population density (3.5 million people)

3. high agricultural potential, high market access, low population density (2.3 million people)

4. low agricultural potential, high market access, low population density (1.7 million people)

These correspond reasonably well to the most important domains in terms of area covered, with the exception that the largest development domain in terms of area is the low-agricultural-potential, low-market-access, low-population-density domain (44,599 square kilometers), which ranks only fifth in terms of number of people covered. The domain categories are useful for descriptive purposes. However, for econometric analyses, we decompose the domain categories into the respective component variables. This is done to distinguish the effects of specific variables and to reduce the confounding influences of exogenous (e.g., rainfall) and endogenous (e.g., population density) variables.

Description of Land Use in Kenya

From this section onward, we make a slight departure from the exclusive focus on the highlands. Data on land use are available for the highlands and other areas, primarily the slightly lower-lying areas adjacent to the highland areas. We have included these additional sites (down to 1,000 meters above sea level) for several reasons: (1) many of the same agricultural enterprises are found in these outlying areas, (2) they enable the analysis to be enriched by more variation in conditioning factors and driving forces, and (3) there is no accepted definition of highlands.

Table 3.2 Percentage area under different land uses

Land use	Cases where observed (%)	Mean area (%)	Median area (%)
Grazing/fallow/pasture	94.4	45.2	43.0
Maize and intercrops	75.7	18.3	13.0
Bare/bush land	80.8	13.4	7.0
Traditional cash crops[a]	34.6	8.3	0.0
Wooded land	47.1	7.5	0.0
Man-made structures	67.6	2.5	2.0
Other staple foods	29.1	1.8	0.0
Water bodies	16.9	1.4	0.0
Horticulture[b]	6.0	0.3	0.0
Legumes	4.2	0.2	0.0

Note: n **= 5,547 45-hectare units.**

[a] Coffee, tea, cotton, sugar cane.

[b] Fruits and vegetables.

As noted in the methodology section, a large number of distinct land uses were identified in the aerial photo interpretation. In order to make the analysis tractable, we have combined the numerous observed land uses into 10 categories. Table 3.2 lists the 10 categories according to mean area, also indicating the median area and the percentage of nonzero observations (among the 5,546 photos). The mean area is based on a total area of 100 (recall the 100 gridpoints used to collect the information), so it can also be treated as the percentage of total area.

As can be seen, noncultivated land occupies the majority of land area. The largest single category is grazing, pasture, and fallow land, which is found in nearly all the 5,546 sites and has a mean percentage area of 45.2 percent. Bare or bush land occupies 13.4 percent of land, wooded land (woodlots, plantations, forests, woodlands) another 7.5 percent, and other noncultivated area 3.9 percent. Some of this land may well be part of a cultivation rotational practice, but at the time of the photos it was not under cultivation.

As for crops, maize and maize intercrops dominate in the areas covered. Eighteen percent of the landscape was devoted to maize, and the crop was found in nearly 76 percent of sampled sites (recall that the sites are restricted to medium- to high-potential areas). About one-fifth of sites show between 1 percent and 10 percent of land area in maize, and about 13 percent have over 40 percent of area in maize. When cultivated land is used as the denominator (and thus omitting cases where there is no cultivated land), the proportion of area under maize soars. Only 7.3 percent of sites with cultivation recorded no maize, and as many as 38.5 percent of these sites are characterized by complete dominance of cultivation by maize. Maize comprises 75 percent or more of cultivated area in 60 percent of the sites.

Traditional cash crops of coffee, tea, sugar cane, and cotton occupy around 8 percent of total land area. However, these crops are found in only about 36 percent of 5,546 cases. Figure 3.3 (see color insert) shows the geographic distribution of cash crops and provides a view of the area covered by the aerial photographs. As can be seen, there is a high concentration in central Kenya north of Nairobi (coffee and tea), in the western rift valley (tea), and in pockets of western Kenya (mainly sugar cane). Other crops are of only minor importance at the landscape scale.[5]

Data for cattle and dairy density (at divisional level) indicate that the mean number of cattle per square kilometer is 101 with a median of 72. Almost every site for which data are available reports the existence of cattle. Presence of dairy cattle is also nearly ubiquitous, though the numbers and density are significantly lower than for all breeds taken together. The average dairy cow density is 39 per square kilometer with the median being 20. There are pockets of high dairy cattle density: 17 percent of sites report dairy cow density of over 75 per square kilometer.

Planted woodlots (by farmers) were identified in 37.5 percent of sites. Most of these (32.7 percent of all sites) exhibited modest woodlot coverage, at 10 percent of land cover or less. Thus, only 4.8 percent of sites showed relatively high concentrations of woodlots (i.e., over 10 percent), and the mean across all sites was 2.1 percent of land cover (only a portion, therefore, of total wooded area). The overall tree canopy cover is expressed as the proportion of all area under tree canopy cover (Figure 3.4; see color insert). It is estimated from visual inspection of the aerial photo and thus independent of the land use assessments based on a grid sampling. For example, it considers tree density on wooded land as well as trees found on other land uses such as cultivated land. The mean tree canopy cover across all sites was 15.8 percent, and as many as 21.2 percent are estimated to have at least one-fifth of area under tree cover. At the other extreme, about 17 percent of sites have virtually no tree cover.

Factors behind Agricultural Enterprise Choice

Farming households in these areas typically have many choices confronting them as to how to best allocate their land. In a nutshell, they can plant maize or other cereal crops, beans or other legumes, a range of horticultural or cash crops, Napier grass or other animal feed crops, plant trees for fruit or fodder or soil fertility (or a combination), or dedicate some land to pastures. In this section, we analyze the factors associated with choice of agricultural enterprise. The particular enterprises examined are maize (including intercrops) area, cash and horticultural area, cattle and dairy cattle density, and woodlot area. Other specific agricultural enterprises are not examined mainly because of lack of prominence.

Because of a restricted number of available explanatory variables, we do not develop causal models but rather models of association or prediction (though there is little reason to believe that causality runs from land use to the explanatory variables). Essentially, although it is clear that population density and travel time to markets are related to climatic conditions (and each other), it was not possible to distinguish these "subrelationships." To compensate, a number of models were run, with and without individual variables, in order to better understand the relationships among explanatory variables and the resulting direct and indirect effects that they may have on agricultural enterprise choice. In some cases where there was high correlation among variables, one or more were removed to avoid multicollinearity problems. Because of the limited number of variables, we are also obliged to run single-equation models. This type of situation lends itself to a seemingly unrelated regression model, but that procedure offers no improvement to single-equation models when the explanatory variables are the same across equations. Further, systems equation models are more complicated when limited dependent variables are concerned.

Tables 3.3–3.6 show regression results for maize, cash crops, cattle, and woodlots, respectively. The models presented are those that include both conditioning factors and driving forces. Results from other specifications will be discussed, but are not presented in tables because of space limitations. We ran models with and without district dummy variables. Because most of the results are the same in terms of sign and significance level, we present only those from the model in which they

Table 3.3 Tobit regression of maize area and percentage of cultivated area under maize

	Maize area		Cultivated area under maize (%)	
Variable	Coefficient estimate	Significance level	Coefficient estimate	Significance level
Constant	–37.47938	0.010	0.41234	0.400
Altitude (meters)	0.014152	0.404	0.0001	0.786
Altitude squared	–0.000006	0.158	–0.00000004	0.696
Precipitation (millimeters)/evapotranspiration (millimeters) ratio (PPE)	106.0421	0.009	0.34531	0.619
PPE squared	–67.2070	0.005	–0.36486	0.368
Travel time to urban area (hours)	0.03581	0.054	0.000715	0.082
Travel time squared	–0.000057	0.007	–0.000001	0.007
Population density (persons/km^2)	0.066772	0.000	0.000025	0.894
Population density squared	–0.000042	0.000	–0.00000002	0.845
Number of observations	5,515		4,501	

Note: District dummy variables included but not reported in the table.

Table 3.4 Tobit regressions of cash crop area and percentage of cultivated area under cash crops

	Cash crop area		Cultivated area under cash crops (%)	
Variable	Coefficient estimate	Significance level	Coefficient estimate	Significance level
Constant	–94.9848	0.002	–1.60977	0.000
Altitude (meters)	0.03528	0.253	0.001169	0.055
Altitude squared	–0.00001	0.199	–0.0000003	0.077
Precipitation (millimeters)/evapotranspiration (millimeters) ratio (PPE)	163.6994	0.004	1.28654	0.235
PPE squared	–77.1062	0.017	–0.42426	0.475
Travel time to urban area (hours)	–0.07860	0.016	–0.001422	0.015
Travel time squared	0.000056	0.091	0.0000016	0.014
Population density (persons per km^2)	0.054827	0.006	0.000246	0.423
Population density squared	–0.000034	0.008	–0.00000015	0.441
Number of observations	5,515		4,501	

Note: District dummy variables included but not reported in the table.

are included. For the sake of space, the coefficient estimates on the district dummies (31 of them) are not included in the tables. In all regressions, many of the district variables turn out to be very important and significantly raise the explanatory power of the models. We also tried to account for the nonindependence of observations (i.e., spatial autocorrelation) through a clustering technique offered in

Table 3.5 OLS regressions of density of cattle and dairy cattle

	Cattle		Dairy cattle	
Variable	Coefficient estimate	Significance level	Coefficient estimate	Significance level
Constant	97.5708	0.044	–79.23615	0.196
Altitude (meters)	–0.01653	0.743	0.09026	0.006
Altitude squared	–0.0000027	0.838	–0.00002	0.018
Precipitation (millimeters)/evapotranspiration (millimeters) ratio (PPE)	112.2307	0.337	157.8382	0.096
PPE squared	–47.0445	0.513	–94.8817	0.083
Travel time to urban area (hours)	0.005150	0.960	–0.035043	0.338
Travel time squared	–0.000032	0.738	0.000026	0.475
Population density (persons per km^2)	0.09932	0.006	0.03498	0.102
Population density squared	–0.000025	0.298	–0.000015	0.224
R^2	0.403		0.549	
Number of observations	4,766		4,766	

Note: District dummy variables included but not reported in the table.

Table 3.6 Tobit regressions of area under woodlots

Variable	Model 1 Coefficient estimate	Model 1 Significance level	Model 2 Coefficient estimate	Model 2 Significance level
Constant	–37.02432	0.000	–36.28394	0.000
Altitude (meters)	0.015225	0.010	0.012687	0.029
Altitude squared	–0.0000036	0.020	–0.000002	0.123
Precipitation (millimeters)/evapotranspiration (millimeters) ratio (PPE)	35.34481	0.008	34.2274	0.009
PPE squared	–16.68914	0.014	–15.4829	0.020
Travel time to urban area (hours)	–0.010756	0.083	–0.00621	0.287
Travel time squared	0.000006	0.346	0.000002	0.742
Population density (persons per km^2)	0.019333	0.000	0.01654	0.000
Population density squared	–0.000011	0.000	–0.000009	0.000
Slope (average change in meters)	0.036862	0.351	0.067665	0.091
Area under off-farm woody vegetation (percentage of 45-hectare site)			–0.17840	0.000
Number of observations	5,515		5,515	

Note: District dummy variables included but not reported in the table.

STATA. This enabled us to treat observations from the same district as non-independent and thereby generate more conservative (i.e., higher) estimates of standard errors for the coefficient estimates.[6]

The dependent variables have been discussed previously, so here we briefly describe the main explanatory variables included in the models. Altitude and the precipitation-to–potential evapotranspiration ratio (P/PE) are used as the conditioning factors. Other variables such as rainfall and length of growing period are essentially captured by P/PE. The squares of each are also used because of the expected reduction in suitability of many crops at very high altitudes or very humid conditions. The mean altitude across all observations is 1,615 meters above sea level. About 22 percent of cases are below 1,200 meters and almost 38 percent are above 1,800 meters. The mean P/PE value is 0.75, which is relatively favorable for a range of crop growth. Population density and travel time to the nearest urban center of at least 2,500 people (and their squared terms) are the two driving forces included. The mean human population density (in 1989) is 233 per square kilometer. Fewer than 18 percent of the sites had relatively low population densities of below 50, and 27 percent of sites had densities of over 250. The mean travel time to the nearest town of 2,500 persons is 1.85 hours. Just about 14 percent of the sites had to travel for 3 hours or more to reach a substantial market, whereas 12 percent could reach one in approximately one-half hour. A measure of slope is also used in the woodlot estimation, which measures the difference in elevation at the site compared to adjacent areas.

Tables 3.3 and 3.4 show the results of regressions on maize and cash crop area as well as the percentage of cropped area under each. We ran models with the absolute land area and the percentage area to better understand the influence of population pressure. For instance, it is expected that population pressure will lead to greater cultivated area, possibly of all types of crops. But the absolute area equations are able to assess the population densities at which this expansion diminishes and possibly stops. On the other hand, the percentage share regressions focus more on the relative importance of cash crops and maize as population density increases. Both types of information are important. Because there are zero values, a high number in the case of cash crop area, censored (Tobit) regressions are used.

In terms of total area, the results show that the maize and cash crop area increases with improved climate and greater population density, but at diminishing rates for both. So favorable climate and population pressure induce conversion of nonagricultural land to maize and other agricultural enterprises. Market access has different influences on maize and cash crops with improved access associated with higher cash crop area and percentage area under cash crops.[7] The opposite effect occurs for maize.

Some interesting results arise from the models in which maize and cash crop area as a percentage of all cultivated area are the dependent variables. The effect of P/PE becomes insignificant, and for cash crops, altitude becomes important. Thus, it is particularly at the relatively high altitudes where cash crops displace maize systems. But the average rainfall has little effect on the ratio of cash to maize crop production. Interestingly, although population pressure leads to expansion of cropped area, it does not directly influence the balance between maize and cash crop cultivation. Such a result has been found in a number of household studies that indicate dual pressures for food production and income generation are equally felt by households constrained by small farm size (e.g., Owuor 1999).

Separate regressions included interaction terms for P/PE and travel time to market variables in order to test whether market access has a greater impact on cash crop area in areas with favorable climates. Indeed, this was confirmed: the negative and significant coefficient estimate indicates that the effect of market access is greater where climate is more favorable.

Table 3.5 shows the factors influencing overall cattle density as well as the density of dairy cattle in particular. Cattle density is not highly linked to the included variables. This is because of the different types of cattle breeds and production systems in Kenya. Some less favorable zones for cropping are attractive habitats for local zebu. Similarly to cash crops, climate and altitude play a role in predicting dairy cattle density. Surprisingly, market access and population density did not have added effects on dairy cattle numbers. This contrasts to a previous wide-scale household-level study of dairy production in Kenya (Staal et al. 2002).[8]

Table 3.6 shows results from regressions aimed at explaining factors influencing a household's decision on how much land to devote to woodlots. Model 2 differs from Model 1 by the inclusion of off-farm wooded area; the hypothesis is that such areas may reduce incentives for farmers to plant their own woodlots. Woodlots are promoted by favorable climate, population density, and to a lesser extent by market access. This is not surprising because, in Kenya, woodlots provide important sources of income, particularly fast-growing eucalyptus poles. Further, there was only weak support for the hypothesis that farmers plant trees on more sloped land because of the comparative advantage of trees over crops on such land. Finally, it does appear that farmers have access to trees off-farm and that this access greatly reduces incentives for investing in woodlots on their farms.

Impacts of Agricultural Enterprise Choice

A natural reaction to the analysis above may be to ask why any particular agricultural enterprise might be preferred over another. In other words, is there any evidence that certain agricultural enterprises are more productive, profitable, or take better care of the natural resource base than others? The one proxy variable calculated from the aerial photos relevant to profits or poverty was the percentage of roofs made of high-quality material (i.e., tin or tiles). This variable is often used as one component of a wealth index of households. Table 3.7 shows the results of censored regressions to explain this ratio. Model 1 contains the same explanatory variables as used in the agricultural enterprise regressions. Model 2 adds three enterprise variables: the percentage of area under cash crops, the density of dairy cattle, and the area under woodlots. These are endogenous variables, but the intention here is to identify whether these choice variables appear to have an impact on poverty and the environment and therefore draw attention for further investigation.[9]

This wealth indicator is related in much the same way to the conditioning factors and driving forces as were the higher-value agricultural enterprises. Agricultural potential, market access, and population density all have a significant influence on household wealth (and the expected signs). Only altitude and travel time remain significant after the three enterprise variables are added in. Cash crops, dairy cattle, and woodlots are each positively related to high-quality roofs, though cash crops are only weakly significant. Although it is not possible to state unequivocally that these land uses promote wealth accumulation, this finding strongly suggests that such enterprises are important ingredients in wealth-generating processes.

Table 3.7 Tobit regressions of ratio of high-quality roofs to total roofs

	Model 1		Model 2	
Variable	Coefficient estimate	Significance level	Coefficient estimate	Significance level
Constant	–0.69617	0.000	–0.48198	0.001
Altitude (meters)	0.000897	0.000	0.000821	0.000
Altitude squared	–0.0000002	0.004	–0.0000002	0.004
Precipitation (millimeters)/evapotranspiration (millimeters) ratio (PPE)	0.65680	0.046	0.29138	0.341
PPE squared	–0.36297	0.052	–0.19265	0.254
Travel time to urban area (hours)	–0.000783	0.002	–0.00077	0.006
Travel time squared	0.0000007	0.088	0.0000005	0.308
Population density (persons per km^2)	0.000216	0.018	0.0001198	0.158
Population density squared	–0.0000001	0.137	–0.00000007	0.262
Density of dairy cattle (number per km^2)	0.000347	0.037		
Percentage cropped area under cash crops	0.001168	0.141		
Area under woodlots (percentage of 45-hectare site)	0.00850	0.001		
Number of observations	4,181		3,640	

Note: District dummy variables included but not reported in the table.

A study by Rommelse (2001a) in western Kenya supports the importance of these enterprises. Of the top ten most common income-generating agricultural enterprises, four were livestock related (e.g., eggs and chickens), three were tree related (e.g., fruits and poles), and the top category was a horticultural enterprise (vegetables). In addition, Nicholson et al. (1999) report significantly higher incomes among dairy producer households in coastal Kenya, compared to nondairy households.

Many of these results are supported or strengthened by recent nationwide research by Tegemeo Institute (Egerton University) and Michigan State University. First, Nyoro (1999) presents data from the Ministry of Agriculture and Rural Development that shows recent (1990–95) expansion of cropped area to be fastest for horticultural crops, followed by traditional cash crops and finally by maize. Second, Owuor (1999) found that commercialization (share of total production that is marketed) is strongly related to value of crop per hectare. This explains a high proportion of the differences in per-hectare value of production both inter-regionally as well as between households within regions. Last, work by Argwings-Kodhek et al. (1999) demonstrate the large differences in income across different farming zones in Kenya. In areas with high concentrations of traditional cash crops or horticultural crops, such as the central highlands, households annually earn about $1,780 per farm from crops and livestock. In the western highlands, where farms are more or less the same size (i.e., very small, less than 1.5 hectares), the average farm earnings were only $613.

A final analysis looked at the impact of land use on the percentage of tree cover across the entire landscape of each site (i.e., the entire 45-hectare photograph). As shown in Table 3.8, tree cover is highest in the lower altitudes and then decreases, but at slower rates, as altitude increases. Tree cover is also much greater in areas with more sloping land, perhaps because of the difficulty in cultivating these lands. Climate, controlled for altitude, was not related to overall tree cover. Market access and population pressure were negatively related to tree cover, as would be expected. Model 2 tests for the relationship between high-value agricultural enterprises and tree cover. It can be seen that all three variables (dairy cattle density, woodlot area, and percentage of cultivated land under cash crops) are positively associated with tree cover, and in the case of woodlots, the coefficient is significant. This means that these agricultural enterprises, which positively impact on wealth, have a neutral or positive impact on vegetation cover as well. Whether this is primarily because of effects within agricultural land or due to pressures on resources outside of agricultural land is not clear, however.

Table 3.8 Tobit regressions of percentage tree cover

	Model 1		Model 2	
Variable	Coefficient estimate	Significance level	Coefficient estimate	Significance level
Constant	26.695	0.039	41.0265	0.000
Altitude (meters)	–0.06675	0.001	–0.05232	0.003
Altitude squared	0.000023	0.000	0.000015	0.003
Precipitation (millimeters)/evapotranspiration (millimeters) ratio (PPE)	8.15459	0.713	–1.94683	0.919
PPE squared	8.78486	0.465	8.45311	0.419
Travel time to urban area (hours)	0.067249	0.001	0.025639	0.008
Travel time squared	0.000066	0.000	0.000008	0.328
Population density (persons per km^2)	–0.02023	0.053	0.011158	0.061
Population density squared	0.000014	0.056	0.0000069	0.131
Slope (average change in meters)	0.92345	0.000	0.56921	0.000
Density of dairy cattle (number per km^2)			0.016944	0.3194
Area under woodlots (percentage of 45-hectare site)			0.45054	0.000
Percentage of cultivated area under cash crops			10.61746	0.369
Number of observations	5,515		5,515	

Note: District dummy variables included but not reported in the table.

Conclusions

Major Empirical Findings

The major empirical findings can be summarized as follows:

- As expected, climate and altitude are important in explaining land use, but other factors also play important roles.
- Population pressure positively influences the area under cultivation but does not automatically lead to adoption of higher-value crops.
- Good market access is critical for promoting production of higher-value agricultural enterprises, especially in the more favorable climate zones.
- Dairy and woodlots contribute to wealth generation (as measured by house quality) and at the same time have neutral or positive effects on overall tree cover.

Methodological Challenges

Our analysis focused on the visible side of rural livelihoods, namely agriculture. However, it is well known (e.g., Argwings-Kodhek et al. 1999) that the nonfarm economy plays a critical role in household strategies directly as well as indirectly through agriculture. This large sector could not be addressed by this analysis. A second limitation is the use of single-equation models that ultimately may show only patterns of association rather than causal relationships. Further progress in this area is constrained mainly by lack of breadth in variables that exist for such wide coverages at sufficient levels of disaggregation. Nonetheless, many of the relationships demonstrated in this analysis are supported by other studies. Qualitative research, such as focus group discussions, have proven very valuable in disentangling timelines of change in variables, which ultimately may enable the distinguishing of causes from effects (e.g., Kanbur 2003; Krishna et al. 2004).

A third limitation concerns the existence of spatial autocorrelation in our dataset without sufficient treatment in our statistical analysis. In case of spatial autocorrelation, the information content of the sample is lowered, rendering it less efficient than uncorrelated counterparts, so parameter estimates are inefficient, although asymptotically unbiased (Anselin 2001). Moreover, the omission of a spatially correlated and important variable may result in biased estimates. We have partially dealt with this issue through clustered regression techniques. Further work to address spatial autocorrelation in limited-dependent variable models is required.

Policy Implications

The promotion of markets through investment in roads and other infrastructure is an obvious implication of our results. This is especially true in the more favorable climatic zones. Support for this result in Kenya for the dairy sector is seen in Staal et al. (2002), and regarding impact on household incomes, in Argwings-Kodhek et al. (1999). This broad-based intervention is a good strategy because evidence shows that farmers like to diversify among many agricultural enterprises, including food, feed, and cash crops. Having said that, there is still scope for promoting markets for long-standing and new cash crops and for disseminating information about their management. In the less favorable areas, there is the additional need to identify and develop higher-value enterprises suitable to these areas (in addition to cattle raising, which is already practiced by households) because road development does not seem to have the same strong impact with the currently available cash crops as it does in the higher-potential zones. Finally, given our results regarding the positive influence cash crops, dairy cattle, and woodlots have on wealth, the predominant role of maize in smallholder agriculture should be seriously addressed within Kenya's Poverty Reduction and Rural Development strategies, and support to these other options pursued.

Notes

1. There was an attempt to "train" GIS software to distinguish among different land uses, but this would have been enormously expensive and risky if the intention was to keep as many as 90 different land use categories. The analysts who did the job were the same who had been doing similar interpretation for over 4 years.

2. Cash and horticultural crops include industrial crops such as sugar, tea, coffee, and pyrethrum, vegetables, and fruits.

3. This is particularly the case in Kenya, where area under irrigation is minuscule.

4. An increase in P/PE of 0.1, holding temperature constant, is approximately equivalent to an increase in rainfall of 143 millimeters annually.

5. These figures match fairly well with other available farm-level surveys, except for Napier grass, which has been found to be quite prominent in many districts yet almost absent in the aerial photo interpretation (Staal et al. 1997).

6. These were the svyreg and svyintreg commands in STATA.

7. The results from the regressions show a curvilinear relationship between market access and land use. For all but a handful of observed values for market access, the effect of improved market access is indeed positive.

8. Indeed, under the assumption of independent observations, market access becomes highly significant in our estimations.

9. As noted earlier, ideally one would use a two-stage procedure to remove biases that may emerge. However, lack of available exogenous variables at this scale prevent such an analysis.

Chapter 4

Village Stratification for Policy Analysis: Multiple Development Domains in the Ethiopian Highlands of Tigray

Gideon Kruseman, Ruerd Ruben, and Girmay Tesfay

Many countries in Sub-Saharan Africa suffer from problems related to poverty, natural resource degradation, and the complex interactions between these phenomena (Cleaver and Schreiber 1994). In the northern Ethiopian highlands of Tigray region, problems of poverty and degradation are extremely severe: population density is very high, rainfall is scarce and erratic, and soil fertility is low. Under such conditions, farmers need to rely on external inputs and soil conservation practices in order to stabilize or increase yields. Within the current land use pattern, a wide range of different options are available for intensification of production systems. The selection of appropriate pathways for intensification may be different for specific locations. Therefore, village stratification can be used to select technologies and practices that are applied under particular agro-ecological, socioeconomic, and institutional conditions.

The concept of development domains is used to facilitate the targeting of development interventions. As discussed in Chapter 2, major dimensions of development domains include the agricultural resource potential, market access, and population density. These aspects may distinguish between situations where Malthusian or Boserupian development is likely to take place (Pender 1998). Areas with high population density, low agricultural potential, and low market access can be expected to follow a Malthusian development path, where land resources typically suffer from soil mining and resource degradation. Boserupian development tends to occur when there is sufficient market access that enables specialization, leading to a more efficient use of scarce resources, as illustrated in the study *More People—Less Erosion* (Tiffen, Mortimore, and Gichuki 1994). In these settings, the proximity of markets allows the adoption of more sustainable agricultural practices. However, in many parts of Africa, soils are so poor that the maximum carrying capacity is reached at rather low population densities (Kruseman 2000).

The identification of development potentials is often addressed in an anecdotal fashion, whereas quantitative analysis is required for identifying more precisely the possibilities for targeting of interventions. This implies a search for an accurate definition of the critical dimensions that broadly determine different strategic development options. Following Pender, Place, and Ehui (1999), the dimensions we use for distinguishing among development domains are (1) agricultural potential (i.e., biophysical environment), (2) population density, and (3) market access (i.e., socioeconomic environment). These dimensions are largely exogenous to the households that try to cope with the biophysical and socioeconomic environment. Household decisions regarding land use practices and production technologies result in particular livelihood strategies. We can differentiate with the three criteria a total of eight different situations. We discuss each of these settings and identify their importance for the selection of typical land use practices.

Identification and quantification of development domains has an important practical meaning. It offers a framework for the design of particular development interventions that are appropriate for certain areas. Village stratification is considered useful in order to identify the structural factors that influence the choice of certain livelihood strategies. When diversity among villages is more important than heterogeneity among households in the same village, targeting can be safely done at the community level (Bigman and Fofack 2000).

Geographic targeting can also be interesting when patterns of heterogeneity within villages are comparable regarding the presence of better- and poorly endowed households, female-headed households, and landlessness. This is broadly the case in Tigray region, where a common cultural, ethnic, and political background provides a shared legacy that results in relative socioeconomic homogeneity among the population.[1] If household resources are relatively homogeneous, the key dimensions we mentioned before (i.e., agricultural potential, population density, and market access) primarily define the development domains. Poverty and productivity in a broad sense are directly linked to such geographic considerations, even if there remains some heterogeneity among households within villages. Differences between villages tend to be more appealing because what constitutes a rich farmer in one village may be considered a poor one in another village. These differences are mainly explained by the development domain dimensions. Geographic targeting can then be considered an effective strategy for selectively enhancing a process of agricultural intensification.

In this chapter we develop a generic methodology for stratifying villages into development domains using multivariate analysis of data derived from a community survey. We determine the relative importance of the critical dimensions of the development domains for particular livelihood strategies. The degree of correspondence between these aspects indicates to what extent geographic targeting is justified. The results of the analysis confirm the close correspondence between development domains and resource use practices.

The remainder of this chapter is structured as follows. In the next section the concept of development domains is discussed within the context of the Ethiopian highlands of Tigray. Next, we outline the methodology used for deriving the main dimensions of the development domains. Hereafter, we discuss the relevance of these development domains for crop choice and land use practices in Tigray. We conclude with some implications for the targeting of development interventions.

Development Domains in Tigray

The northern Ethiopian highlands of Tigray face serious problems related to high population density and limited agro-ecological potential. Regional programs for soil and water conservation have been launched that are intended to increase land and labor productivity. However, given the modest public resources that are available, choices have to be made about where to target specific activities. Not all activities are suitable for each community, and different communities are likely to benefit most from specific types of interventions. Under these conditions, we cannot rely on a "one-size-fits-all" strategy, and specific criteria must be developed in order to differentiate among *kushets* (communities) and to select the most appropriate development strategies.[2]

The concept of development domains can be used to identify the critical dimensions that influence the adoption of certain resource management practices (Hagos, Pender, and Gebreselassie 1999; Pender, Place, and Ehui 1999).[3] This approach is based on the notion that it is possible to disentangle the core elements of past local development strategies in terms of adopted technologies. These can be used as a first step to analyze what selective array of technologies or services might be offered to potentially benefit other communities with similar development domain dimensions. Patterns of cropping and livestock activities per se do not indicate successful local development strategies, nor do they represent less-than-preferable outcomes. The successful adoption of technology, however, is an indicator of potential development pathways.

One of the main hypotheses of the development domains concept is the existence of differences in comparative advantages for adopting alternative livelihood strategies, giving rise to essentially different development pathways. These differences in comparative advantage can be attributed to three main factors: agricultural potential, market access, and population pressure.

Agricultural potential is a complex aggregate of various biophysical and agroclimatic factors that can be decomposed in a number of different underlying factors, including rainfall, soil type and quality, altitude, slope, topography, and the presence of pests and diseases. These aspects are, to a large extent, exogenous to the farm households but are of overriding importance for determining the comparative advantage of producing different types of agricultural commodities in a specific setting. The role of the agricultural potential varies for different commodities and over time as a result of human-induced (e.g., soil degradation) and exogenous change (e.g., climate change). The multidimensional aspect of agricultural potential, especially the fact that it can change over time, should be taken into account in developing medium- and long-term strategies. Taking a cross section of a larger region that captures to some extent different stages of human-induced and exogenous change makes the use of a comparative static approach acceptable in the absence of a long time series of relevant data.

Market access is equally important for determining the comparative advantage of a specific locality for producing certain tradable commodities. Market access also involves various dimensions and encompasses such components as distance to roads, quality of roads, travel time, distance to markets and urban centers, degree of competition, information costs, and transport opportunities. Although many factors play a role, travel time is usually considered most crucial for market exchange and input purchase decisions. Travel time is the result of some of the previously mentioned variables (e.g., distance, quality of roads, and transport opportunities) and determines others (information costs). It is therefore important to define a measurable proxy for this factor. Market access is closely linked to the concept of transaction costs whereby the penalty related to lack of market access influences farm household decisions related to consumption and production (Omamo 1998; Goetz 1992).

Population pressure has long been acknowledged as being a major driving force with respect to the labor intensity of agriculture, creating a conducive environment for innovations in technology, institutions, markets, and infrastructure (Boserup 1965; Ruthenberg 1980; Hayami and Ruttan 1985; Binswanger and McIntire 1987). It refers to both the density of population and the local available purchasing power. Population pressure affects labor utilization decisions and hence agricultural management practices as well as the return to different types of investments.

These three main factors obviously interact with each other in complex ways. In general, population pressure tends to be higher in areas with a greater agricultural potential and with better market access or both, allowing the existing population to make a decent living while encouraging immigration from less favored areas. On the other hand, increased population pressure is considered a major contributing factor to the severe land degradation found in many parts of Africa, thus affecting the agricultural potential. Market access tends to be better in highly populated areas, where the per capita costs of infrastructure investment are lower. Availability of infrastructure also tends to be better in high-agricultural-potential areas that guarantee higher returns to investment. In their seminal study Machakos, Tiffen, Mortimore, and Gichuki (1994) made a case for increased population pressure leading to less soil degradation. In this specific case, better market access permitted the necessary investments to reverse the process of soil degradation, allowing alternative employment outside agriculture to reduce population pressure. The absence of such market outlets in other parts of eastern Africa has led to accelerated degradation. In Tigray, off-farm employment opportunities are limited primarily to food-for-work and food-for-cash schemes of public goods provision. In areas with low population density and limited agricultural potential where market access is constrained, small demographic changes can occasion a chain of events leading to degradation beyond the point of no return, as illustrated by the case of the Mossi plateau in Burkina Faso (Savenije and van Zutphen 1991).

In summary, the variables of market access and population pressure are very often correlated at the local level. Increasing population pressure may lead to better market access, and improved market access tends to attract immigration and hence increasing population pressure. Similarly, agricultural potential may be related to population pressure, but this relationship is easily offset under conditions of scarcity of market infrastructure.

In the northern Ethiopian highlands of Tigray we can identify settings with high and low population density in both remote and accessible regions. In addition, there is no clear correspondence between population density and the available agro-ecological potential. This is largely because population movements were originally induced by health considerations (escaping from malaria incidence in the lowlands) and in later stages by political factors (moving away from conflict areas). Tenure policies assigning land according to household size and family needs further reinforced relatively equal factor distribution at the village level. In addition, recurrent droughts in the early 1970s and mid-1980s led to a general process of asset loss and destitution that affected both poor and better-off households (Devereux, Sharp, and Amare 2004). Finally, during the two decades of military conflict, farm investment decisions were seriously affected.

Methods and Data

In order to develop a spatial classification of different village-level development domains for the northern Ethiopian highlands of Tigray, a statistically robust methodology is required. We used multivariate statistical techniques to identify critical development dimensions and their implications for crop choice and land use practices. Therefore, we perform an analysis in three stages, addressing the following issues:

- Identification of the main dimensions of village development domains

- Analysis of the mutual independence of the development domain dimensions, in order to adequately distinguish what kind of interventions might be useful

- Identification of the linkages between the development domain dimensions and selected land use and cropping practices

The methods used in this chapter rely on the availability of a village level survey conducted by IFPRI, ILRI, and Mekelle University in 1998 and 1999.[4] The goal of this survey was to capture main characteristics of the villages in terms of physical and social infrastructure, predominant economic activities, and development indicators. We used this survey to classify each village (*kushet*) in the region into a three-dimensional matrix of factors influencing development potential. At the same time, predominant production systems and livelihood strategies were derived from the same survey, giving an indication of the selected development strategies in these particular settings.

The development domains are differentiated according to three key factors: agro-ecological potential, market access, and population density. Major factors contributing to agricultural potential are rainfall, altitude, and initial soil quality. The community-level survey also provides data with respect to altitude and both quantitative and qualitative measures of soil quality.[5] Rainfall data from other sources were combined with the community survey. The factor *market access* is measured in terms of distances and walking times to roads, services, towns, and market outlets. The factor *population density* is directly derived from survey data.

For each of these dimensions there are usually a number of different variables available. Choosing the useful proxy variables is not always easy. Especially in the case of agricultural potential, which by definition includes multiple dimensions, we should be careful to avoid arbitrariness. We relied on factor analysis methods to reduce the data, deriving single quantitative measures for each main factor. This has the advantage of using all the variables in the data set that are relevant to the analysis while preventing the occurrence of dependency among the factors used to define development domain dimensions. Because we are not able a priori to determine whether the development domain dimensions are completely independent, we test for this using a two-stage least-squares and seemingly unrelated regression.

Once we quantified the development dimensions, we performed a detailed analysis of the effects of these variables on the choice of particular land use systems and cropping practices. This provides insight into the determinants of different livelihood strategies and development opportunities within the communities.[6] This analysis is based on regressing the development domain dimensions with variables related to land use (i.e., crop choice, livestock) and related production technologies (i.e., fertilizer use, animal feeding regimens, soil conservation practices). In addition, we analyze the impact of the development domains on credit use and some welfare indicators (housing, education). The latter variables represent the outcomes of the current development pathways for the communities in Tigray and are likely to depend to some degree on the development domain dimensions.

Once we have determined the relative importance of the development domain dimensions, we are able to stratify the villages in the survey. Instead of using cluster analysis to categorize households into quasi-arbitrary groups, we opt for a more structural approach to identify the extremes using the available dimensions. For this purpose, we divide the villages into three groups for each dimension depending on whether they have a high, low, or intermediate score on each dimension. We prefer this procedure because development domain dimensions in general tend to present themselves on a sliding scale.

Identifying Development Domains

This section presents the results from the village-level analysis of critical development domains and compares these to the hypothetical development opportunities (as identified by other authors, including Hagos, Pender, and Gebreselassie 1999). Population density is directly captured by the corresponding variable in the community survey.[7] With respect to agricultural potential, we differentiate between soil quality and rainfall or altitude. For soil quality, two different dimensions are distinguished that explain 60 percent of the variation (see Table 4.1).[8] The explanatory variables include proportions of different quality classes of cultivated and grazing land. Factor analysis results for defining agricultural potential indicate the importance of land degradation and soil quality (see Table 4.1).

Other components of the agricultural potential dimension are elevation and precipitation.[9] By combining these factors into the factor analysis, normalized

Table 4.1 Factor analysis results for soil quality in agricultural potential

	Factor loadings	
Variable	**Level of degradation**	**Soil quality**
Proportion of severely eroded cultivated land	0.822	0.103
Proportion of moderately eroded cultivated land	0.578	0.461
Proportion of severely eroded grazing land	0.779	–0.03
Proportion of moderately eroded grazing land	0.863	–0.07
Proportion of good soil	–0.303	0.882
Percentage of variance loaded onto the factor (extraction sums of squared loadings)	49.04	20.14

Note: Extraction method: principal-component analysis.

values can be obtained (see Table 4.2). Note that data on elevation were obtained from two different sources.[10]

Market access is divided into two separate factors. The first factor relates to physical distance from markets and infrastructure (see Table 4.3), and the second relates to the presence of external institutions that facilitate market access (see Table 4.4).[11] Table 4.3 shows that remote villages have a consistently high score on all distance variables.

Table 4.4 shows the importance of the presence of local institutions. The first factor represents the local water associations in charge of the promotion of irrigation and the distribution of water. The second factor loads the presence of cooperatives and indicates that there is a negative correlation between the presence of cooperatives and the availability of credit by other agencies (NGOs and state Bureau of Agriculture). The third factor loads the activities of the Bureau of Agriculture, delivering credit and actively involved in the promotion of improved crop

Table 4.2 Factor analysis results for rainfall and altitude in agricultural potential

	Factor loadings	
Variable	**Elevation**	**Rainfall**
Expected annual precipitation (millimeters)	0.053	0.997
Elevation (meters above sea level)	0.989	–0.010
Lower bound on altitude (meters above sea level)	0.937	–0.115
Upper bound on altitude (meters above sea level)	0.901	0.048
Mean altitude (meters above sea level)	0.980	0.023
Percentage of variance loaded onto the factor (extraction sums of squared loadings)	72.65	20.21

Note: Extraction method: principal-component analysis.

Table 4.3 Factor analysis results for market access (distance)

Variable	Factor loading Market access
Walking time to market center (minutes)	0.932
Walking time to bus service (minutes)	0.876
Walking time to all-weather road (minutes)	0.919
Distance to town (kilometers)	0.875
Distance to all-weather road (kilometers)	0.881
Percentage of variance loaded on factors (extraction sums of squared loadings)	80.44

Note: Extraction method: principal-component analysis.

and livestock practices. The fourth factor loads the delivery of credit by the NGO Relief Society of Tigray (REST) in areas where commercial credit (traders and moneylenders) do not have a strong presence.

Testing for Independence of Development Domain Dimensions

The interesting element in this analysis is that it is not clear a priori whether these factors are endogenous or exogenous. It could be the case, for instance, that institutional presence is the result of some of the other dimensions in development domains. We therefore need to test for the independence of these aspects.

Summarizing the factors determining development domains, we included the following factors for the agricultural potential: precipitation (*RF*); two variables

Table 4.4 Factor analysis results for market access (institutions)

Factor	Irrigation institutions	Cooperatives	Bureau of Agriculture	NGOs (REST)
Market cooperative	0.37	0.65	0.21	0.00
Consumer cooperative	0.37	0.77	–0.08	0.05
Water association	–0.71	0.39	0.31	0.15
Credit by REST	0.35	–0.03	–0.34	0.64
Credit by Bureau of Agriculture	0.22	–0.47	0.70	0.06
Irrigation promoted	–0.75	0.24	0.26	0.23
Livestock improvement promoted	0.41	0.00	0.61	0.45
Commercial credit	0.26	0.18	0.33	–0.61
Percentage of variance loaded on factors (extraction sums of squared loadings)	21.8	18.6	16.3	13.2

Note: Extraction method: principal-component analysis, variables all of yes/no type.

defining soil properties, soil quality (*SQ*) and degradation level (*DL*); and elevation (*EL*). Population density (*PD*) and market access (*MK*) are captured in single variables. We can test for independence or linkages among these factors through the following system of equations:[12]

$$DL = f(SQ, RF, PD, MK) \tag{4.1}$$

when the inherent soil quality, rainfall, market access, and population density may influence degradation level.

$$PD = f(DL, SQ, RF, EL, MK) \tag{4.2}$$

where population density may be caused by a variety of factors relating to other biophysical or institutional factors determining development domains.

$$MK = f(SQ, RF, EL, PD) \tag{4.3}$$

where market access may be related to biophysical factors and to geographic location.

For each of the institutional factors (IF_i) we test,

$$IF = f(SQ, DL, PD, MK, EL) \tag{4.4}$$

Results of the independence tests indicate that in this system of equations the independent variables are almost completely independent, so they are not likely to be endogenously determined.[13] The variables that are not endogenously determined are inherent soil quality, elevation, and rainfall. Degradation level is only slightly correlated with rainfall; population density with inherent soil quality, elevation, and rainfall; and market access is correlated with elevation. This poses no major problems for the subsequent analysis because there is no endogenous determination. In the case of institutional factors, a minor problem with endogeneity emerged because some of the factors depend on population density and market access in addition to being slightly correlated to exogenous factors. This implies that to be on the safe side, we need to use three staged least-squares to determine which right-hand-side variables should be used in the equations. Arguably, equations (4.1)–(4.4) might contain some omitted variables because factors pertaining to development domain dimensions include only a limited number of underlying variables as a result of data availability. We consider, however, that the model captures the major development domain dimensions as indicated by theoretical considerations regarding rural development.

Village Stratification

For a further analysis of the village development domains we can now use the following six dimensions: market access, population density, and four aspects related to the agricultural potential—altitude, rainfall, soil quality, and degree of degradation. Stratifying the communities according to the specific development domains is used to identify different homogeneous settings. In the graphs of Figures 4.1–4.3, the villages are plotted according to the main development dimensions.

From Figure 4.1 we notice important differences in market access and population density among the villages. The diversity in these dimensions is wide, and situations with high and low population density occur in both well-endowed and poorly endowed villages.

Figure 4.2 depicts the data concerning altitude and rainfall. It illustrates basically three different situations: villages with low altitude and high rainfall, villages with high altitude and low rainfall, and only a few cases with high altitude and high rainfall. Variability in rainfall is, however, only between 475 millimeters and 770 millimeters per annum, whereas altitudes range from 1,500 to more than 3,000 meters above sea level. Scarcity of rainfall in this area generally represents a major limiting factor for arable cropping.

Figure 4.3 indicates a rather even distribution of soil quality and degradation over the communities. Soil degradation occurs both in villages with good soil quality

Figure 4.1 Development domain dimensions: Population density and market access

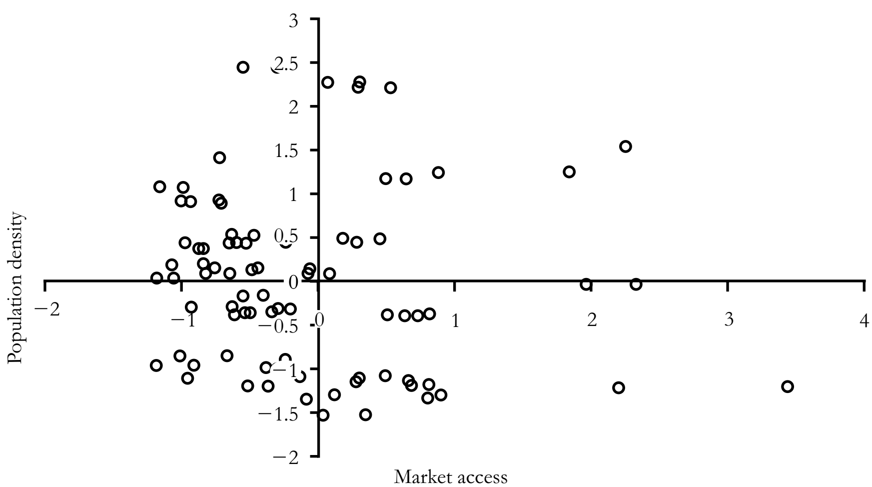
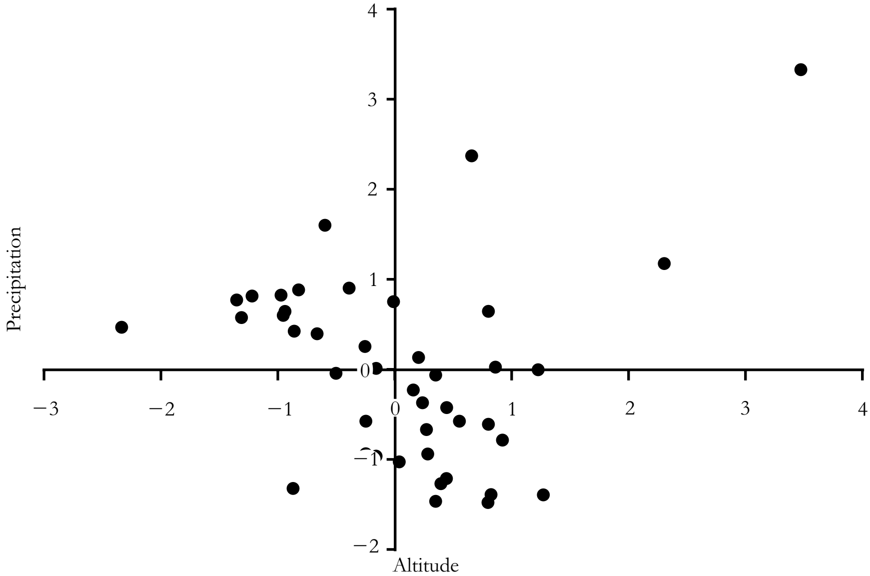


Figure 4.2 Development domain dimensions: Altitude and precipitation



and in villages with poor soils. However, the impact of degradation is substantially stronger in settings characterized by low intrinsic soil quality.

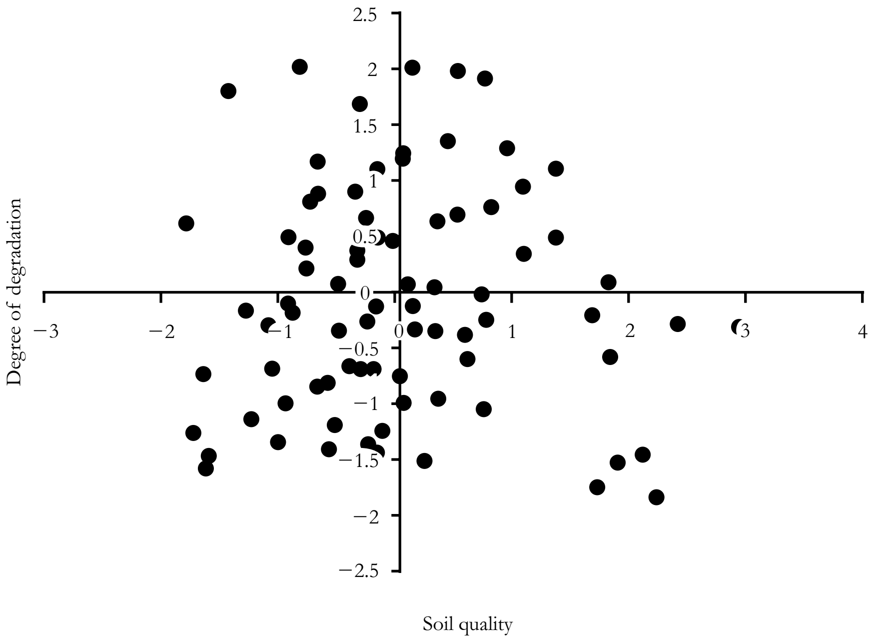
When we combine all the information available from 45 villages, the sample can be classified into eight different development domains (see Table 4.5). We used the factor scores on the three dimensions discussed before and excluded the data ranges close to zero. In the case of agricultural potential we used a weighted average of rainfall, soil quality, and degree of degradation to determine overall potential.[14]

The communities in the area are distributed fairly evenly over high- and low-altitude areas, except that the communities with low market access, high population density, and low agricultural potential are concentrated in the high-altitude areas.[15] This diversity implies that farmers exhibit different choices or preferences regarding suitable land use practices and market orientation that are most appropriate to their local conditions.

Land Use Patterns and Production Systems

We analyze the importance of different critical dimensions of the village development domains in order to identify the most important elements for the corresponding development pathways. Therefore, we examine the influence of the exogenous

Figure 4.3 Development domain dimensions: Soil quality and degree of degradation



indicators of agro-ecological potential (population density, distance to markets, and access to institutions) for the resource management strategies. The latter strategies represent choice variables at the level of farm households.

We can distinguish three specific domains of household decisionmaking. First, strategies for land use are discussed, focusing on cropping and livestock activities. Crop choice is expected to depend mostly on differences in agricultural potential but

Table 4.5 Village stratification

		Agricultural potential	
Market access	**Population density**	**Low**	**High**
Low	Low	6	6
	High	4	3
High	Low	6	4
	High	7	9

Note: $N = 45$.

is also influenced by market access and population density. These factors together determine the comparative advantage for the agricultural production activities. Livestock activities involve long-term investments for the purchase and maintenance of animal numbers and require the availability of pastures and institutional support. The second aspect we explore refers to technology choice. The selection of appropriate cropping and livestock management regimes tends to be influenced by land and labor resource endowments, market outlets, and institutional support. Given the importance of rural financial services for the adjustment of land use practices, we explicitly discuss the determinants of credit use.[16] Finally, we discuss a number of social development indicators in Tigray region that reflect differences in welfare.

The data analysis is focused on the relationship between the structural village dimensions and the land use and production systems that reflect specific livelihood strategies. The dimensions of development domains are considered to be indicators for the possibility of relying on a certain development pathway. We used three-stage least-squares (3SLS)[17] to estimate the relationship between the endogenous and exogenous variables. Endogenous variables are variables such as activity and technology choice that form part of predominant livelihood strategies. Exogenous variables are the development domain dimensions and institutional dimensions. Only those factors related to livelihood strategies and development pathways with an adjusted R^2 higher than 5 percent are included to avoid spurious correlation.[18]

Activity Choice

The community survey data provide information on the proportions of arable cropping activities within agricultural systems. This can be considered as the aggregate outcome of individual choices at village level. Main cereal crops in the area are barley, *teff,* maize, wheat, sorghum, and finger millet. The selection of cereal crops strongly depends on the agro-ecological conditions, especially rainfall. In addition, some pulses are grown, including chick peas, fava beans, and field peas. To a very small extent cash crops are grown, such as flax, sunflower, sesame, and haricot beans. The single-year production pattern masks to some extent the occurrence of crop rotations, but intercropping appears in the overall land use pattern.[19] Livestock activities are particularly important for the highland communities, but not all households are equally involved. The survey indicates that about 25 percent of the households have no oxen, 40 percent possess only one ox, 25 percent possess two oxen, and 10 percent have more than two oxen. The distribution of livestock indicates that there are marked differences within communities with respect to livestock holdings.

The factors pertaining to elevation and rainfall are most important in determining cropping patterns (see Table 4.6). This confirms the key importance of

Table 4.6 Relation between crop choice and development domain dimensions using three-stage least-squares

Dimension	Barley	Maize	Wheat	Sorghum	*Teff*	Niger seed	Chickpea	Fava beans	Lentils	Field peas	Doliches	Haricot beans
Constant	0.2119***	0.1276***	0.1060***	0.0972***	0.2024***	0.0079***	0.0269***	0.0446***	0.0181***	0.0235***	0.0025***	0.0113***
Soil degradation	–0.0411***	–0.0036	–0.0182*	–0.0083	0.0376**	0.0027	–0.0066	–0.0079	–0.0012	–0.0010	–0.0009	0.0026
Soil quality	0.0006	0.0283**	–0.0135	0.0181	–0.0131	–0.0006	–0.0005	–0.0025	–0.0009	0.0097	0.0005	–0.0030
Elevation	0.1491***	–0.0209	0.0623***	–0.0641***	–0.0909***	–0.0044**	–0.0084*	0.0499***	0.0186***	0.0132*	0.0076***	–0.0070*
Rainfall	–0.0895***	0.0696***	–0.0386***	0.0435***	0.0662***	0.0036**	0.0097**	0.0196**	0.0061*	0.0057	0.0033***	0.0031
Population density	–0.0441***	–0.0303**	0.0163	–0.0156	0.0326*	0.0031*	0.0083*	0.0061	0.0010	0.0078	–0.0033***	–0.0058
Distance to markets	0.0093	0.0164	0.0038	0.0398**	–0.0544***	–0.0008	–0.0020	0.0039	0.0062	0.0022	0.0009	0.0061
Cooperatives	–0.0372**	0.0316**	0.0140	–0.0164	0.0346*	0.0002	0.0042	–0.0083	–0.0041	0.0072	0.0010	0.0017
NGO credit	0.0087	0.0480***	–0.0135	–0.0081	–0.0009	–0.0003	0.0012	0.0110	–0.0010	0.0057	0.0020	–0.0037
Irrigation institutions	0.0303**	0.0137	–0.0009	0.0107	–0.0332*	0.0010	–0.0002	0.0136	0.0025	–0.0035	0.0021*	0.0000
Adjusted R^2	0.5364	0.3172	0.3935	0.3532	0.2808	0.0477	0.0567	0.2693	0.2326	0.0895	0.4027	0.1492

Note: Dependent variable is proportion of farm households growing a specific crop.

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent level, respectively.**

rainfall and altitude (temperature) as major limiting factors for crop production in Tigray, whereas intrinsic soil fertility only plays a secondary role (except for maize). Wheat and barley are both grown in high-elevation areas with low rainfall. Given its lower labor demands, barley tends to be grown in less-populated areas where there are no cooperatives and there is a presence of irrigation institutions. The cereals cultivated in the higher-rainfall areas (maize, sorghum,[20] *teff*) show differences with respect to soil quality requirements. *Teff* production is found in areas with a high degree of land degradation, whereas maize is selected in areas where better soils are more prevalent. In addition, *teff* is cultivated in areas with better market access, and sorghum is found in more remote villages. Maize cultivation is favored by the presence of cooperatives and NGOs that guarantee input provision and technical support.[21] Likewise, *teff* cultivation is positively correlated with the presence of cooperatives, but this crop is replaced by higher-value horticulture crops when irrigation institutions are active. With respect to pulses and other diversification crops, the factors *elevation* and *rainfall* are of major importance. Doliches is grown in low-population-density areas where irrigation institutions are present, whereas chickpeas and niger seed are found in higher-density population areas.

The factor *rainfall* is also influencing livestock strategies in the area (see Table 4.7). More rainfall, better soils, and lower population density are positively related to ox availability, indicating that both the quality and the quantity of resource endowments are relevant for ox acquisition. Market access and cooperative presence tend to favor the proportion of farmers with more than two oxen, who usually operate more input-intensive and commercially oriented farming systems. Cows are found in remote areas with less degraded soils, sheep are maintained in settings with low population density and high elevation, whereas goats are located in villages with the opposite characteristics. Beekeeping is located in remote but highly populated areas.[22] The effect of the livestock promotion programs by the Bureau of Agriculture (BoA) is clearly noticed in the growing proportion of households with two oxen but is inversely related to goatkeeping. It is also clear that the involvement of local NGOs in livestock promotion is rather minimal.

Technology Choice

In Tigray region, a wide range of different land use technologies have been promoted and adopted by rural households. Table 4.8 provides an overview of the proportion of farmers who make use of external inputs (i.e., fertilizers, seed), rely on improved land use practices, and made fixed investment for soil conservation, pasture development, or anti-erosion works. Intercropping and crop rotation, agroforestry, and terracing are adopted by more than half of the farmers, but irrigation is limited to some selected locations. Fertility-enhancing practices such as green

Table 4.7 Relationship between livestock ownership and development domain dimensions

Dimension	No oxen	One ox	Two oxen	More than two oxen	Cows	Sheep	Goats	Beehives
Constant	0.2411***	0.4291***	0.2461***	0.0946***	0.3888***	0.2987***	0.2860***	0.1749***
Soil degradation	0.0094	–0.0046	–0.0012	–0.0028	–0.0683***	–0.0327	0.0103	–0.0160
Soil quality	–0.0320**	–0.0119	0.0240*	0.0240***	–0.0097	0.0357	–0.0234	–0.0153
Elevation	0.0209	–0.0106	–0.0160	–0.0047	–0.0561**	0.0595**	–0.0799***	–0.0095
Rainfall	–0.0149	–0.0285*	0.0256**	0.0248***	0.0228	–0.0132	0.0332	0.0016
Population density	0.0193	0.0321*	–0.0380***	–0.0225**	0.0056	–0.0517**	0.0467*	0.0343**
Distance to markets	0.0074	–0.0320*	0.0007	0.0268**	0.0491**	–0.0115	0.0299	0.0418**
Cooperatives	–0.0116	0.0256	–0.0074	0.0403***	–0.0227	–0.0100	–0.0117	0.0212
NGO credit	0.0109	0.0212	–0.0057	–0.0170	0.0218	0.0370	–0.0253	0.0059
Bureau of Agriculture	0.0009	–0.0141	0.0165*	0.0037	–0.0110	0.0131	–0.0499***	–0.0051
Adjusted R^2	–0.0042	0.0981	0.1340	0.3418	0.1385	0.0511	0.1127	0.0422

Note: Bureau of Agriculture factor has a strong component related to livestock promotion.

Dependent variable is proportion of farm households having specific livestock units.

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent level, respectively.**

Table 4.8 Land use technologies

Technology	Mean	S.D.
Proportion of farmers using:		
Fertilizers	0.672	0.278
Pesticides	0.137	0.236
Herbicides	0.030	0.103
Improved seed	0.290	0.247
Livestock vaccine	0.728	0.276
Purchased feed	0.400	0.300
Proportion of farmers who:		
Burned to clear land	0.630	0.406
Fallowed fields for more than a year	0.185	0.299
Used improved fallow	0.015	0.082
Rotated crops	0.864	0.248
Used intercropping	0.499	0.394
Contour plowed	0.957	0.126
Mulched	0.006	0.051
Manured	0.623	0.280
Composted	0.208	0.251
Plowed in crop residues	0.072	0.206
Used green manure	0.002	0.014
Proportion of farmers making investments (since 1991) in:		
Stone terraces	0.515	0.305
Soil bunds	0.226	0.304
Check dams and gully stabilizers	0.408	0.298
Drainage ditches	0.148	0.297
Irrigation wells	0.009	0.053
Irrigation canals	0.241	0.314
Grass strips	0.013	0.066
Tree planting	0.575	0.364
Live fences	0.412	0.324
Private nurseries	0.001	0.010

manure, mulching, and plowing under crop residues are only rarely applied. Chemical fertilizers, livestock vaccines, and contour plowing are applied by more than two-thirds of the households. On the opposite end, herbicides, improved fallow, mulch, green manure, irrigation wells, grass strips, and private nurseries are used by fewer than 5 percent of the households.

We can identify some of the structural variables that influence the choice of land use practices and technologies (see Table 4.9). Fertilizers tend to be used on lower-quality soils in settings with higher population density and with good market access. Under these conditions, intensification of land use is mainly a demand-driven option. Pesticide use is similarly related to higher population density, which requires more intensive pest and disease control. Improved seeds are mainly used in areas with less-degraded soils. Vaccinations are mainly applied in high-potential agricultural areas. Improved feeding practices (i.e., more balanced feed menus based on crop residue grazing, cut and carry grass harvesting, and feed purchase) are found in low-rainfall areas with little institutional presence.

We notice that fallow is practiced on less-degraded soils in areas with low population density. Less population pressure allows fallowing as a practice for controlling degradation. Manure and composting are mostly applied in low-rainfall areas. The latter practice is most often found in areas with relatively good soils, and where NGOs and irrigation institutions are present.

Investments in soil and water conservation structures show some interesting results. Stone terracing is constructed where severe soil degradation is present. Live fences are found where soils are degraded but soil quality is inherently good and higher population densities permit labor-intensive investments. Other investments such as soil bunds, drainage ditches, and tree planting are also found in less-degraded areas. Cooperatives seem to enhance terracing but are less effective in tree planting. Availability of NGO credit is particularly linked to soil bunds and drainage ditches.

Credit Use

The most important sources of credit in the region are friends or relatives and NGOs, followed by the state BoA. Professional moneylenders and traders play an important role in some communities. Most credit provision is not very closely related to agro-ecological conditions (Table 4.10). Only the NGO REST focuses its activities mainly in highly populated areas with low rainfall and high soil degradation. Money lenders are the most important source of credit in villages where cooperatives and irrigation organizations are active. Formal credit provision is generally concentrated in areas with less degraded or good soils, where prospects for semi-commercial production prevail.

Welfare Implications

In Table 4.11 we present some development indicators extracted from the survey. These provide insight into the investments made for housing and schooling. Most houses have a dirt floor, but major differences appear with respect to the roof. Metal roofs are found in higher-rainfall areas with better market access and presence of cooperatives. The high rainfall makes an investment in metal roofs more important, and returns from trade and loans from local institutions allow farmers to make these investments. Literacy rates are higher in areas with less rainfall and higher population density. The presence of irrigation institutions and livestock promotion programs of the BoA is positively correlated with education efforts.

Table 4.9 Relationship between technology choice and development domain dimensions

Dimension	Fertilizers	Pesticides	Improved seed	Vaccinations	Improved feeding practices	Soil bunds
Constant	0.6636***	0.1455***	0.2904***	0.7229***	0.4184***	0.2249***
Soil degradation	–0.0179	–0.0440	–0.0728***	–0.0805***	0.0409	–0.0772**
Soil quality	–0.0795***	0.0024	0.0381	0.0630**	–0.0590*	0.1058***
Elevation	0.0004	–0.0234	–0.0071	0.0100	0.0122	–0.0501
Rainfall	0.0230	–0.0142	–0.0437*	–0.0257	–0.1025***	–0.0493
Population density	0.1076***	0.0767***	0.0254	0.0032	0.0438	0.0128
Distance to markets	–0.0625*	0.0044	–0.0185	–0.0029	0.0009	–0.0172
Cooperatives	0.0209	0.0438	0.0329	0.0499	–0.0944***	0.0109
NGO credit	0.0192	–0.0287	0.0264	–0.0005	–0.1004***	0.0651*
Irrigation institutions	0.0222	0.0183	0.0234			0.0304
Bureau of Agriculture				0.0240	–0.0010	
Adjusted R^2	0.1588	0.0670	0.0661	0.0698	0.1515	0.1586

Note: Dependent variable is proportion of farm households using a specific technology.

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent level, respectively.**

Synthesis

The three core dimensions of the village development domains in Tigray have important implications for rural development options. Biophysical aspects, especially rainfall and temperature—and to a minor extent soil fertility—determine the

Table 4.10 Relationship between credit use and development domain dimensions, by credit source

Factor	NGO REST	Women's Bureau of Agriculture	Society of Tigray	Money lenders	Traders	Family and friends
Constant	0.4618***	0.2264***	0.0008	0.0470***	0.0010	0.5981***
Soil degradation	–0.0661**	–0.0025	–0.0003	0.0032	–0.0016*	–0.0989**
Soil quality	–0.0287	–0.0093	0.0032***	–0.0109	–0.0002	–0.0474
Elevation	0.0183	–0.0277	–0.0018	–0.0052	–0.0007	–0.0264
Rainfall	–0.0741**	–0.0437	0.0023**	–0.0085	–0.0008	–0.0661
Population density	0.0994***	0.0261	0.0015	–0.0031	–0.0005	–0.0394
Distance to markets	0.0375	–0.0582	–0.0013	0.0138	0.0005	–0.0775
Cooperatives	–0.0248	–0.0973***	–0.0012	0.0161	0.0066***	–0.0486
NGO credit	0.0504	0.0129	0.0011	–0.0565***	0.0000	–0.0863*
Irrigation institutions	0.0716**	0.0653*	0.0010	0.0215**	0.0036***	–0.1503***
Bureau of Agriculture	–0.0024	0.1733***	0.0005	0.0234***	0.0029***	0.0275
Adjusted R^2	0.1502	0.3229	0.0967	0.3414	0.4355	0.1301

Note: Dependent variable is proportion of farm households using specific credit sources.

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent level, respectively.**

Gully stabilization	Drainage ditches	Fallow	Manure application	Compost application	Irrigation canals	Stone terraces	Tree planting
0.3973***	0.1389***	0.1780***	0.6282***	0.2555***	0.5058***	0.5973***	0.1958***
0.0427	–0.0672**	–0.0643*	–0.0071	–0.0327	0.1025***	–0.0671*	0.0054
0.1342***	0.0679**	–0.0003	–0.0433	0.0312	–0.0257	–0.0068	0.0447*
0.0626**	0.0196	0.0035	–0.0379	0.0074	–0.0041	0.0501	–0.0015
0.1093***	0.0719**	–0.0458	–0.0662**	0.0726**	0.0188	–0.0930**	–0.0628***
–0.0424	–0.0470	–0.0990***	–0.0368	0.0014	0.0141	0.0580	0.0366
0.0063	–0.0296	0.0305	0.0216	0.0601	0.0515	–0.0202	–0.0291
–0.0312	–0.0328	–0.0007	0.0155	0.0052	0.0820**	–0.1235***	0.0021
–0.0171	0.0963***	0.0499	0.0268	0.0474	0.0223	–0.0054	0.0699**
–0.0262	0.0632***	–0.0280	0.0165	–0.1036***	0.0352	0.0862**	0.0427*
			0.0227				
0.3535	0.1825	0.0392	0.0634	0.0758	0.1232	0.1067	0.1725

scope for crop choice and livestock production. Population density influences the degree of input intensification of cropping systems, whereas livestock intensification takes place in areas with lower population density. Formal credit is mainly concentrated in high-potential areas, but NGOs target credit to resource-poor regions and households. Market access and institutional organization appear as key

Table 4.11 Relationship between human development indicators and development domain dimensions

	Houses with metal roofs	Adult literacy	School-age children attending school
Constant	0.0916***	0.5304***	0.6573***
Soil degradation	0.0096	–0.0150	–0.0254
Soil quality	–0.0039	–0.0076	0.0283
Elevation	–0.0243	–0.0332	–0.0012
Rainfall	0.0457**	–0.0427**	–0.0473**
Population density	0.0562***	0.0506**	0.0750***
Distance to markets	–0.0604***	–0.0025	–0.0296
Cooperatives	0.0429*	0.0114	0.0387
NGO credit	–0.0193	0.0151	0.0244
Irrigation institutions	–0.0102	0.0169	0.0621***
Bureau of Agriculture	0.0205	0.0726***	0.0301*
Adjusted R^2	0.1308	0.1445	0.1698

Note: Dependent variable is proportion of farm households meeting the human development indicator criterion.

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent level, respectively.**

incentives for cropping systems intensification and for enhancing investments in soil and water conservation activities. In a similar vein, investments in housing are made under more favorable agro-ecological, market, and institutional conditions, whereas investments in schooling are an attractive device for enhancing engagement in nonfarm employment in low-potential areas with high population density.

Discussion and Conclusions

We developed in this chapter a quantitative methodology for identifying relevant dimensions for village development domains that determine the scope for specific land use and production systems. This analysis can be useful both for extension and policy purposes; results can be used as a first step for the definition of recommendation domains for technical assistance services and for the identification of effective incentive regimes that permit farm household resource intensification. In addition, the methodology gives insight into the different local development pathways and the critical factors that influence farmers' livelihood strategies.

With the data derived from community surveys, it proved to be possible to extract the relevant dimensions of local development domains. We distinguished among agro-ecological potential, population density, and market access. The agro-ecological potential is by far the most complicated dimension because it includes multiple aspects: rainfall, soil quality, soil degradation, and elevation. Rainfall and soil quality determine the cropping potential, and altitude (as a proxy for temperature) needs to be taken into account because it determines the feasible options for crop diversification within the agricultural system. The distance to market outlets is relevant to determine whether these activities can be made economically attractive.

The relative independence of the critical dimensions of the development domains has been evaluated using regression methods. The correlations among these development domain dimensions are very low: the correlation is less than 1 percent between the level of degradation and rainfall and between population density and soil quality, and less than 4 percent between market access and altitude. The R^2 for most regressions is so low that we can safely ignore these interdependencies in our further analysis.

Understanding current production systems in terms of cropping patterns, livestock activities, and technology choice in relation to development domain dimensions gives a good indication of how development has occurred in the past. Although the past is not the only determinant of future pathways, and dynamic factors are not captured explicitly, it constitutes a relevant frame of reference. The systematic quantification of development domains and the predominant livelihood strategies therein provide a benchmark against which development strategies can be evaluated.

The occurrence of predominant cropping systems mainly depends on the variables pertaining to rainfall and altitude (temperature). These variables determine the suitability of a certain agro-ecological zone for certain land use systems. Soil quality and degradation only play a secondary role. In some cases crop choice depends on factors such as population density and market access. Maize production is found in more densely populated areas where otherwise sorghum would prevail. Better market access in the low-altitude areas seems to favor millet production. Market access is very important in the adoption of cash crops.

The development of livestock production depends on different factors. Rainfall and availability of pastures and feed are required for the maintenance of oxen. Ox ownership is fairly widespread in Tigray to guarantee timely land preparation. However, the number of oxen per household varies considerably. More oxen per household are found in settings where soils are of better quality and population densities are lower, permitting the availability of sufficient pasture and feed of good quality. Ox ownership tends to be greater in more remote areas. Under conditions of poor soil quality, dairy production and beekeeping arise as alternative strategies for farmers who possess stable market outlets. When markets are more remote, small stock production for local use appears as a useful alternative.

The selection of suitable and appropriate land use technology depends strongly on soil quality and the level of land degradation. The use of improved seeds depends on market access, whereas the use of external inputs is related to higher population density. In a similar vein, gully stabilization mainly occurs in erosion-prone areas located at higher elevations receiving higher rainfall on terrains with relatively good soil, whereas compost application is mostly done in low-rainfall settings to maintain soil fertility and improve moisture retention. This implies that farmers seem to be more inclined toward intensification of their land use systems in villages with high population pressure, especially when soil degradation is not yet a large problem. In general, adoption of improved land use technologies is positively correlated with better soils or less-degraded soils.

Geographic targeting of interventions requires the identification of appropriate technologies, followed by the application of suitable incentives. This means that technology packages should be oriented toward the specific development domains, taking into account the institutional and market conditions that prevail in each village. Institutional factors appear to play a major role in defining the incentive framework. However, institutional support by the state or NGO agencies is not fully independent of the other development dimensions. The presence of marketing institutions is relevant for the selection of commercially oriented cropping activities, and credit proved to be important for the expansion of oxen traction. For the adoption of improved land use practices, the availability of credit plays an overriding role.

Access to markets tends to be less important than institutional support. There are indications that farmers are able and willing to make the necessary investments for improving production and yields under conditions of increasing population pressure because some investment indicators are positively correlated with population density. Financial services also play an important role in controlling land degradation. Formal credit from state development agencies tends to be concentrated in less degraded areas because demand for credit is higher in better-endowed areas. By contrast, NGO credit provisions focus on less-favored areas.

The results in this chapter indicate some promising perspectives for further research. Making use of community-level surveys for collecting information on resource endowments, predominant land use patterns, and production systems enables the identification of some common dimensions of different development domains. Although this does not directly provide an indication of appropriate development pathways per se, the results from this analysis are useful for identifying feasible options when combined with location-specific information. Although the methodology in itself is sufficiently robust, further research at the farm household level is required to identify the farm household's responsiveness to specific policy incentives. The results of the stratification can also be used for developing bioeconomic household and village models that reveal the welfare and sustainability implications of different incentive regimes (see Kruseman 2000; Ruben, Kruseman, and Kuyvenhoven 2006).

The methodology developed in this chapter generates structural information that needs to be complemented by local case studies that could reveal other more behavioral motives for farming systems choice and livelihood strategies. This approach can be considered as a step toward differentiating predominant development patterns from idiosyncratic situations. Moreover, the approach offers a more generalized analysis compared to location-specific farming systems research, which provides a useful benchmark for comparing alternative development interventions. It is not meant to offer exact policy recommendations, however, but rather provides guidance to the directions in which these policy recommendations might be found.

Notes

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1. Diversity between household configurations in terms of differences in life cycle and intrahousehold relations can, of course, be registered, as indicated by Bauer (1977) and Abate (1995).

2. The lowest administrative level in Ethiopia is the *tabia.* In Tigray a number of *kushets* (hamlets) can be distinguished within the *tabia.* In this chapter we refer to *kushets* as villages, although some of the data we use are at the *tabia* level.

3. The notion of recommendation domains with fine-tuned development interventions was suggested as a general methodological framework in Farming Systems Research (FSR) in the 1980s. These approaches tended to be less formalized with a much broader set of criteria defining the domains than we use in our analysis. By narrowing down the criteria to three broad dimensions, we make the approach much more comparable across geographic locations, thus addressing one of the major criticisms against FSR as being too site-specific.

4. For details on the village survey, see Pender et al. (2001a).

5. Farmers' perceptions of soil properties are based on farmer perceptions of soil quality and are therefore a good measure of perceived short- and medium-term land use potential.

6. The use of SUR with identical X matrices takes into account that the analysis considers the activities as being done not in isolation but as parts of broader livelihood strategies. We report on this elsewhere in more detail (Kruseman, Ruben, and Tesfay 2006).

7. We choose to include population density in the factor analysis in order to get a normalized value for this variable.

8. In order to maintain meaningful variables, we combined some of the variables through a number of data reduction steps.

9. Only total rainfall is used as a determinant of development domain dimension because data on interannual and intraseasonal variation is either missing or incomplete.

10. Tigray is a mountainous area, and indicators for altitude depend on the criteria used for defining what is relevant. By using two data sources we attempt to reduce biases. One source is the village-level survey, and the other is based on general geographic information.

11. We have chosen not to use all the variables related to distance available in the community survey. A number of variables related to walking time and distance to local (grain mills) and social infrastructure (schools and medical services) are excluded from the analysis. They load on a separate factor that is not expected to have an important influence on development domains.

12. Soil quality (SQ) is considered as inherent soil quality based on prevalent soil types, not the result of cultivation practices. Testing for endogeneity does not indicate otherwise.

13. We relied on three-stage least-squares to determine the interdependence of the development domain dimensions using the truly exogenous factors (inherent soil quality, rainfall, and elevation) as instruments. Although some coefficients are significantly different from zero, all adjusted R^2 values are well below zero, indicating that the system of equations cannot adequately explain any variation. It can thus be concluded that there is no correlation among the error terms.

14. The weights used range between 1 and –1 to indicate how the factor scored on agricultural potential.

15. Superimposing the results of this analysis with recently defined agro-ecological zones of the country might be helpful in guiding research priorities and development needs.

16. We focus on actual use of credit, given the supply by local institutions, because credit use is an endogenous decision of farm households.

17. Three-stage least-squares is the seemingly unrelated regression method with correction for endogeneity. The seemingly unrelated regression method (SUR) applies to a system in which each

equation has an endogenous variable on the left side and only exogenous variables on the right side. As in the standard regression case, the disturbances are assumed to be uncorrelated with the exogenous variables. Each equation of this kind of system could be estimated by regression, equation by equation. However, if the disturbances of the equations are correlated, the SUR estimator is more efficient because it takes into account the entire matrix of correlations of all the equations. The SUR estimator minimizes the determinant of the covariance matrix of the disturbances.

18. The excluded endogenous variables all represent minor activities with only few observations.

19. The existence of some rotations appears when factor analysis is done on cropping patterns (not reported here).

20. This is an interesting finding because sorghum is usually not considered as a high-rainfall-demanding crop. However, rainfall is limited in the highlands of Tigray, even in relatively "higher rainfall" parts of this region.

21. This does not exclude the fact that maize is also grown in areas with little NGO presence.

22. The statistical relationships found in the data do not exclude the occurrence of other situations, such as beekeeping in low-population-density areas, but rather, they indicate predominant patterns.

Chapter 5

Land Management, Crop Production, and Household Income in the Highlands of Tigray, Northern Ethiopia: An Econometric Analysis

John Pender and Berhanu Gebremedhin

Low agricultural productivity, poverty, and land degradation are critical and closely related problems in the Ethiopian highlands. These problems are particularly severe in the highlands of Tigray in northern Ethiopia. Cereal yields average less than 1 ton per hectare in this region, and over half of the area of the Tigray highlands has been characterized as severely degraded, according to one study (Hurni 1988).[1] The average farm size is only 1 hectare, and most households subsist on incomes of less than $1 per day (based on results of the survey discussed in this chapter).

In recognition of these problems, the regional government of Tigray has undertaken a massive program of investment and resource conservation since the fall of the Derg regime in 1991. The regional development strategy of conservation-based agricultural development–led industrialization has focused on promoting conservation of natural resources and improvement of agricultural productivity and welfare through a broad program of rehabilitation of natural resources, investment in infrastructure, agricultural extension, education, and other services. These efforts built on the philosophy of self-reliance and strategies of local democratic participation and community mobilization for local conservation and development efforts that were initiated during the struggle of the Tigray People's Liberation Front (TPLF) against the Derg regime (Young 1996; Hagos, Pender, and Gebreselassie 1999; Hailu and Haile 2001) and have been given high priority as a result of the recurrent famines in the region.

Empirical evidence of the impacts of these policies and identification of specific areas where problems need to be addressed are needed. Addressing this information need is the primary objective of this study.

This study is based on econometric analysis of household and plot-level surveys conducted in 100 villages in 50 *tabias* (the lowest administrative unit in Tigray, usually comprising four or five villages) in the highlands of Tigray during 1999–2000.[2] It builds on a prior study based on *tabia*- and village-level surveys in the same communities in 1998–99 (Pender et al. 2001a), which were used in the empirical work reported in Chapter 4. This broad sample and the information collected at different levels enable investigation of the impacts of community-level factors such as population density, investments in irrigation and roads, as well as household and plot-level factors such as household wealth, education, land tenure, and other factors on land management and the implications for agricultural productivity and land degradation.

Empirical Model, Methods, and Hypotheses

Empirical Model

The key outcomes of interest in this study are agricultural production and per capita income.[3] We consider the proximate causes of each of these, including household choices regarding income strategies, land management, and other decisions, and the underlying determinants of these choices.

Crop production. For agricultural production, we focus on the value of crop production per hectare. We assume that the value of crop production by household *h* on plot *p* (y_{hp}) is determined by the amount of inputs (labor, ox power, fertilizer, seeds) used (IN_{hp});[4] the land management practices (manure or compost, burning, contour plowing, reduced tillage, intercropping) used (LM_{hp}); the "natural capital" of the plot (NC_{hp}) (biophysical characteristics and presence of land investments); the tenure characteristics of the plot (T_{hp}) (how plot was acquired, i.e., whether allocated in prior land distribution, inherited, leased [sharecropped in almost all cases], received as gift, or borrowed); the household's endowments of physical capital (PC_h) (land, livestock, radio [reflecting access to information as well as wealth], human capital (HC_h) (education, age, and gender of household head, size of household), financial capital (use of credit and accumulation of savings), and "social capital" (SC_h) (assets in form of relationships, indicated by participation in programs and organizations); the household's income strategy (IS_h) (primary and secondary income sources); village-level factors that determine local comparative advantages (X_v) (agro-ecological conditions, access to markets and infrastructure, and population density); and random factors (u_{yhp}):

$$y_{hp} = y(IN_{hp}, LM_{hp}, NC_{hp}, T_{hp}, PC_h, HC_h, FC_h, SC_h, IS_h, X_v, u_{yhp}) \quad (5.1)$$

Equation (5.1) is not a production function but rather a gross revenue function. As such, it aggregates the value of production per hectare of different crops and depends on the farm-level prices of the crops produced.[5] Because different crops are produced by different households in different locations in Ethiopia, we do not explicitly include crop prices as determinants of crop revenue per hectare; this would result in many missing observations for farm level prices. Instead, we assume that farm-level prices are determined by village-level factors determining local supply, demand, and transportation costs of commodities (X_v) and household-level factors affecting households' transactions costs and marketing abilities (HC_h, FC_h, SC_h, IS_h). Land tenure (T_{hp}) can affect productivity, for example, by affecting incentives to apply labor effort and other inputs to sharecropped land compared to owner-operated land (Shaban 1987).[6] Household endowments of physical capital (PC_h) can also affect crop production if there are imperfect factor markets. For example, ownership of oxen may influence crop production even after controlling for the amount of ox labor used because owners of oxen have preferential access to ox power at times of peak demand. In addition, agro-ecological conditions, households' human and social capital, and their farming experience may also influence agricultural productivity, even if these factors have no impact on prices.

Input use and land management. In equation (5.1), input use and land management are choices in the current year, determined by the natural capital and tenure of the plot; the household's endowments of physical, human, social, and financial capital at the beginning of the year; the household's income strategy; agro-ecological conditions, access to markets and infrastructure, and population density (X_v); and unobservable factors (u_{INhp} and u_{LMhp}):

$$IN_{hp} = IN(NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, FC_h, IS_h, X_v, u_{INhp}) \quad (5.2)$$

$$LM_{hp} = LM(NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, FC_h, IS_h, X_v, u_{LMhp}) \quad (5.3)$$

Most of the determinant factors in equations (5.2) and (5.3) are either exogenous to the household (e.g., X_v) or state variables that are predetermined at the beginning of each year (e.g., NC_{hp}, PC_h, HC_h, and FC_h). Income strategies may change from year to year but are usually slow to change because of irreversible investments in human and social capital (required for such changes as development of new skills and investments in developing market connections are needed to shift from subsistence to cash crop production).[7] Thus, we assume that households' current income strategies are determined by fixed or slowly changing factors and therefore are predetermined in equations (5.1)–(5.3).

Participation in programs and organizations (SC_h) and use of credit (FC_h) may be partly or wholly determined in the current year and hence potentially affected by current decisions about input use and land management. In the econometric analysis (discussed in more detail below), we use predicted participation in programs and organizations and predicted use of credit as instrumental variables to address this potential endogeneity concern. We predict participation in programs and organizations and use of credit using village-level factors affecting local comparative advantages and placement of programs (X_v), household endowments of land (NC_h), and human capital (HC_h).[8] For example, membership in an agricultural cadre requires literacy and some experience in modern agricultural practices, access to credit may depend on the household's endowment of land, and placement of programs may depend on local comparative advantages.

$$SC_h = SC(HC_h, NC_h, X_v) \tag{5.4}$$

$$FC_h = FC(HC_h, NC_h, X_v) \tag{5.5}$$

The determinants of value of crop production will be estimated using the structural model (accounting for potential endogeneity bias, as discussed below) represented by equation (5.1) as well as in reduced form. The reduced form is obtained by substituting equations (5.2)–(5.5) into equation (5.1):

$$y_{hp} = y'(NC_{hp}, T_{hp}, PC_h, HC_h, IS_h, X_v, u'_{yhp}) \tag{5.6}$$

Per capita income. We assume that household per capita income is determined by the same endowments that determine land management and input use decisions, except that plot-level factors are aggregated to the household level:[9]

$$I_h = I(NC_h, T_h, PC_h, HC_h, SC_h, FC_h, IS_h, X_v, u_{Ih}) \tag{5.7}$$

Equation (5.7) is a reduced-form equation because we do not include endogenous decisions that affect income such as input use and land management practices, as in equation (5.1). It is not a fully reduced form, however, because it includes FC_h and SC_h, which are potentially endogenous variables as noted above. These variables are included in this specification because we want to investigate the impacts of these factors on household income. Substituting equations (5.4) and (5.5) into equation (5.6), we also can derive the fully reduced form version of equation (5.7):

$$I_h = I'(NC_h, T_h, PC_h, HC_h, IS_h, X_v, u'_{Ih}) \tag{5.8}$$

Equations (5.1)–(5.8) are the basis for the econometric estimations.

Methods

Data Sources

This study is based on a survey of 500 households in 100 villages in 50 communities (*tabias*) in the highlands of Tigray conducted in 1999 and 2000. *Tabias* less than 1,500 meters above sea level elevation were excluded from the sample frame. A random sample of *tabias* was used, stratified by distance to the *woreda* (district) town and whether an irrigation project was present in the *tabia.* Two villages were randomly selected within each sample *tabia,* and five households were randomly selected from each village. In addition to household-level information, information was collected on all plots owned or operated by the respondent households. The survey data were supplemented by data from *tabia* and village surveys on prices and other factors, secondary data from the 1994 Population Census on the population of each *tabia,* and maps of the boundaries of each *tabia* (used to calculate population density).

Econometric Approach

The dependent variables analyzed in this study include the amounts of inputs used on each plot in 1998 (labor, draft animal power, and seeds), adoption of the most common crop and land management practices in 1998 (use of fertilizer, improved seeds, manure or compost, burning to clear the plot, contour plowing, reduced tillage, and intercropping or mixed cropping), the value of crop production on the plot, per capita income of the household, and whether the household head participated in the extension program, used formal or informal credit, or participated as a member in certain community organizations (*tabia* council, village council, marketing cooperative, or agricultural cadre).[10] The econometric model used depends on the nature of the dependent variable. For use of labor, ox-power, and seeds, the value of crop production, and per capita income, least-squares regressions were used.

For explaining whether various land management practices were used, whether the household participated in agricultural extension, various organizations, or used credit, probit models were used.

The explanatory variables include indicators of agricultural potential (average rainfall and altitude); population density; access to roads and markets (walking time to nearest all-weather road and to the *woreda* [district] town); wealth (land and livestock owned); human capital (gender, age, and education of household head, and household size, a proxy for family labor endowment); income strategy (primary and secondary income source); ownership of a radio (a determinant of access to information); availability of cash savings; household social capital (membership in various organizations); use of formal or informal credit; contact of the household with the agricultural extension program; and various plot-level factors, including land use of cultivated plots[11] (whether homestead, rain-fed, or irrigated), land tenure (how plot acquired), presence of investments on the plot (stone terrace, soil bund, fence), and several indicators of different aspects of quality of the plot (size of plot, distance of the plot to the farmer's residence, plot slope, position on slope, soil depth, color, texture, and presence of gullies).

In the crop production regression and the input use regressions, we used a logarithmic Cobb-Douglas specification. We included interaction terms between fertilizer use and presence of a stone terrace, a soil bund, or irrigation to test whether there is complementarity between fertilizer use and these investments, because of the expected impact of these investments on soil moisture availability. Because inputs and land management practices are endogenous choice variables in the crop production regression, and participation in programs and organizations and use of credit may be endogenous, we use instrumental variables (IV) estimation, using instruments for input use, land management practices, participation in programs and organizations, and use of credit. We also estimate the full model using ordinary least squares (OLS) and test for endogeneity bias using a Hausman (1978) test. Predicted values of the endogenous discrete explanatory variables from probit regressions (equations [5.2]–[5.5]) were used as instrumental variables. Exclusion restrictions for other instrumental variables excluded from the regression were based on joint statistical Wald tests (only variables that were jointly statistically insignificant at the 20 percent level or greater in both OLS and IV models were excluded). We also estimate the reduced form (RF) specified in equation (5.6) and report the robustness of our results across specifications.[12] The reduced form gives an indication of the total effect of underlying explanatory variables on crop production, allowing for change in input use, land management practices, participation in programs and organizations, and use of credit. We also investigate indirect effects using simulations as discussed below.

We also use IV estimation in the input use and income per capita regressions to account for possible endogeneity of participation in programs and organizations and use of credit, as noted above, and report the robustness of our results. In the land management (probit) regressions, IV estimation could not be used.[13] We used predicted values of the potentially endogenous variables as explanatory variables. Because of space limitations, we do not report the results of the probit regressions used to predict participation in programs and organizations and use of credit.[14] As for the value of crop production, we also estimate the determinants of per capita income in reduced form (equation [5.8]).

We tested the regression specifications for problems of multicollinearity but found this not to be a serious problem in any of the specifications.[15] Various regression diagnostics were used to identify outliers and influential observations and to find and correct data errors. All models used the Huber-White estimator of the covariance matrix, which is robust to heteroskedasticity, accounted for clustering of the data by household (i.e., estimated standard errors are robust to nonindependence of observations from the same household), and accounted for the stratification and probability of sampling each village and household in the sample frame (StataCorp 2003). The results are thus robust to potential problems of heteroskedasticity and nonindependence and are statistically representative of the highlands of Tigray.

Predicted Impacts of Selected Variables

In a complex structural model, such as estimated in this study, a change in a particular causal factor may have impacts on outcomes of interest through many different channels, given the many intervening response variables that may be affected. For example, improvements in education may affect agricultural productivity directly by affecting farmers' ability to use technologies that affect productivity. But it may also influence productivity indirectly, for example, by affecting households' choice of land management practices or participation in extension. Such indirect effects must be accounted for if we are to understand the full effect of causal factors on agricultural production and income.

In studies in which the empirical relationships are linear and involve continuous variables, the predicted total impacts of changes in explanatory variables can be determined using total differentiation of the system (Fan, Hazell, and Thorat 1999). In this study, this approach is not practical because of the nonlinear limited dependent variable models estimated. To address this issue, we simulate the predicted responses implied by the estimated econometric relationships under alternative assumptions about the values of the explanatory variables for the entire sample and carry these predicted responses forward to determine their influence on subsequent relationships in the system.[16]

Agriculture and Land Management in the Highlands of Tigray

Biophysical and Socioeconomic Conditions

The average annual rainfall is generally less than 1,000 millimeters in the semiarid highlands of Tigray and averages about 650 millimeters for all sample households (Table 5.1). Altitude in the highlands averages 2,174 meters above sea level and ranges from 1,500 to well over 3,000 meters above sea level.

The rural population is growing rapidly at more than 3 percent per annum, and population pressure is high in the Tigray highlands, with average population density of 137 persons per square kilometer in the sample communities. As a result, the average farm size in the Tigray highlands is only 1 hectare. Land is relatively equally distributed in the Ethiopian highlands because of the radical land reform program begun in 1975 by the Derg regime (Rahmato 1984; Bruce, Hoben, and Rahmato 1994; Abate 1995; Amare 1995) and the continued prohibition of land sales and mortgages under the current government of the Ethiopian Peoples Revolutionary Democratic Front (EPRDF), a policy enshrined in the new Ethiopian constitution.[17] Hence, the maximum farm size in our sample was only about 4 hectares. Almost all households own livestock, with cattle most important (in value terms), followed by sheep and goats. The average household size is 5.4.

Access to roads, transportation, and other services has improved substantially in Tigray since 1991. Nevertheless, most households are still far from roads, transportation services, and markets. In 1998, the average walking time (the dominant mode of transport) to the nearest all-weather road was more than 2 hours, while walking time to the nearest *woreda* town averaged 3.5 hours.

Education has improved dramatically in Tigray since 1991 as a result of the greatly increased number of schools and literacy campaigns. Still, only about 15 percent of household heads had formal schooling by 1998 (only 6 percent had more than 2 years), and 7 percent had participated in a literacy campaign.

The availability of agricultural extension and credit services has also greatly expanded. Nearly three-fifths of households had access to credit from formal sources in 1998. Development agents of the extension service were involved in virtually every community, though only about 11 percent of sample households had direct contact with an extension agent.

About 6 percent of households have members in a marketing cooperative that is involved in marketing agricultural (mainly crop) outputs and providing inputs. About 2 percent of households have a member in an agricultural cadre that focuses on improving agricultural production. A similar small proportion of households are involved as community leaders in the local *tabia* or village council.

Table 5.1 Descriptive statistics of households in Tigray highlands survey, 1998

Variable	Number of observations	Mean (standard error)
Annual rainfall (millimeters)	480	652 (5)
Altitude (meters above sea level)	500	2,174 (22)
Population density (persons/km^2)	490	136.8 (4.4)
Female head of household	500	21.8 (2.2)
Age of household head (years)	500	46.0 (0.7)
Household size (number)	500	5.4 (0.1)
Education of household head (percentage of households)		
1–2 years	500	9.2 (1.6)
3+ years	500	6.1 (1.3)
Literacy campaign	500	7.3 (1.5)
Walking time to nearest (hours)		
All-weather road	496	2.33 (0.l3)
Woreda town	497	3.54 (0.17)
Ownership of assets		
Land (hectares)	477	0.98 (0.04)
Oxen (number)	496	1.12 (0.05)
Other cattle (number)	496	2.71 (0.16)
Small ruminants (number)	496	4.95 (0.54)
Pack animals (number)	496	0.71 (0.06)
Radio (percentage owning)	500	13.2 (1.9)
Cash savings (percentage having)	500	54.4 (2.7)
Secondary income source (percentage of households)		
No secondary source	496	20.6 (2.2)
Cereals	496	2.9 (0.9)
Perishable annuals	496	3.3 (1.1)
Perennial crops	496	3.6 (1.2)
Cattle	496	35.0 (0.9)
Small ruminants	496	2.2 (0.9)
Beekeeping	496	0.4 (0.3)
Food-for-work	496	6.1 (1.1)
Salary employment	496	1.6 (0.6)
Farm employment	496	1.4 (0.6)
Trading	496	6.5 (1.3)
Food/other assistance	496	6.5 (1.3)
Other nonfarm	496	10.0 (1.7)
Membership in organizations (percentage of households)		
Tabia council	500	1.6 (0.7)
Village council	500	2.0 (0.9)
Marketing cooperative	500	6.4 (1.2)
Agricultural cadre	500	1.6 (0.7)
Use of credit (percentage of households)		
Formal credit	500	57.7 (2.7)
Informal credit	500	18.9 (2.1)
Contact with extension (percentage of households)	500	11.4 (1.7)
Household income (birr)	477	1,924 (120)
Per capita income (birr)	477	388 (22)

Poverty is severe in the highlands of Tigray. Average per capita income among the sample households was only 388 EB in 1998 (less than $60).[18] Per capita income is even lower among female-headed households and larger households.

Income strategies. For at least 2,000 years, the predominant farming system and income strategy in the northern Ethiopian highlands has been cereal cultivation supported by ox-plow tillage (McCann 1995). Not surprisingly, the dominant source of income in the highlands of Tigray is still cereal crop production, which is the primary source of income for 97 percent of sample households. Different income strategies are thus distinguished more by differences in the secondary source of income. One-fifth of households have no secondary source of income; cereal crop production is their sole income source. In about one-third of households, the secondary source of income is cattle production. Nonfarm activities—including trading activities, food-for-work, salary employment, and other nonfarm activities—are the secondary income source of about one-fourth of households. Other less common secondary sources of income include production of perishable annual or perennial crops, small ruminants, beekeeping, farm wage labor, and food aid and other forms of assistance.[19]

Land management. Preharvest labor use in crop production averaged 86 person-days per hectare, most of this for plowing, planting, and weeding (Table 5.2). Draft animal use (mainly oxen) averaged 25 animal days per hectare. Seed use averages 118 kilograms per hectare. Fertilizer was used on 27 percent of plots, and manure or compost on about 20 percent of plots in 1998. Improved seeds were used on only about 2 percent of plots.

The most common investments in land improvement in Tigray are stone terraces and soil bunds. Stone terraces existed on nearly 37 percent of cultivated plots in 1998, while soil bunds existed on about 8 percent. These investments have been widely promoted in Tigray during the past few decades through food-for-work programs and community labor mass mobilization campaigns,[20] as well as resulting from farmers' own private investment initiatives (Hagos, Pender, and Gebreselassie 1999; Kinfe 2002; Hagos and Holden 2005). Although public conservation investments are most common, private soil and water conservation investments are also relatively common, and the intensity of such investment is greater where private investment is involved (Hagos and Holden 2005). Other less common investments included constructing a fence or planting a live fence, and planting trees.

Several land management practices are commonly used in Tigray, including contour plowing, burning to prepare fields, reduced tillage, and intercropping or mixed cropping. Contour plowing is very common, practiced on nearly 90 percent of plots.

Table 5.2 Descriptive statistics of plots in Tigray highlands survey, 1998

Variable	Number of observations	Mean (standard error)
Land investments (percentage of plots)		
Stone terrace	1,785	36.5 (1.9)
Soil bund	1,785	8.3 (1.0)
Constructed fence	1,785	3.8 (0.7)
Live fence or barrier	1,785	3.1 (0.6)
Land use (percentage of plots)		
Homestead	1,785	19.7 (1.0)
Rainfed cultivated	1,785	73.7 (1.1)
Irrigated cultivated	1,785	6.6 (1.0)
Use of inputs		
Labor (person-days/hectare)	1,785	86.4 (9.5)
Oxen power (animal-days/hectare)	1,785	25.3 (1.9)
Seed (kilogram/hectare)	1,785	118.1 (7.7)
Improved seed (percentage of plots)	1,785	2.4 (0.5)
Fertilizer (percentage of plots)	1,785	27.0 (1.6)
Use of land management practices (percentage of plots)		
Burning to prepare field	1,785	11.0 (1.3)
Contour plowing	1,785	87.5 (1.6)
Reduced tillage	1,785	12.3 (1.2)
Intercropping/mixed cropping	1,785	11.4 (1.2)
Manure or compost	1,785	22.8 (1.3)
Value of crop production (EB/hectare)	1,593	1816 (176)
How plot acquired (percentage of plots)		
Leased in	1,785	13.7 (1.3)
Allocated by *tabia*	1,785	84.0 (1.4)
Inherited	1,785	1.4 (0.5)
Received as gift/other	1,785	0.9 (0.3)
Plot area (hectares)	1,508	0.30 (0.01)
Walking time to residence (hours)	1,780	0.39 (0.02)
Plot slope (percentage of plots)		
Flat	1,779	57.8 (2.0)
Gentle	1,779	32.3 (2.0)
Steep	1,779	9.9 (1.4)
Position on slope (percentage of plots)		
Top	1,785	13.1 (1.4)
Middle	1,785	21.1 (1.6)
Bottom	1,785	28.0 (2.2)
Not on slope	1,785	37.9 (2.2)
Soil depth (percentage of plots)		
Deep	1,767	21.9 (1.4)
Medium	1,767	38.1 (1.7)
Shallow	1,767	40.0 (1.8)
Soil color (percentage of plots)		
Black	1,767	27.8 (2.2)
Brown	1,767	12.4 (1.1)
Grey	1,767	22.9 (1.8)
Red	1,767	36.8 (2.0)
Soil texture (percentage of plots)		
Clay	1,767	27.6 (2.2)
Loam	1,767	31.7 (2.0)
Sand	1,767	29.7 (1.8)
Silt	1,767	11.1 (1.3)
Gullies on plot (percentage of plots)	1,785	5.1 (0.7)

Crop production. The average estimated value of crop production on surveyed plots was 1,815 EB per hectare in 1998.[21] The average value of production was higher on plots where inorganic fertilizer was applied (2,184 EB/hectare) than where no fertilizer was applied (1,684 EB/hectare). The average value of production was substantially higher on irrigated plots (6,726 EB/hectare) than on non-irrigated homestead plots (1,838 EB/hectare) or rain-fed field plots (1,428 EB/hectare). These figures are the total value of production during the year, including multiple crops, which is why the irrigated production value was so much higher. These differences may also result from other factors besides fertilizer use or irrigation (such as differences in cropland quality); multivariate analysis is needed to control for such factors.

Results of Econometric Analysis

Input use and land management practices. Population pressure is associated with higher use of labor and animal draft power per hectare and with a higher probability of use of fertilizer and intercropping (Table 5.3). We also find that households that own more land are less likely to apply fertilizer to a particular plot and more likely to use

Table 5.3 Determinants of input use and land management practices in crop production, 1998

Variable[a]	Labor ln(person days/ha)[b]	Oxen ln(animal-days/ha)[b]	Seeds ln(kg/ha)[b]	Fertilizer[c]
ln(Population density/km^2)	0.122**+	0.154***+++	0.079	0.076**++
Female head of household	–0.415***–––	–0.207***––	0.241**	–0.050
ln(Age of household head) (years)	0.224**++	–0.045	0.216	0.071
ln(Household size) (number)	0.123*	0.061	0.152*	–0.019
Education of household head				
3+ years	0.319***++	–0.001	0.201	–0.009
Literacy campaign	0.047	0.119	–0.005	–0.012
Walking time to (hours)				
All-weather road	–0.081***–––	–0.016	–0.001	–0.048***–––
Woreda town	0.016	–0.044***–––	–0.009	0.006
Plot from residence	–0.125	–0.026	0.077	–0.095**––
Ownership of assets				
Land (tsimad)	0.015	–0.005	–0.025	–0.059**–
Oxen (number)	0.087**+	0.071**++	0.039	0.013
Other cattle (number)	0.012	0.007	0.022*+++	0.011**++
Small ruminants (number)	–0.008**––	–0.006***––	–0.014***–––	–0.002
Pack animals (number)	–0.004	–0.009	0.026	–0.015––
Radio (yes/no)	0.028	–0.127**––	0.096	0.052+
Cash savings (yes/no)	0.080+	–0.008	0.125	0.058*+++

reduced tillage. These findings support the Boserup (1965) hypothesis that population pressure causes farmers to intensify use of labor and other inputs and to adopt more intensive land management practices, and are consistent with the findings of Kruseman, Ruben, and Tesfay in Chapter 4.[22]

Access to roads, markets, and farmers' fields also affects the intensity of land management. Households closer to an all-weather road use more labor per hectare and are more likely to use fertilizer, burning, and contour plowing, also consistent with findings in Chapter 4.[23] Households closer to a *woreda* town use more draft animal power per hectare but are less likely to contour plow. Farmers are more likely to use fertilizer, improved seeds, and manure or compost on plots closer to their residence, probably because of the difficulty of transporting inputs to distant plots. This is consistent with the findings of Gebremedhin and Swinton (2003a), who found that farmers in central Tigray were more likely to use stone terraces on plots nearer to the homestead, in the sense that more intensive land management is used on plots closer to the residence.

Income strategies affect land management. Households for which cereals are a secondary income source use less ox power per hectare and are more likely to use

Improved seed[c]	Manuring/ composting	Burning to prepare field[c]	Contour plowing[c]	Reduced tillage[c]	Intercropping/ mixed cropping[c]
0.0002	0.0491*	–0.0025	–0.0048	–0.0160	0.0605***+++
–0.0018	–0.0871***–––	0.0245	–0.1112***	0.0018	–0.0199
0.0024*+++	–0.0464	0.0347*+++	0.0466*++	–0.0325	0.0182+++
–0.0006	–0.0138	–0.0043++	0.0049	–0.0472*	0.0199++
0.0014+++	0.0171	0.0220+++	0.0278++	–0.0126	–0.0148++
0.0020	0.0489	0.0442+++	–0.0075	–0.0118	–0.0063
0.0009	–0.0097	0.0156***–––	–0.0143**–	0.0069	0.0049
–0.0012*	0.0061	0.0054+++	0.0114**++	–0.0036	–0.0110**
0.0082***–––	–0.3178***–––	0.0106	–0.0317*–	0.0381	–0.0280–
–0.0009	–0.0136	0.0072	0.0276**	0.0551***++	–0.0082
0.0008+	0.0388***++	0.0097	0.0378***+++	–0.0359***––	0.0153*+
0.0000	0.0043	0.0046**+	0.0000	0.0021	0.0024
–0.0001	0.0017	–0.0028***–––	0.0009	0.0018	–0.0019**–
–0.0014***–––	–0.0143	–0.0056	0.0064	0.0026	–0.0195***––
–0.0014	0.0051	–0.0150	–0.0030	0.0402	–0.0362*––
0.0003	–0.0659**––	0.0058	–0.0231	–0.0063	–0.0050

(*continued*)

Table 5.3 (continued)

Variable[a]	Labor ln(person days/ha)[b]	Oxen ln(animal-days/ha)[b]	Seeds ln(kg/ha)[b]	Fertilizer[c]
Secondary income source				
Cereals	–0.112	–0.404**––	0.003	–0.009
Perishable annuals	0.534**	–0.108	0.004	–0.012
Perennial crops	0.247*+	0.039	0.001	–0.009
Cattle	–0.188**––	–0.211***––	0.145	–0.012
Small ruminants/beekeeping	–0.272*–	–0.215	0.163	–0.009
Food-for-work/farm work	–0.438***–––	–0.368***–––	0.248*	–0.012
Salary employment	0.129	–0.067	0.192	–0.009
Trading	0.019	–0.119	–0.189	–0.012*
Food/other assistance	–0.310*	–0.351***–––	0.321*	–0.009
Other nonfarm	0.006	–0.099	0.083	–0.012
Contact with extension	–0.095	–0.120*–	–0.061	–0.046
Membership in organizations				
Tabia council	–0.041	–0.036	–0.263	–0.057
Village council	0.644***+++	0.178	0.243	0.119
Marketing cooperative	–0.111	0.007	0.250*+	0.013
Agricultural cadre	–0.301**	0.079	–0.778***	0.191
Use of credit				
Formal credit	0.023	–0.006	0.179**	0.191***
Informal credit	0.048	–0.064	–0.066	0.038
Land use (cf. rain-fed plot)				
Homestead plot	0.426***+++	0.160***+++	0.236***+++	0.006
Irrigated plot	0.875***+++	0.308**++	–0.025	0.160*+
Initial investment on plot				
Stone terrace	0.023	–0.028	0.068	0.091***+++
Soil bund	0.064	0.090++	0.024	0.052
Fence (live or constructed)	0.367***+++	0.002	0.053	0.016
Intercept	7.215***+++	6.652***+++	3.394	NR
Number of observations	1,402	1,353	1,435	1,607
Mean of dependent variable	3.932	3.184	4.229	0.2698
Mean predicted dependent variable	3.932	3.184	4.229	0.2685
R^2 or pseudo-R^2	0.5314	0.3357	0.4913	0.2125

Note: NR means that the intercept is not reported by the Stata procedure showing marginal effects in probit models.

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent levels, respectively.**

+, ++, +++ and –, ––, ––– mean coefficient is positive (negative) and statistically significant at 10 percent, 5 percent, and 1 percent levels, respectively in IV regressions and probit models using predicted values of participation in extension, credit, and organizations.

[a]Coefficients of biophysical variables (annual rainfall, altitude, plot slope, position on slope, soil depth, soil color, soil texture, and presence of gullies), plot area, and how plot acquired not reported to save space. Full results available upon request.

Improved seed[c]	Manuring/ composting	Burning to prepare field[c]	Contour plowing[c]	Reduced tillage[c]	Intercropping/ mixed cropping[c]
–0.0005	–0.1002	–0.0192	–0.0439	0.1922**++	–0.0356*
0.1522***+++	0.0180	0.0123	–0.1398*	0.1838**++	0.0631
0.0592***+++	–0.0790	–0.0377*––	–0.0248	–0.0255	[d]
0.0044*+	–0.0092	–0.0681***––	–0.0367	0.0295	–0.0419**
[d]	–0.0935**––	0.0271	0.0578	0.0501	–0.0493***–––
0.0163**+	–0.0520	–0.0337*–	–0.0711*	0.0715++	0.0015
0.0041	–0.0981*–	–0.0291	–0.0043	–0.0445	–0.0112
0.0079	–0.0193	–0.0277	0.0245	0.1383**+++	0.0025
0.0087+	–0.0852**––	–0.0448**–––	–0.0561	0.0407	–0.0430**––
0.0088	–0.0667	–0.0142	–0.0391	–0.0011	0.0238
0.0013–––	–0.0207	–0.0190–––	0.0171–	–0.0039––	0.0185–
[d]	–0.0713–	0.0349	[e]	0.0312	[d]
0.2415***++	0.2785***+++	[d]	[e]	–0.0476	0.2535**+
0.0001	0.0174	–0.0326*––	–0.0110	0.0389	0.0189
–0.0017*	–0.0755–	0.0548	–0.0036	–0.0265	0.0007––
0.0024**+	0.0060	0.0183–	0.0305*	0.0001	–0.0249
–0.0011+++	–0.0304	0.0238++	0.0143+	0.0292+	–0.0224+
–0.0028***–––	0.4402***+++	0.0092	0.0365*+	0.0371	0.0228
0.0156**++	0.1125	0.0380	–0.0171	0.125***+++	–0.0382
–0.0004	0.0274	0.0137	0.0361**++	0.0193	0.0068
–0.0015–	–0.0188	0.0773***+++	0.0387	0.0196	0.0154
0.0020	0.2783***+++	0.0096	0.0375	–0.0259	0.0015
NR	NR	NR	NR	NR	NR
1,528	1,607	1,559	1,524	1,588	1,528
0.0236	0.2429	0.1078	0.8803	0.1181	0.1176
0.0233	0.2437	0.1078	0.8674	0.1182	0.1171
0.3512	0.4241	0.2717	0.2951	0.1748	0.2747

[b] Least squares regression. Coefficients and standard errors adjusted for sampling weights, clustering, and stratification. Hausman test failed to reject OLS model in all cases (*P* = 1.000).

[c] Probit regression. Reported coefficients represent effect of a unit change in explanatory variable on probability of use at the mean of the explanatory variables.

[d] No positive values of dependent variable for positive values of the explanatory variable. Observations with positive values of the explanatory variable dropped from the regression.

[e] Only positive values of dependent variable for positive values of the explanatory variable. Observations with positive values of the explanatory variable dropped from the regression.

reduced tillage. Producers of perishable annuals and perennial crops are more likely to use improved seed than cereals-only producers. Producers of perishable annuals also are more likely to use reduced tillage. Cattle producers use less labor and draft power in crop production than cereals-only farmers and are less likely to use burning, suggesting that cattle producers are less focused on intensive crop production than cereals-only producers. Similarly, small ruminant producers are less likely to apply manure or compost or to use intercropping. Households dependent on food-for-work or farm employment use less labor and draft power than cereals-only producers but are more likely to use improved seeds. Households involved in trading are more likely to use reduced tillage, probably because of labor and capital constraints. Households dependent on food aid or other assistance use less draft power and are less likely to apply manure or compost, to use burning, or to use intercropping. Such households apparently lack the ability to farm as intensively as others.

As expected, irrigation increases use of labor, ox power, improved seeds, and fertilizer (impact on fertilizer weakly significant at the 10 percent level) because of the production of multiple crops per year.[24] Irrigation also promotes reduced tillage. Fertilizer use and contour plowing are more likely on plots with a stone terrace, suggesting complementarity of such soil and water conservation investments with use of inputs and contour plowing. Labor use and use of manure and compost are greater on plots that have a fence, suggesting that fences help to promote labor-intensive practices. Burning is more common on plots with soil bunds; perhaps such bunds contribute to problems with weeds (Herweg 1993b).

Not surprisingly, use of formal-sector credit is strongly associated with greater use of fertilizer and improved seeds. This is because this credit is used primarily to purchase such crop inputs.[25] Informal credit is not significantly associated with use of any crop inputs or land management practices, perhaps because informal credit is used for other purposes than agricultural production. Surprisingly, contact with the extension program is not significantly associated with use of inputs or land management practices. It appears that it is not the extension program per se that is leading to significant increases in use of fertilizer in Tigray but, rather, availability of credit and other factors.

Ownership of livestock and other assets affects land management. Households that own more oxen use more labor and ox draft power per hectare, suggesting that oxen and labor are complements and that imperfect markets for hiring oxen constrain households that own fewer oxen. Greater ox ownership also increases use of manure and compost and contour plowing but decreases use of reduced tillage. Greater ownership of other types of cattle is associated with greater use of seeds and fertilizer, probably because income generated from cattle products helps farmers afford to buy these inputs. Consistent with this explanation, households with cash savings are more likely to use fertilizer and less likely to use manure and compost, suggesting that cash constraints limit use of fertilizer. By contrast, greater ownership of small ruminants is associated with less use of labor, draft power, seeds, and burning. This suggests that small ruminant producers focus less of their effort on crop production.

Human capital affects land management. Female-headed households use significantly less labor and draft power, probably because of labor constraints and a cultural taboo against women plowing and threshing in Tigray.[26] Consistent with this, female-headed households also are less likely to apply manure or compost and less likely to use contour plowing. Older household heads use more labor, probably because of greater availability of family labor old enough to be involved in crop production. Farmers who have completed three years of education use more labor than uneducated heads.

Social capital also affects land management. Households with members of a village council use more labor per hectare and are more likely to use improved seeds, manure or compost, and intercropping. Such households appear to be more oriented toward intensive crop production than other households.

Crop production. The amounts of seed and ox power used have relatively large and statistically significant positive impacts on production (elasticities of 0.27 and 0.20 in the OLS model) (Table 5.4). By contrast, the impact of human labor is quantitatively small (elasticity = 0.04) and statistically insignificant. This suggests that surplus labor exists in crop production in Tigray, with additional labor yielding little positive impact, although capital and seed inputs are key constraints. This is not surprising, given the very small farm sizes and marginal agricultural conditions in Tigray, and it implies that population growth can have very negative consequences for human welfare because the additional labor may not be productively used in agriculture (Lewis 1954). Of course, as we have seen, population pressure and small farm sizes contribute to adoption of more intensive practices such as use of oxen and fertilizer, which can increase yields. Thus, the negative consequences of population pressure can be mitigated to some extent by such Boserupian responses. We investigate the extent of this mitigation below.

Several land investments and land management practices have large and statistically significant influences on the value of crop production. The predicted value of production is 23 percent higher on plots with stone terraces controlling for labor use, land management practices, and other factors.[27] Use of burning to prepare the field is associated with 29 percent lower yields, and reduced tillage with 45 percent higher yields. Use of fertilizer is associated with 14 percent higher yields, and manure or compost with 13 percent higher yields (both effects statistically significant

Table 5.4 Determinants of value of crop production per hectare, 1998

	ln(Value of crop production/hectare)		
Variable[a]	**OLS[b]**	**IV[b]**	**RF**
ln(Population density/km^2)	–0.013	–0.154	0.016
Female head of household	–0.551***	–0.478**	–0.481***
ln(Age of household head) (years)	–0.148	c	–0.090
ln(Household size) (number)	–0.145*	–0.212*	–0.090
Education of household head			
3+ years	0.139	c	0.235*
Literacy campaign	0.003	c	0.066
Walking time to (hours)			
All-weather road	0.017	c	0.014
Woreda town	–0.056**	–0.028	–0.069***
Plot from residence	0.066	c	0.052
Ownership of assets			
Land (hectares)	–0.009	c	–0.019
Oxen (number)	–0.043	c	–0.035
Other cattle (number)	0.052***	0.014	0.063***
Small ruminants (number)	0.006	c	0.005
Pack animals (number)	–0.046*	c	–0.032
Radio (yes/no)	–0.147*	c	–0.078
Cash savings (yes/no)	0.098	c	0.027
Secondary income source (cf. none)			
Cereals	0.263	c	0.121
Perishable annuals	–0.250	–0.413	–0.337
Perennial crops	0.269*	d	0.199
Cattle	–0.226*	–0.245*	–0.223*
Small ruminants/beekeeping	0.049	c	0.080
Food-for-work/farm employment	0.007	c	0.133
Salary employment	–0.197	c	–0.190
Trading	0.106	c	0.193
Food/other assistance	0.403**	0.319	0.604***
Other nonfarm	–0.016	c	–0.009
Contact with extension	–0.142*	0.104	e
Membership in organizations			
Tabia council	0.435**	d	e
Village council	0.227	c	e
Marketing cooperative	0.342***	0.073	e
Agricultural cadre	–0.130	c	e
Use of credit			
Formal credit	0.067	c	e
Informal credit	–0.067	c	e
Land use (cf. rain-fed plot)			
Homestead plot	0.147**	–0.359	0.425***
Irrigated plot	–0.173	–0.714	0.134
Initial investment on plot			
Stone terrace	0.206***	0.397***	0.163**
Soil bund	0.153	–0.458	–0.100
Fence (live or constructed)	0.083	0.086	0.068

Table 5.4 (continued)

	ln(Value of crop production/hectare)		
Variable[a]	**OLS**[b]	**IV**[b]	**RF**
Use of inputs			
Fertilizer (1 = yes)	0.130*	0.799*	e
Fertilizer × stone terrace	–0.076	–0.804**	e
Fertilizer × soil bund	–0.455***	0.369	e
Fertilizer × irrigation	0.131	0.663	e
ln(Seed/hectare) (kilograms/hectare)	0.268***	0.617***	e
Improved seed (1 = yes)	0.162	0.352	e
ln(Labor/hectare) (days/hectare)	0.040	–0.124	e
ln(Oxen labor/hectare) (days/hectare)	0.199***	0.819*	e
Use of land management practices			
Burning to prepare field	–0.336***	–0.728	e
Contour plowing	0.099	0.276	e
Reduced tillage	0.375***	1.571***	e
Intercropping/mixed cropping	–0.043	–0.048	e
Manure or compost	0.125*	0.628	e
Intercept	18.159***	11.231**	23.124***
Number of observations	1,160	1,020	1,340
R^2	0.4948	0.0735	0.3758

Note: Least-squares regressions. Coefficients and standard errors adjusted for sampling weights, clustering, and stratification.

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent levels, respectively.**

[a]Coefficients of biophysical variables (annual rainfall, altitude, plot slope, position on slope, soil depth, soil color, soil texture, and presence of gullies), plot area and how plot acquired not reported to save space. Full results available on request.

[b]Hausman test failed to reject OLS model (P = 1.000).

[c]Variables jointly statistically insignificant in full version of both OLS and IV models dropped from reported version of IV model.

[d]Variable coefficient not estimable due to multicollinearity. Variable dropped in IV estimation.

[e]Endogenous variable excluded from reduced form.

only at the 10 percent level). Presence of a soil bund reduces the predicted return to fertilizer. This may be because of weed or pest problems caused by the combination of these technologies.

Almost all of these impacts are robust to the regression specification. The impacts of stone terraces, fertilizer, seed, ox labor, and reduced tillage are still statistically and quantitatively significant in the IV model.[28] Stone terraces also have a significant positive impact on crop production in the reduced form specification.

Population pressure and farm sizes have a small and statistically insignificant impact on crop production per hectare in all regressions, even though we found that higher population density and smaller farm size promote greater use of some inputs. Larger households attain lower crop yields (significant at the 10 percent level). These findings do not support the Boserupian optimistic perspective about the responses of households to population pressure leading to increased yields and suggest that food production per capita will not keep pace with increasing population as farm sizes decline because there is very little possibility to expand area under crop production in the densely populated highlands of Tigray. Unless households are able to depend on alternative livelihoods, food insecurity is thus likely to worsen as population continues to grow.

Households with better access to a *woreda* town had higher values of crop production, probably because of greater production of high-value products closer to towns. For example, *teff* (the highest value cereal produced in Tigray) production is negatively correlated with distance to the nearest *woreda* town (correlation = 0.12, 0.6 percent significance level).[29]

Most income strategies have an insignificant impact on crop production. One exception is households dependent on food aid or other assistance, whose yields are surprisingly significantly higher than those of other households. We also find that households dependent on food aid and other assistance have higher incomes per capita than cereals-only households (results for income discussed in the next subsection). These findings may be related to a lack of targeting of food aid in Ethiopia, as has been observed by other authors (Clay, Molla, and Habtewold 1999; Jayne, Strauss, and Yamano 2002; Barrett and Clay 2003; Gebremedhin and Swinton 2003b).

We do not find a statistically significant effect of irrigation on the value of crop production, other factors being equal. However, irrigation increases crop production indirectly by increasing the use of inputs, including labor, oxen, fertilizer, and improved seeds. Below, we estimate the impacts of these indirect effects of irrigation and other factors.

Use of credit (formal or informal) is not associated with significant increases in crop production, even though we found that formal credit promotes use of fertilizer. This is consistent with the fact that our evidence shows only limited impacts of fertilizer on crop production. Contact with the agricultural extension program also has insignificant impact on crop production.

Ownership of cattle other than oxen is associated with higher crop productivity. This may be related to greater deposition of manure on plots operated by households owning more livestock (especially homestead plots).

Female-headed households achieve 42 percent lower crop yields than male-headed households with similar use of labor, ox power, and other inputs. Thus, not only are female-headed households disadvantaged in terms of their ability to apply inputs, but their productivity in using inputs is lower.

Households with members of a marketing cooperative attain substantially higher output value per hectare, probably because they focus on higher-value crops and have more timely availability of inputs. For example, members of marketing cooperatives produce nearly three times as much *teff* (the highest value cereal in Tigray), on average, as nonmembers.

Income. Many of the same factors that affect the value of crop production also affect per capita income (Table 5.5). Households with better access to a *woreda* town earn higher income (significant only in the IV regression), consistent with the result that value of crop production is higher closer to towns. This result is consistent with the findings of Kruseman, Ruben, and Tesfay in Chapter 4 that housing quality (as measured by proportion of households with a metal roof) is better in areas closer to markets. Households with more cattle (other than oxen) earn higher income, whereas female-headed households earn significantly lower income per capita. Members of a marketing cooperative earn significantly higher income than other households (significant only in the OLS regression). Larger households earn less income per capita. Population density, farm size, other assets, and access to credit and extension have statistically insignificant impacts on per capita income.[30]

Households pursuing many types of income strategies earn higher incomes than cereals-only producers. This includes households for whom cereals are a secondary income source and households whose secondary income source is cattle, food-for-work or farm employment, salary employment, trading, other nonfarm activities, and food aid or other assistance. In general, households with secondary income sources earn higher income per capita than those solely dependent on cereal production. The fact that households dependent on food aid or other assistance earn higher incomes (excluding such aid as income) is consistent with the finding discussed above that these households have higher crop yields and with the argument that food aid is not well targeted.

Direct and Indirect Effects on Production and Income

The predicted direct and indirect effects of changes in selected policy-relevant factors on crop production and per capita income are shown in Table 5.6. The factors considered include increase in population density, improved access to an all-weather road or to a *woreda* town, increased education, increased access to extension or formal

Table 5.5 Determinants of per capita income, 1998 (birr)

Variable[a]	OLS	IV	RF
Population density (persons/km^2)	–0.36	–0.36	–0.36
Female head of household	–108.76*	–110.82**	–106.23*
Age of household head (years)	–0.02	b	0.58
Household size (number)	–74.27***	–71.14***	–73.78***
Education of household head (cf. <3 years)			
3+ years	101.15	b	93.70
Literacy campaign	185.11*	173.50	175.5*
Walking time to (hours)			
All weather road	–7.96	b	–9.41
Woreda town	–20.53	–25.83**	–19.76
Plot from residence	59.00	b	66.42
Ownership of assets			
Land (hectares)	24.58	b	21.86
Oxen (number)	6.55	b	3.18
Other cattle (number)	12.48*	18.63**	15.15**
Small ruminants (number)	–0.39	b	–0.50
Pack animals (number)	27.30	b	24.49
Radio (yes/no)	49.55	b	47.38
Cash savings (yes/no)	30.45	b	19.12
Secondary income source (cf. none)			
Cereals	213.10**	272.38***	256.72***
Perishable annuals	–93.50	–99.15	–90.61
Perennial crops	84.36	103.78	85.10
Cattle	127.20**	148.49**	135.16**
Small ruminants/beekeeping	372.22	425.59*	411.00
Food-for-work/farm employment	200.80***	191.54***	202.78***
Salary employment	251.63***	241.93***	267.01***
Trading	149.20*	243.32*	206.37**
Food/other assistance	313.93**	344.18***	327.76**
Other nonfarm	152.63**	178.41***	159.38**
Contact with extension	32.00	b	c
Membership in organizations			
Tabia council	–223.03	b	c
Village council	–64.58	b	c
Marketing cooperative	195.92**	–137.19	c
Agricultural cadre	14.31	b	c
Use of credit			
Formal credit	–13.32	b	c
Informal credit	–38.48	b	c
Land use (cf. rain-fed plots) (proportion of area)			
Homestead plots	–28.15	–57.74	–33.39
Irrigated plots	151.72	229.14	194.61
Initial investment on plot in 1998 (proportion of area)			
Stone terrace	93.10	89.32	93.72
Soil bund	73.16	76.09	89.23
Fence (live or constructed)	–107.32	–39.94	–94.29
Intercept	662.32*	851.47***	658.51**

Table 5.5 (continued)

Variable[a]	OLS	IV	RF
Number of observations	436	425	436
R^2	0.2604	0.2129	0.2445

Note: Least squares regressions. Coefficients and standard errors adjusted for sampling weights, clustering, and stratification. The Hausman test result was inconclusive (negative test statistic).

***, **, *** mean coefficient is statistically significant at 10 percent, 5 percent, and 1 percent levels, respectively.**

[a]Coefficients of biophysical variables (annual rainfall, altitude, plot slope, position on slope, soil depth, soil color, soil texture, and presence of gullies); how plot acquired not reported to save space. Full results available upon request.

[b]Variables jointly statistically insignificant in full version of both OLS and IV models dropped from reported IV model.

[c]Endogenous variable excluded from reduced form.

credit, increased participation in marketing cooperatives, investment in irrigation or stone terraces, or increased ox or cattle ownership.

Participation in marketing cooperatives has the largest predicted impacts on both crop production and income, increasing both by more than 40 percent. Investment in stone terraces also has relatively large and positive predicted impacts on both crop production and income (around 14 percent), though the impacts on income are statistically insignificant. Improved access to a *woreda* town (by up to one hour walking time) is predicted to increase both the value of crop production and income by about 5–6 percent. Increased ownership of cattle (by one cow) also is predicted to increase crop production and income moderately. All of these scenarios represent possible "win-win" outcomes, increasing both productivity and incomes.

Many of the changes considered have relatively small (less than 5 percent change) and statistically insignificant predicted quantitative effects on crop production and income. This includes the influences of population growth (10 persons/km^2 increase), improved access to an all-weather road (up to one hour closer), universal access to formal credit, and increased ox ownership (by one ox). Some of the changes have quantitatively large but statistically insignificant effects, including investment in primary education (large positive influences on both crop production and income), extension (negative effect on crop production but positive effect on income), and irrigation (small effect on crop production but large influence on income). However, given the statistical insignificance of the coefficients on which these predicted influences are based, not too much should be made of their magnitudes.

These results suggest that the most promising investments for increasing agricultural productivity and incomes in the highlands of rural Tigray are in marketing institutions, improved access to markets, in soil and water conservation measures such as stone terraces, and in cattle (other than oxen). Investments in roads, extension,

Table 5.6 Simulated impacts of changes in selected variables on value of crop production and per capita income

Variable	Scenario	Mean of selected variable		Value of crop production (plot level) (percentage)		Per capita income (percentage)	
		Before change	After change	Direct effects	Total effects	Direct effects	Total effects
Population density (persons/km^2)	10 persons/km^2 increase	137	147	–0.1	+0.4	–1.0	–1.1
Access to all-weather road (hours walking)	Maximum 1 hour closer	2.3	1.3	–1.4	–1.2	+1.7	+2.8
Access to market town (hours walking)	Maximum 1 hour closer	3.5	2.5	+5.5**	+6.8R	+5.3++	+5.6
Primary education (proportion of household heads)	Minimum 3 years for household heads with less	0.06	0.92	+12.0	+17.6	+23.4	+23.4
Access to extension (proportion of household)	Universal access	0.11	1.00	–11.1*	–14.0	+7.6	+7.6
Access to formal credit (proportion of household)	Universal access	0.58	1.00	+2.0	+3.9	–1.5	–1.5
Participation in marketing cooperative (proportion of household)	Universal participation	0.06	1.00	+33.7***	+45.5	+48.7**	+48.7
Irrigation (proportion of plots)	All rain-fed plots irrigated	0.07	0.80	–10.7	–1.2	+25.8	+19.0
Stone terraces (proportion of plots)	All plots terraced	0.37	1.00	+13.6***+++	+13.8R	+14.5	+14.5
Oxen ownership (number owned)	1 additional ox owned	1.1	2.1	–4.2	–2.4	+1.8	+1.8
Other cattle ownership (number owned)	1 additional animal owned	2.7	3.7	+5.4***+	+6.2R	+3.3*++	+3.3R

Note: Values are percentage change in mean predicted values. Simulation results for direct effects based on predictions from OLS model regressions reported in Tables 5.4 and 5.5. Results of OLS and probit regressions predicting input use and land management practices were used to predict indirect effects on crop production. Results of probit regressions for determinants of use of credit, participation in extension, and organizations used to predict indirect effects on income.

***, **, *** mean direct effect is based on a coefficient that is statistically significant in the OLS regression at 10 percent, 5 percent, or 1 percent level, respectively.**

+, ++, +++ and –, ––, ––– mean direct effect is of the sign shown and statistically significant in the IV regression at 10 percent, 5 percent, or 1 percent level, respectively.

R Coefficient is of the same sign and statistically significant at 5 percent level in the reduced form regression.

and credit are of less clear benefit. The effects of education may be large and positive, though we cannot be confident of its influence based on our results.

Key Findings and Implications

Here we summarize key findings with regard to our hypotheses and their implications. The qualitative findings are summarized in Table 5.7.

Population Pressure

Population pressure, as reflected by higher population density, is associated with more intensive use of labor, ox power, fertilizer, and intercropping. Smaller farms are also more likely to use fertilizer on a given plot and less likely to use reduced tillage. These findings are consistent with the predictions of population-induced intensification, as hypothesized by Boserup (1965) and her followers. However, increased farming intensity in more densely populated areas was not found to lead to significantly higher crop yields. In addition, population pressure at the household level, in terms of larger household size, is associated with lower yields and lower income per capita. These findings suggest that population growth, larger households, and smaller farm sizes will lead to reduced food production and income per capita because options for expanding crop production onto new land are very limited in the highlands of Tigray. The negative implications of population pressure are consistent with findings of other recent studies in the Ethiopian highlands (Grepperud 1996; Pender et al. 2001a).

Access to Roads and Markets

Better access to an all-weather road contributes to more intensive use of labor, fertilizer, burning, and contour plowing. However, we find little impact of better road access on the value of crop production or income. This probably is because even in areas with relatively better road access, most households are still quite far from roads and rely primarily on walking and donkeys to transport commodities and inputs. The impacts of improved road access are quite limited in such a setting.

Households with better access to a *woreda* town use more ox draft power but less contour plowing and obtain higher values of crop production and higher per capita income than households in more remote locations (though impact on per capita income was significant only in IV regression). In contrast to road access, access to even small urban markets makes a difference for rural livelihoods.

Income Strategies

As expected, different income strategies are associated with differences in input use and land management practices. For example, households having several types of

Table 5.7 Summary of qualitative empirical results

Factor	Labor intensity	Capital intensity (oxen, purchased inputs)	Land management practices	Value of crop production	Per capita income
Population pressure					
Population density	+	+ oxen, fertilizer	+ intercropping	0	0
Smaller farm size	0	+ fertilizer	– reduced tillage	0	0
Household size	0	0	0	0	–
Access to roads	+	+ fertilizer	+ burning, contour plowing	0	0
Access to markets	0	+ oxen	– contour plowing	+	0
Income strategies					
Cattle	–	– oxen	– burning	0	+
Nonfarm	0	– oxen	+ reduced tillage	0	+
High-value crops	0	+ improved seeds	+ reduced tillage	0	0
Food-for-work/farm work	–	– oxen, + improved seeds	0	0	+
Food/other aid	0	– oxen	– manure, burning, intercropping	+	+
Irrigation	+	+ oxen, improved seed	+ reduced tillage	0	0
Credit	0	+ improved seed	0	0	0
Extension	0	0	0	0	0
Physical capital	0				
Oxen	+	+ oxen	+ manure, contour plowing, – reduced tillage	0	0
Other cattle	0	+ seeds, fertilizer	+ burning	+	+
Small ruminants	–	– oxen, seeds	–burning, intercropping	0	0
Human capital					
Primary education	+	0	0	0	0
Female head	–	– oxen	– manure	–	–
Financial capital (savings)	0	+ fertilizer	– manure	0	0
Natural capital					
Stone terrace	0	+ fertilizer	+ contour plowing	+	0
Soil bund	0	0	+ burning	0	0
Social capital					
Village council	+	+ improved seed	+ manure, intercropping	0	0
Marketing cooperative	0	0	– burning	+	0

Note: + Positive (– negative) and statistically significant impact (5 percent level) in at least one specification and significant at 10 percent level in two specifications. 0 impact not statistically significant and robust.

noncrop income use labor and ox draft power less intensively than cereals-only producers, whereas producers of perennials and perishable annuals are more likely to use improved seeds. Despite such differences in cropping practices, we find no significant difference among most income strategies in value of crop production, except (surprisingly) households dependent on food aid and other assistance, which have higher crop production. These aid-dependent households also earn higher income per capita than cereals-only households (suggesting lack of targeting of food aid and other assistance), as do households pursuing many other income strategies. In general, households with more diversified income sources have higher incomes per capita.

Irrigation

As expected, irrigation increases the intensity of input use in crop production, including labor, ox power, fertilizer, and improved seeds. Surprisingly, however, we do not find that irrigation contributes to higher value of crop production or income, even after accounting for the indirect effects of increased intensity of production. There are many problems affecting the performance of small-scale irrigation in Tigray, including problems of inadequate access to irrigation water when needed, salinity buildup as a result of seepage and poor drainage, lack of experience in using irrigation, and other factors (Tesfay et al. 2000). These problems are certainly limiting the potential of small-scale irrigation in Tigray. But our inability to identify an independent effect of irrigation may also be caused by multicollinearity and an inadequate sample of irrigated plots.[31] We have a relatively small sample of irrigated plots in our sample (91 plots), and irrigation is correlated with other plot quality factors, especially plot size. Further research on the influence of small-scale irrigation in Tigray and the policy, institutional, and technical factors affecting its effectiveness, is needed.

Agricultural Extension and Credit

The agricultural extension and credit program has sought to boost productivity largely by promoting use of fertilizer and improved seeds. The evidence presented shows some influence of fertilizer use on crop production (though the impact is statistically weak and not robust), increasing predicted value of production by 250 EB/hectare on average, other factors remaining constant. This yield increase is insufficient to cover the average costs of fertilizer (about 280 EB/hectare in 1998), indicating that fertilizer use was unprofitable on average and explaining why farmers are reluctant to adopt it, despite substantial efforts to promote its use. In a semiarid environment as in the highlands of Tigray, use of fertilizer can be risky as well as unprofitable if adequate soil moisture cannot be assured. Given the heavy emphasis of the agricultural extension and credit program on promoting fertilizer use at the time of the study, it is not surprising that these programs were found to have little influence on crop production and income.

Although the return to fertilizer is low, there are indigenous technologies with potential to substantially increase crop yields. Stone terraces increase crop productivity by an estimated 23 percent. Because stone terraces help to conserve soil moisture, they also increase the benefit of using fertilizer, which is probably why we find more fertilizer adoption on plots that have stone terraces. The estimated average rate of return to stone terraces is 46 percent, based on the predicted increase in annual value of crop production and our data on costs of constructing these terraces. This is comparable to the estimated rate of return to stone terraces in south central Tigray by Gebremedhin, Swinton, and Tilahun (1999), who estimated a 50 percent rate of return to stone terraces, and shows that investment in stone terraces is fairly profitable in Tigray. Several other low external input land management practices, including application of manure and compost, reduced tillage, and no burning also could have substantial impacts on crop productivity. Promotion of such technologies by the extension program could yield greater benefits than the emphasis on fertilizer and improved seeds.

Endowments of Physical, Human, and Social Capital

Livestock ownership significantly influences land management. Households that own more oxen use more ox draft power, are more likely to use contour plowing and to apply manure, and are less likely to use reduced tillage. Despite these differences, we find no significant differences in crop production or income per capita resulting from differences in ox ownership, suggesting that informal arrangements to share or lease oxen work relatively well in Tigray. Thus, although ox draft power is a critical component of the farming system in northern Ethiopia (some argue it is the most critical component), and most households are not able to own as many oxen as desired (Bauer 1977; Amare 1995, 2003; McCann 1995), many households are able to overcome this constraint through ox-sharing arrangements, especially between households owning only one ox (e.g., Amare 1995), and households without any oxen will often sharecrop out their land. Ownership of other cattle is associated with greater use of seed and fertilizer, perhaps because this helps to relax financial constraints. Households with more cattle (other than oxen) obtain higher yields and incomes, supporting Aune's (Chapter 12 of this volume) argument that milking animals are more profitable than oxen in the highlands of Ethiopia. Ownership of small ruminants appears to reduce intensity of crop production; small ruminants are associated with less use of labor, ox power, burning, and intercropping.

Primary education is associated with more intensive use of labor, though the reason for this is not clear. We find generally insignificant impacts of education on other aspects of land management, crop yields, and income, probably because of the generally low levels of education among all households in the sample. By contrast, gender is very important in affecting land management and outcomes. Female-headed households use much less labor and ox power, are less likely to apply manure, and obtain substantially lower crop yields and incomes than male-headed households. A cultural taboo against women using oxen for plowing is one factor disadvantaging female-headed households. Moreover, women are not usually included in agricultural extension programs. Priority should be given to promoting changes in such attitudes as well as assisting female-headed households to pursue alternative livelihoods.

Some forms of social capital, as measured by involvement in local organizations, have a significant influence on crop production. Members of a village council farm with greater labor intensity and are more likely to use improved seeds, manure, and intercropping than other households. Members of a marketing cooperative use less burning and attain substantially higher value of crop production per hectare, probably because they focus on producing higher-value crops and/or have better access to input and output markets than other farmers.

Conclusions

We have investigated the impacts of many factors commonly hypothesized to affect land management and agricultural productivity in the highlands of Tigray. Some of these factors, including population pressure, small landholdings, access to roads, irrigation, and extension and credit programs, have weaker influences on agricultural production and incomes than often hypothesized. Most of these factors do affect the intensity of agricultural production and adoption of various land management practices. However, these effects on intensity do not add up to much influence on total crop production, in part because of the low marginal product of labor in crop production and limited productivity effect of inputs such as fertilizer that have been promoted by some of these factors.

Some land management practices were found to substantially increase crop production, including construction of stone terraces, reduced burning, and reduced tillage. These practices possibly contribute to productivity by helping to conserve soil moisture and organic matter. Greater ownership of cattle (other than oxen) is also strongly associated with increased crop productivity, probably as a result of increased manure availability, and higher income. Promotion of such conservation practices and exploitation of complementary livestock production show more promise to boost crop production and incomes than large application of modern inputs such as inorganic fertilizer and improved seeds. However, there do appear to be opportunities to exploit complementarities between use of such inputs (especially fertilizer) and investment in stone terraces.

Livelihood diversification is a key to reducing poverty in the highlands of Tigray because of population pressure and the low productivity of land. Households that focus only on cereal production earn significantly lower incomes than households having more diversified income sources, including livestock, off-farm employment, and nonfarm activities.

Special attention to the problems of female-headed households is needed. Efforts to change attitudes about women plowing, enhance their farming skills, and to promote alternative livelihoods for women are needed to address the low levels of agricultural productivity and income of this vulnerable group.

Overall, the findings of this study show that profitable opportunities exist to increase agricultural production and incomes and to achieve more sustainable land management in the highlands of Tigray. These opportunities include improvement of crop production using low-external-input investments and practices such as terraces, reduced tillage, and reduced burning and improved livestock management. The comparative advantage of people in the Tigray highlands appears not to be in input-intensive cereal crop production but more in low-external-input technologies and alternative livelihood activities, such as livestock raising and nonfarm activities. As a result, greater emphasis on developing these alternatives in agricultural extension and other development programs is needed. Food crop production should not be ignored in the development strategy, especially if more drought-resistant varieties can be developed, but more prudent use of external inputs such as fertilizer and improved seeds, and greater emphasis on low-external-input sustainable land management practices would be helpful.

Notes

1. There is considerable variation in estimates of the size and impacts of soil erosion and other forms of land degradation in the Ethiopian highlands, causing controversy about the exact magnitude of these impacts (FAO 1986; Hurni 1988; Hurni and Perich 1992; Sutcliffe 1993; Böjo and Cassells 1995; Kappel 1996; Sonneveld 2002). For example, the Ethiopian Highlands Reclamation Study (FAO 1986) estimated an average rate of soil loss of 35 tons per hectare per year in the highlands, with much higher rates on cultivated land (130 tons/hectare per year), leading to a predicted loss of 7.6 million hectares of productive cropland and a loss of 2.6 million tons of annual crop production by the year 2010. Hurni (1988) estimated much lower rates of soil erosion, averaging 42 tons/hectare per year on cropland but reaching as high as 300 tons/hectare per year on some steeply sloping lands, based on measurements of soil erosion taken at several sites throughout the highlands under the Soil Conservation Research Project (SCRP). Studies in specific locations in

Tigray have also estimated high average but widely varying rates of erosion (Eweg, van Lammeren, and Yifter 1997; Hengsdijk, Meijerink, and Mosugu 2005) and soil nutrient depletion (Abegaz 2005). Hurni and Perich (1992) estimated that Tigray's soils have lost 30–50 perecnt of their original productive capacity as a result of land degradation. Subsequent studies have argued that both FAO's and Hurni's estimates overstate the impact of soil erosion because they do not account for deposition of eroded soils elsewhere in the landscape (Sutcliffe 1993; Böjo and Cassells 1995). Based on assumptions about the amount of soil deposition and the influence of net soil loss on productivity, Böjo and Cassells estimated the cumulative gross discounted economic losses caused by soil erosion in the Ethiopian highlands to be between EB 3 billion and EB 7 billion, and Kappel (1996) estimated these losses to be somewhat larger ($1.25 billion). Considering the value of soil nutrients lost via burning of dung and crop residues, Böjo and Cassells estimated that the discounted economic losses through nutrient depletion were even greater than those from erosion (EB 8 billion). Regardless of the variation in estimates, there seems little dispute that land degradation and its costs are severe in many locations in the Ethiopian highlands, though these vary greatly across locations and land uses (Keeley and Scoones 2004; Nyssen et al. 2004).

2. Highlands were defined to include areas at or above 1,500 meters above sea level.

3. This empirical model is based on a theoretical dynamic household model that is presented in Nkonya et al. (2004).

4. In the econometric work, we use dummy variables for whether the household applied fertilizer or improved seeds, rather than the quantities of these inputs, because of zero values of these inputs for many households, making it difficult to account for the amount of use in a logarithmic production function as estimated in this chapter.

5. We did not estimate separate production functions for each crop produced in order to simplify the analysis because that would result in much smaller sample sizes for each crop (hence reduced statistical power) and because intercropping or mixed cropping cannot be modeled with single-output production functions. The revenue function is an aggregation of production and local price functions and hence depends on the variables that influence both production and prices. That is, if production of crop i on plot p depends on a vector of inputs and biophysical conditions (X_p) according to the production function $f_i(X_p)$, and the farm level price of crop i depends on a vector of conditions related to market access and household-level transaction costs and marketing abilities (Z_h) according to the relationship $p_i(Z_h)$, then revenue from plot p of household h is equal to $\Sigma p_i(Z_h) f_i(X_p)$, which we define as the revenue function $y(Z_h, X_p)$.

6. If labor effort and other inputs are measured perfectly, these effects would be reflected in the effects of these inputs on production. However, if they are measured imperfectly, tenure may have a greater influence on productivity.

7. Fewer than 3 perecnt of households in our sample changed their primary source of income between 1991 and 1998, and only one-fifth changed their secondary income source.

8. We do not include other, more variable factors such as ownership of physical assets as determinants of participation in programs or use of credit because these may not be predetermined relative to decisions about participation or credit use, which may have occurred before the current year.

9. For example, in the income regression, we use share of farmland of different tenure, slope, and soil type classes.

10. Members of agricultural cadres are supposed to be innovative farmers who are contact farmers for technical assistance programs.

11. Pasture, woodlots, and fallow plots were excluded from the analysis.

12. Except where noted, the results discussed below are statistically significant at the 5 percent level in at least two of the specifications.

13. Normal IV estimation requires a continuous uncensored dependent variable, which we do not have in the case of the land management regressions. Instrumental variables estimation approaches have been developed for probit models (e.g., Smith and Blundell 1986; Blundell and Smith 1989), but these approaches assume that the endogenous explanatory variables are continuous uncensored variables, or that they are continuous, uncensored latent variables (Maddala 1983). Neither assumption holds in our models.

14. These regression results are available on request.

15. The maximum variance inflation factor was less than five in all cases (except when predicted values of explanatory variables were used, in which case multicollinearity was a problem).

16. The method used to predict direct and indirect influences is explained fully in Nkonya et al. (2004).

17. As a result of the predominant *risti* land tenure system that existed in northern Ethiopia before the 1975 land reform (which also involved periodic land redistribution and prohibited land sales and mortgages), land ownership was not greatly unequal in most places even before 1975 (Bruce, Hoben, and Rahmato 1994).

18. The official exchange rate averaged about 7 EB per U.S. dollar in 1998.

19. Remittance income from family members residing elsewhere accounted for less than 1 percent of household income of our sample households. This is consistent with Bauer's (1977) description of a high degree of individualism in Tigray society.

20. In Tigray, adults are required to contribute 20 days per year to community labor mass-mobilization campaigns, which are used to construct conservation measures, plant trees, build roads, and for other activities (Hagos, Pender, and Gebreselassie 1999). During the 1980s up to four months of such labor contribution was expected, but this was reduced to 20 days in 1992 (Hagos, Pender, and Gebreselassie 1999).

21. To compute the value of production, we used average prices in Tigray based on community- and household-level surveys. We were not able to compute value of production using local prices because of a limited number of observations for many crops. Thus, the data represent a weighted production index, where regional prices are used to weight production of different crops and do not reflect local variation in prices.

22. In Chapter 4, Kruseman, Ruben, and Tesfay found that higher population density is associated with a greater proportion of households who use fertilizer and pesticides and a smaller proportion who use fallow.

23. Kruseman, Ruben, and Tesfay found a positive impact of road access on fertilizer use in Chapter 4.

24. This contrasts with the results in Chapter 4, in which the presence of irrigation institutions was positively but not significantly correlated with the proportion of households using inputs such as fertilizer and improved seeds; this may reflect weaker statistical power of community survey results to explain household- and plot-level technology adoption.

25. Again, the relationship between formal credit and use of fertilizer and improved seed was positive but not statistically significant in Chapter 4.

26. The prohibition against women plowing and threshing is a long-standing one that, according to Bauer (1977), is based on "an indigenous theory that their participation in these activities would decrease the amount of crops produced" (Bauer 1977, p. 98). These attitudes may be changing in Tigray as some female-headed households have had the need and courage to challenge such

norms, though this can be difficult, and such women may be subject to ridicule or intimidation (Abay et al. 2001).

27. Because of the logarithmic specification for the dependent variable, the predicted impact of stone terraces using the OLS specification is exp(0.206) = 1.229, or a 23 percent increase.

28. The Hausman test failed to reject the OLS model (*P* = 1.000), so the OLS model is the preferred model.

29. In Chapter 4, Kruseman, Ruben, and Tesfay also found greater production of *teff* closer to markets.

30. These results contrast with the findings of Kruseman, Ruben, and Tesfay in Chapter 4 that higher population density is associated with better housing quality. That finding may reflect the influence of household-level variables that are correlated with income and wealth and may also be correlated with population density, such as education, which are included as explanatory variables in our analysis but were not controlled for in their analysis. Consistent with this explanation, Kruseman, Ruben, and Tesfay found that indicators of education were greater in more densely populated communities.

31. Recall that the value of crop production per hectare was much higher on irrigated plots than on rain-fed or homestead plots in our descriptive analysis. Such differences are not found in the econometric analysis when plot size and land quality indicators are included.

Chapter 6

Policies for Livestock Development in the Ethiopian Highlands

Samuel Benin, Simeon Ehui, and John Pender

Livestock have diverse functions for the livelihood of farmers in mixed crop-livestock systems in the highlands of East Africa. Livestock provide food in the form of meat and milk, nonfood items such as draft power, manure, and transport services as inputs into food crop production, and fuel for cooking. Livestock are also a source of cash income through sale of the above items, animals, hides, and skins. Furthermore, they act as a store of wealth and determine social status within the community. Because of these important functions, livestock play an important role in improving food security and alleviating poverty. Because they are central to nutrient cycling, livestock are important to the efficiency, stability, and sustainability of farming systems in the East African highlands (Ehui et al. 1998). The International Livestock Research Institute (ILRI) and its partners and collaborators have shown that securing the current and future livestock assets of the poor is a major pathway to get the rural poor out of the poverty spiral (ILRI 2002).

In Ethiopia, livestock contribute about 30 to 35 percent of agricultural gross domestic product (GDP) and more than 85 percent of farm cash income. They also contribute about 13 to 16 percent of total GDP. Between 1987–88 and 1995–96, the share of livestock in total exports averaged 16 percent (Degefe and Nega 2000).[1] Ethiopia has the largest livestock population in Africa, which potentially plays an important role in improving food security and alleviating poverty in the region as a whole and in Ethiopia in particular. However, performance in the production of the main food commodities of livestock origin in Ethiopia has been poor compared to other African countries, including neighboring Kenya (Degefe and Nega 2000). Inadequate feed and nutrition, widespread diseases and poor health, poor breeding stock, and inadequate livestock policies with respect to credit, extension, marketing, and infrastructure have been cited as major constraints affecting livestock performance (Degefe and Nega 2000; Desta et al. 2000), leading to severe losses in times of drought (Webb, von Braun, and Yohannes 1992; Ndikumana et al. 2000).

In 1991, when the present federal government of Ethiopia came to power, it launched, in addition to market liberalization, the Agricultural Development Led Industrialization (ADLI) strategy to improve the productivity of the agricultural sector within the framework of transforming the entire economy such that the relative contributions of agriculture, industry, and services to economic growth would shift significantly in favor of the latter two over time. Improving the livestock subsector is duly recognized, as the development strategy seeks to (1) enhance the quality and quantity of feed by allocating sites for grazing, providing improved animal feed, and improving extension services to farmers; (2) increase livestock health service coverage and improve vaccination sites; and (3) improve productivity of local cows by artificial insemination but also preserve and improve indigenous breeds (BOA 1999a).

From a survey conducted in 1999 and 2000 in the highlands of the Amhara region in northern Ethiopia to examine the development of the livestock subsector since 1991, when ADLI was launched, we find that there have been significant changes in utilization of feed resources: although use of communal grazing lands, private pastures, woodlots, and forest areas as feed sources has declined, use of crop residues and purchased feed has increased. In addition, availability and quality of grazing lands have declined. Furthermore, as use of animal health services and adoption of improved livestock breeds and modern management practices (e.g., artificial insemination, stall feeding, and fattening) have increased, ownership of various types of livestock has declined. These changes may not be a matter of concern if they resulted from the rapid expansion of the crop sector or nonfarm sector to make farmers better off. However, data from the same survey and another one conducted in the Tigray region show that there has been little change in livelihood strategies in the northern Ethiopian highlands. Agricultural and crop-livestock production continue to dominate income sources, and several welfare conditions (including average wealth, availability of food, and nutrition of children) have worsened since 1991 (Pender et al. 2001a). The contribution of agriculture to the national economy has remained fairly stable: its share of GDP averaged 53 percent between 1980 and 1991 and 51 percent between 1991 and 1998 (Degefe and Nega 2000), and it employed 86 percent and 82 percent of the labor force in 1990 and 2000, respectively (FAO 2002). Average cereal yield was stagnant, and the incidence of poverty declined only slightly (4.4 percent) in rural areas between 1995 and 2000 (Woldehanna and Alemu 2002).[2] On the other hand, other changes in the national political economy during that period, including, for example, the implementation of the massive agricultural package program leading to substantial increases in the cultivated area under chemical fertilizers and improved seeds, continuing the policy of land redistribution especially in the Amhara region (see Chapter 9 for further discussion), the recurrent drought situation, and rapid population growth, may have affected farm-livestock dynamics and livestock investment decisions and caused the observed changes in the livestock subsector.

The objective of this chapter is to determine the factors that have contributed to the above changes in the livestock subsector in the mixed crop–livestock farming systems in the Ethiopian highlands in order to increase our knowledge of the effect of changes in the socioeconomic and policy environment on livestock keeping and provide information for policy discussions on the use of livestock to get rural people out of the poverty trap. This chapter focuses on the effects on livestock development of similar factors to those considered in Chapters 3, 4, and 5—including agricultural potential, market access, population pressure, and credit—as well as other factors, such as land tenure policies. However, this chapter is significantly different from other chapters in this book in focusing mainly on livestock development and taking a dynamic perspective, considering factors affecting changes in livestock ownership and use of various management practices and technologies. Thus, this chapter is complementary to other chapters in the book, adding a substantially different dimension.

The rest of this chapter is organized as follows. The next section describes the data and then examines trends since 1991 in ownership of various types of livestock, use of livestock feed resources and animal health services, and adoption of improved breeds and modern management practices. The third section presents the empirical framework for analyzing the factors contributing to the trends. Results and discussion are presented in the fourth section, and conclusions and implications are drawn in the fifth.

Data

This research is based on a community-level survey conducted in 98 villages in the Amhara region of northern Ethiopia in 1999–2000, very similar to the community survey conducted in Tigray that was analyzed in Chapter 4. A stratified random sample of 49 peasant associations (PAs)[3] was taken, and two villages were randomly selected from each PA from highland areas (above 1,500 meters above sea level) of the region. Using *woreda* (district) level secondary data, the stratification was based on indicators of agricultural potential (whether or not the *woreda* is drought-prone, as classified by the Ethiopian Disaster Prevention and Preparedness Committee), market access (access or no access to an all-weather road), and population density (1994 rural population density greater than or less than 100 persons per square kilometer). Two additional strata were defined for PAs where an irrigation project is present (in drought-prone vs. higher-rainfall areas), resulting in a total of 10 strata. Five PAs were then randomly selected from each stratum (except the irrigated drought-prone stratum, in which there were only four PAs), for a total of 49 PAs and 98 villages. *Woredas* predominantly (more than 50 pecent of total area) below 1,500 meters above sea level were excluded from the sample frame.

Information was collected at both PA and village levels using group interviews with about 10 respondents from each PA and village, selected to represent different genders, ages, occupations, and, in the PA-level survey, different villages. Information collected include perceived changes in use of various feed resources, adoption of improved livestock technologies and management practices, and ownership of livestock since 1991 (the year when the current government replaced the former Marxist government). The data were supplemented by secondary information on population from the 1994 population census, geo-referenced maps of the boundaries of each sample PA, and geographic attributes, including altitude and climate.

Trends since 1991 in the Livestock Subsector in Amhara Region

The Amhara region is located in the northwestern part of Ethiopia. The region covers about one-eighth of the total area of the country and is home to about 27 percent of the total human population (Degefe and Nega 2000) and 35 percent of the total livestock population (BoA 1999b).[4] In the region, livestock and human populations are concentrated in the highland areas, which constitute about 66 percent of the total area (BoA 1999b). Historically, human and livestock settlements have concentrated in the highland areas, especially in the range of 2,300–3,200 meters above sea level (*dega* agroecological zone), because of the relatively good rainfall reliability, cool temperatures, and absence of diseases (e.g., malaria and trypanosomosis).

From the survey conducted in the region, household ownership of livestock has generally declined between 1991 and 1999, with the percentage decrease being larger in drought-prone areas compared to higher-rainfall areas (Table 6.1). The only exception to the declining trend is ownership of donkeys, which increased only slightly, particularly in higher-rainfall areas. Community respondents revealed that a combination of loss to drought and diseases and sale during crop failure were the major causes for the declining ownership of livestock. Recurrent drought (late rains or failure of main and small rains) is a common phenomenon in Ethiopia, especially in the central and northeastern highlands, stretching from northern Shewa

Table 6.1 Proportion of households owning livestock, by agricultural potential

Livestock	Location	Sample mean 1991	Sample mean 1999	Percentage change
Oxen	All communities	0.73	0.59	–19
	Drought-prone areas	0.71	0.41	–42
	Higher-rainfall areas	0.75	0.73	–3
Cows	All communities	0.46	0.30	–35
	Drought-prone areas	0.50	0.28	–44
	Higher-rainfall areas	0.43	0.31	–28
Heifers	All communities	0.34	0.20	–41
	Drought-prone areas	0.35	0.16	–54
	Higher-rainfall areas	0.33	0.22	–33
Bulls	All communities	0.33	0.18	–46
	Drought-prone areas	0.37	0.15	–60
	Higher-rainfall areas	0.29	0.20	–31
Calves	All communities	0.35	0.20	–43
	Drought-prone areas	0.39	0.17	–56
	Higher-rainfall areas	0.32	0.22	–31
Sheep	All communities	0.38	0.25	–34
	Drought-prone areas	0.47	0.21	–55
	Higher-rainfall areas	0.31	0.28	–10
Goats	All communities	0.28	0.15	–46
	Drought-prone areas	0.36	0.13	–64
	Higher-rainfall areas	0.22	0.16	–27
Donkeys	All communities	0.32	0.36	13
	Drought-prone areas	0.33	0.32	–3
	Higher-rainfall areas	0.31	0.40	29
Horses	All communities	0.09	0.08	–11
	Drought-prone areas	0.10	0.05	–50
	Higher-rainfall areas	0.09	0.10	11
Mules	All communities	0.08	0.05	–38
	Drought-prone areas	0.12	0.07	–42
	Higher-rainfall areas	0.05	0.04	–20
Poultry	All communities	0.61	0.56	–8
	Drought-prone areas	0.80	0.70	–13
	Higher-rainfall areas	0.48	0.47	–2

Note: Sample means are adjusted for stratification, weighting, and clustering of sample.

through Wello into Tigray, and low-lying areas in the southern and southwestern parts, leading to severe food shortage and loss of livestock (Webb, von Braun, and Yohannes 1992). For example, during the 1971–75 drought period, which resulted from a sequence of rain failures, it was estimated that 50 percent of livestock in Wello and Tigray areas alone were lost (Webb, von Braun, and Yohannes 1992). The drought of 1984–85 and the recent one in 2003 have had even greater devastating effects (Webb, von Braun, and Yohannes 1992; FDRE 2003).

With the exception of purchased feed[5] and crop residues, use of other sources of fodder (communal grazing lands, woodlots, forests, homestead [e.g., prickly pear], and private pastures) declined between 1991 and 1999, and the decline was larger in higher-rainfall areas (Table 6.2). The increase in use of crop residues was greater in higher-rainfall areas, whereas the increase in use of purchased feed was greater in drought-prone areas, with the proportion of households buying feed being about three times larger in drought-prone areas (Table 6.3). Consistent with the decline in use of communal grazing lands is the perception that both availability and quality have been declining.

Community respondents revealed that use of grazing lands for cropping, settlement, and other nongrazing activities as a result of increasing population pressure has contributed to the decline in availability of grazing lands. Although the highlands account for about 45 percent of the total area of the country, they are home to about 80 percent of the total human population (Degefe and Nega 2000). Rapid population growth (averaging 2.7 percent for the whole country between 1993 and 2001) (FAO 2002) is increasing the demand for farmland and contributing to farming in traditional grazing areas such as hillsides. Restrictions on use of communal resources (e.g., grazing lands, woodlots, and forest areas) for fodder have also contributed to the declining use of these resources. Similar restrictions in use of communal resources are also found in Tigray (Chapter 10). Grazing lands managed at the village level, compared to those managed at the PA level, are more likely to have imposed grazing restrictions (e.g., grazing at certain times of the year only

Table 6.2 Perceived changes since 1991 in use of feed resources and availability and quality of grazing lands, by agricultural potential

	Sample mean		
Resources	**All communities**	**Drought-prone areas**	**Higher-rainfall areas**
Feed sources			
Communal grazing lands	–0.41	–0.31	–0.49
Area enclosures	–0.02	–0.04	0.00
Woodlots and forests	–0.11	–0.02	–0.17
Private pastures	–0.28	–0.28	–0.29
Crop residues	0.60	0.29	0.83
Homestead (e.g., prickly pear)	–0.05	0.15	–0.19
Purchased feed	0.30	0.52	0.15
Availability of grazing land	–0.75	–0.78	–0.72
Quality of grazing land	–1.18	–1.15	–1.20

Note: Change is an ordinal indicator of perception, where –2 = decreased significantly, –1 = decreased slightly, 0 = no change, +1 = increased slightly, +2 = increased significantly. Sample means are adjusted for stratification, weighting, and clustering of sample.

Table 6.3 Proportion of households buying feed and using animal health services, by agricultural potential

		Sample mean		
Assistance	Location	1991	1999	Percentage change
Purchased feed	All communities	0.19	0.25	32
	Drought-prone areas	0.28	0.41	46
	Higher-rainfall areas	0.12	0.13	8
Animal health services	All communities	0.33	0.55	67
	Drought-prone areas	0.23	0.49	113
	Higher-rainfall areas	0.40	0.60	50

Note: Sample means are adjusted for stratification, weighting, and clustering of sample.

and/or certain animals only) and for those restrictions to be enforced. With respect to the decline in use of private pastures, about 45 percent of the communities reported conversion of private pastures into cropland because of shortage of farmland. With the other sources of feed on the decline, crop residues and purchased feed have tended to be used more.

Use of animal health services (vaccine and treatment) and adoption of improved breeds (especially of cattle and small ruminants) and modern management practices (artificial insemination, stall feeding, and fattening) have increased since 1991 (Tables 6.3 and 6.4). The proportion of households using health services increased by almost twofold between 1991 and 1999. Although the proportion of households using health services is higher in higher-rainfall areas, the proportionate increase between 1991 and 1999 in drought-prone areas is almost double that in higher-rainfall areas. Common health problems, in order of importance, revealed by community respondents include anthrax, black leg, contagious bovine pleuropneumonia, pasteurellosis, parasites, rinderpest, trypanosomosis, sheep and goat pox, and African horse sickness. Adoption of improved breeds and stall-feeding practices since 1991 are more common than adoption of artificial insemination and fattening practices. Stall-feeding practice is twice as common in higher-rainfall

Table 6.4 Proportion of communities (with some of their residents) adopting improved breeds and modern livestock management practices since 1991, by agricultural potential

Practice	All communities	Drought-prone areas	Higher-rainfall areas
Improved breeds	0.26	0.28	0.25
Artificial insemination	0.05	0.04	0.06
Stall feeding	0.38	0.23	0.48
Fattening	0.03	0.00	0.05

Note: Sample proportions are adjusted for stratification, weighting, and clustering of sample.

areas than in the drought-prone areas, whereas fattening practices are undertaken exclusively in low-rainfall areas.

Community respondents revealed that they adopted the above technologies in order to increase livestock productivity (e.g., meat and milk yield and draft power). Improvement in access to animal health services and credit and extension were cited by most of the communities as having contributed to the above changes. Between 1995 and 2000 alone, 323 veterinary clinics were constructed (ANRSC 2000a), and the number of vaccinations and treatments increased by 33 percent from 5.4 million in 1993–94 to 7.2 million in 1997–98 (BoPED 1998, 1999). Traditionally, credit and associated extension focused on crop production to the neglect of the livestock subsector. However, there are now many nongovernmental organizations (NGOs) involved in the region providing credit for purchasing livestock, extension on improved forage development, and veterinary services.[6] In addition, compared to past programs, the current extension system, Participatory Agricultural Demonstration Extension and Training System (PADETES), launched in the region in 1997, gives more attention to livestock by employing an integrated approach to crop, livestock, and natural resource management and postharvest technology.[7] Furthermore, a revolving credit program especially to address livestock and other long-term investment activities has been instituted by the regional government. This credit fund is granted from various bilateral and multilateral organizations and administered by the Bureau of Agriculture (Wondafrash, Grace, and Assefa 1998).

Because livestock are very important to the livelihood of farmers engaged in mixed crop–livestock farming systems in the highlands, a declining trend in ownership of livestock is cause for worry, especially in light of the livestock revolution that is anticipated to take place in developing countries within the next 20 years (Delgado et al. 1999) and the aim of making the livestock revolution work for the rural poor (ILRI 2000). Below we investigate the determinants of changes in use of feed resources, availability and quality of grazing lands, use of animal health services, adoption of improved breeds and modern management practices, and ownership of livestock.

Econometric Approach

We have five types of dependent variables: (1) changes in ownership of livestock; (2) changes in use of feed resources; (3) changes in availability and quality of grazing lands; (4) changes in use of animal health services and purchased feed; and (5) adoption of improved livestock breeds and modern management practices. Depending on the type of dependent variable, different econometric techniques are utilized. However, the general econometric model to be estimated is given by the first-difference model[8]

$$\Delta y_v = a_2 - a_1 + b(x_{v2} - x_{v1}) + (c_2 - c_1)z_v + e_{v2} - e_{v1} \tag{6.1}$$

where Δy_v represents the dependent variable in village *v*, x_{vt} the vector of observed time-varying factors affecting Δy, z_v the vector of observed fixed factors affecting Δy, and e_{vt} are unobservable factors affecting Δy. The observed fixed factors, z_v, will have an influence only if the marginal effect of such factors has changed over time. In the remaining part of this section, we first describe the dependent variables to be estimated and the specific econometric techniques utilized to estimate them. Then the explanatory variables used in the estimations are presented.

Changes in Ownership of Livestock

We obtained information on the proportion of households that owned various types of livestock (cattle, small ruminants, pack animals, and poultry) in a particular year. Here, we are interested in the differences in the proportions between 1999 and 1991. We use ordinary least squares to estimate the factors affecting the differences in the proportions because there was no censoring of the dependent variables (i.e., the proportions were never zero or one in any village). Different types of livestock are examined because each type has different functions in the farming system. Primarily, oxen are used for plowing, cows for milk, young cattle (bulls and heifers) for food and herd replacement, small ruminants and poultry for cash, and equines for transport. With respect to oxen, the ownership is further disaggregated into the proportion of households owning one ox only, two oxen only, and more than two oxen. Households without oxen have to rely entirely on others through rentals or borrowing, which can severely affect the timeliness of cultivation and subsequent crop yields. Those with one ox only are better off because they can pair up with their neighbors in a similar situation, whereas those with two oxen can be deemed self-sufficient in their plowing needs. Households with more than two oxen can rent out plowing services to other needy farmers to generate additional income. In general, the disaggregation helps to provide as much information as possible.

Changes in Use of Feed Resources and Availability and Quality of Grazing Lands

Survey respondents provided their perceptions of change in use of various feed resources and availability and quality of grazing lands. These perceptions were measured using ordinal indicators of change since 1991 with five possible levels: significant reduction, slight reduction, no change, slight increment, and significant increment. Ordered probit models (Maddala 1983) were therefore used to estimate the determinants of these changes.

Changes in Use of Animal Health Services and Purchased Feed

Similar to the information on ownership of livestock, we obtained information on the proportion of households that used animal health services and bought feed in 1991 and 1999. However, the resulting dependent variables that are calculated here are censored. For example, if the proportion of households buying feed was one in 1999, then the dependent variable was right censored. On the other hand, if the proportion of households buying feed was zero in 1999, then the dependent variable was left censored. Therefore, we estimate a maximum likelihood censored regression model (or "two-limit Tobit model"), taking into account both left and right censoring. The regression model on the change in proportion of households that bought feed was not statistically significant at the 10 percent level, and so it is not reported.

Adoption of Improved Livestock Breeds and Modern Management Practices

Survey respondents revealed whether or not some of the residents of the community had adopted improved livestock breeds,[9] artificial insemination, stall feeding, or fattening practices since 1991. We use probit regression models to estimate the factors affecting the probability of adopting these technologies, where the dependent variable is one if some residents have adopted and zero otherwise. Because only 5 percent and 3 percent of the communities reported having some of their residents adopting artificial insemination and fattening practices, respectively, there was not enough variation in the respective binary dependent variables to estimate the adoption of these management practices.

Explanatory Variables and Hypotheses

We expect that changes in feed use, adoption of livestock technologies, and change in ownership of livestock will be affected by several factors (both static and dynamic), including agricultural potential, changes in access to markets, population growth, land tenure policy, changes in participation in credit and extension programs, education, and community natural resource management (Pender, Scherr, and Durón 1999; Desta et al. 2000; Pender et al. 2001a; Chapter 2). These factors influence the awareness, availability, costs, benefits, and risks associated with the different livestock technologies and management practices and livestock ownership.

Increase in population pressure can reduce the availability and quality of grazing resources. Although better market access can increase the use of purchased feed, it can reduce the use of crop residues, as farmers may shift to producing less cereals and more marketable crops (e.g., vegetables) whose residues may not be suitable for livestock. Better market access may also increase use of health services and adoption of improved breeds through increased availability of those technologies and facilitating use of cash income from sale of crops to finance their purchase. Credit and extension can contribute to livestock intensification by increasing ownership and adoption of improved breeds (through either in-kind livestock credit or cash credit to purchase livestock), use of crop residues (through increased use of fertilizer), and adoption of stall feeding and use of health services (through extension services).

Regarding the effects of land tenure policy, the main issue is land redistribution, which has been frequent and ongoing since 1975 (instituted by the military government) to reduce landlessness and equalize landholdings and quality across households. Although land redistribution was stopped in many regions of Ethiopia in 1991 (with the current government coming to power), it continued in many parts of the Amhara region. A major recent redistribution exercise in the region took place in 1996–97, raising the proportion of farmers who owned land. However, actual implementation, type and amount of land affected, and population affected were not uniform across the region, as the exercise was left to local officials for needs assessment and implementation. In general, the exercise drew a massive reaction, both against and in support of it. See Chapter 9 for further discussion on the policy, its implementation, reaction to it, and expected effects on land investments and productivity. By improving farmers' access to land, land redistribution can increase ownership of livestock by smallholders. On the other hand, by reducing field size for supporting livestock, land redistribution may reduce ownership. Community management of grazing lands is expected to increase availability and quality of grazing lands (Gebremedhin, Pender, and Tesfay 2004; Chapter 10).

Table 6.5 shows a description of the explanatory variables used in the analyses and their means and standard errors. Agricultural potential is measured by average annual rainfall (with a mean of 1,217 millimeters), altitude (2,182 meters above sea level), and change in proportion of area irrigated (0.04 percent). Access to markets is measured by distance to the *woreda* town (37 kilometers) and whether there has been an improvement in access to an all-weather road (5 percent).[10] The other explanatory variables are population growth, which is measured by change in number of households per square kilometer (11), changes in proportion of households obtaining credit (and associated extension services) from BoA (20 percent), ACSI (9 percent),[11] and other formal sources (e.g., NGOs, 19 percent), change in adult literacy (15 percent), whether there has been land redistribution since 1991 (49 percent), and whether villages manage their own grazing lands (39 percent). Note that the above changes, unless otherwise stated, refer to the difference between 1999 and 1991 levels.

One econometric problem to address here is that several of the time-varying explanatory variables may be endogenous. Population growth, change in participation

Table 6.5 Means and standard errors of explanatory variables

Explanatory variable	Mean	Standard error
Annual rainfall (×1,000 millimeters)	1.2177	0.0312
Altitude (×1,000 meters above sea level)	2.1824	0.0809
Change in proportion of area irrigated	0.0004	0.0002
Distance (×100 kilometers) to *woreda* town	0.3739	0.0569
Whether there is improvement in access to all-weather road	0.0527	0.0267
Change in household density (×100/km^2)	0.1107	0.0169
Change in proportion of households with:		
Credit from ACSI	0.0890	0.0300
Credit from BoA	0.1988	0.0674
Credit from other formal sources (e.g., NGOs)	0.1880	0.0715
Change in proportion of adult literates	0.1446	0.0159
Whether there was land redistribution since 1991	0.4879	0.0673
Whether village exclusively manages own grazing land	0.3909	0.0782

Note: Change in explanatory variable refers to difference between 1999 and 1991 levels. Sample means and standard errors are adjusted for stratification, weighting, and clustering of sample.

in credit and associated extension programs, change in area irrigated, and change in adult literacy may respond to or be affected by changing opportunities in agriculture and changing livestock technologies and ownership. We therefore tested for exogeneity of those potentially endogenous explanatory variables using a Hausman test (Hausman 1978; Greene 1993).[12] We failed to reject exogeneity of those explanatory variables in the regressions except the regression for change in ownership of goats. Nevertheless, we report the robustness of the significant coefficients to using predicted values of those potentially endogenous variables.

Results

We present only results of those regressions in which the overall model is statistically significant at the 10 percent level of significance.

Changes in Ownership of Livestock

Table 6.6 shows the factors affecting changes in the proportions of households owing livestock. With respect to oxen, it is further broken down into ownership of one ox only, two oxen only, and more than two oxen. Among the factors that were hypothesized to affect changes in ownership of livestock, rainfall, altitude, changes in proportion of households obtaining credit from BoA, and adult literacy have no statistically significant effect on change in ownership of any type of livestock. Our finding of a limited association of rainfall and altitude with changes in livestock ownership contrasts with results for Tigray in Chapter 4, in which ownership of

Table 6.6 Determinants of changes in proportion of households owning livestock, 1991 to 1999

Explanatory variable	Oxen	One ox only	Two oxen only	More than two oxen	Heifers	Bulls	Sheep	Goats	Donkeys
Annual rainfall (×1,000 millimeters)	–0.016	–0.129	–0.010	0.083	0.139	0.128	–0.225	–0.013	0.042
Altitude (×1,000 meters above sea level)	–0.001	0.012	–0.027	0.007	–0.094	–0.058	–0.177	0.067	–0.089
Change in proportion of area irrigated	4.946	36.53*	–20.93	–8.732	–2.241	–10.92	–4.392	–16.11*	–27.16***
Distance (×100 kilometers) to *woreda* town	–0.288***R	–0.033	–0.181***R	–0.068**	–0.002	–0.007	–0.178	–0.192***R	0.030
Whether there is improvement in access to all-weather road	–0.108*R	–0.045	0.008	–0.065	–0.081	–0.079	0.013	–0.056	–0.077
Change in household density (×100/km²)	–0.428	0.144	–0.240	–0.402***R	–0.545***R	–0.678***R	0.272	–0.125	0.383
Change in proportion of households:									
Credit from ACSI	0.050	0.191	–0.035	–0.112*	–0.248***R	–0.247***	0.103	–0.132	–0.126
Credit from BoA	0.021	–0.014	0.025	–0.011	0.008	0.044	0.152	–0.042	0.058
Credit from other formal sources	–0.043	–0.133***	–0.022	0.072***R	0.045	0.030	–0.014	–0.016	–0.003
Change in proportion of adult literates	–0.188	–0.247	0.084	0.103	–0.016	0.047	–0.146	–0.105	0.082
Whether there was land redistribution since 1991	0.176**	0.104***	0.126**R	–0.063***R	–0.018	0.008	0.213**	0.154***R	0.151**
Whether village exclusively manages own grazing land	0.046	0.077*	0.008	–0.022	0.005	0.017	0.075	–0.035	–0.002
Intercept	–0.043	0.045	0.025	–0.053	–0.015	–0.087	0.410*	–0.190	0.055
Number of observations	86	86	86	86	86	86	86	86	86
F-statistic	4.50***	5.23***	2.79**	5.18***	4.82***	2.73**	3.59***	2.27**	5.04***
R^2	0.39	0.29	0.35	0.29	0.32	0.26	0.43	0.28	0.34

Note: Ordinary least-squares regressions. Change in explanatory variable refers to difference between 1999 and 1991 levels. Coefficients and standard errors are adjusted for stratification, weighting, and clustering of sample.

***, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.**

[R]Coefficient of same sign and significant at 10 percent level when predicted values used for changes in proportion of households using ACSI, BoA, and other formal credit, adult literacy, household density, and proportion of area irrigated.

oxen was found to be greater in higher-rainfall areas, and cows and goats less common, but sheep more common, at higher altitude. These differences may reflect the fact that factors influencing differences in *levels* of livestock ownership were investigated in Chapter 4, whereas we are investigating differences in *changes* in livestock ownership. Both sets of results may be consistent with each other; for example, it may be that ox ownership is generally greater in higher-rainfall areas but also be true that changes in ox ownership are not.[13]

Increase in proportion of area irrigated generally is associated with a reduction in ownership of livestock, although it is statistically significantly associated with a reduction in ownership of goats and donkeys only and an increase in ownership of one ox. The general declining trend suggests less reliance on livestock as we find that, compared to nonirrigated areas, production of cereals, pulses, and perishable annuals are more common dominant livelihood strategies in irrigated areas.

Better access to the *woreda* town is associated with an increase in ownership of oxen in general (and two or more oxen in particular) and goats. Improvement in access to all-weather roads, on the other hand, is associated with a decline in ownership of oxen in general. This latter result is consistent with the findings of Chapter 4.[14]

Increase in household density is associated with robust reductions in ownership of more than two oxen, heifers, and bulls. These findings reflect the increasing pressure on already degraded resources to adequately support large herds of cattle and are similar to the results of Chapter 4, which found higher population density associated with less ownership of oxen. We also find that increase in use of ACSI credit reduces ownership of more than two oxen, heifers, and bulls. This is probably a result of sale of extra oxen (more than the pair that is needed for plowing) and young stock to repay loans (fertilizer and improved seed) in times of crop failure or to supplement repayment when crop prices are at their lowest, immediately following harvest.[15] Increase in use of credit from other formal sources, on the other hand, is associated with an increase in ownership of more than a pair of oxen (while reducing ownership of only one ox). With many NGOs providing credit to farmers for the purchase of livestock, extension efforts emphasizing development of improved pasture and forages, and veterinary services, more farmers can improve their ownership of a larger herd of cattle.

Land redistribution is associated with increases in ownership of up to a pair of oxen, small ruminants, and donkeys, but a reduction in ownership of more than two oxen. It seems that access to own land, which is enhanced through land redistribution, is a major driving force for owning livestock (oxen for plowing and donkeys for transportation). However, as land redistribution reduces plot sizes and grazing areas and, therefore, the resources to support a large herd, it causes a reduction in the ownership of more than two oxen (either by selling or gifting extra oxen to newly formed households who acquired land in the redistribution).

The regression models of changes in ownership of cows, calves, horses, and mules were not statistically significant, and so they are not reported.

Changes in Use of Feed Resources

The determinants of changes in use of various feed sources are shown in Table 6.7. Several factors have statistically significant effects on change in use of some feed resource. Increase in use of private pastures is positively affected by an increase in the proportion of area irrigated and in areas where land redistribution has taken place. Irrigation allows higher cropping intensity to achieve higher crop yields or production of higher-value products. With higher yields from irrigated plots, part of cropland can then be released for private pasture development, especially in areas where part of traditional grazing areas (hillsides and waste lands) has been distributed for cropping and tree-planting activities. Decreased use of private pastures, however, is associated with an increase in adult literacy. Perhaps, as education increases, people become more aware and shift to cheaper alternative sources of feed, such as prickly pear, which grows wild in the homestead. Another explanation may be that people diversify into nonfarm activities as they become more educated.

Increase in use of crop residues is positively affected by increased use of credit from ACSI, where land redistribution has taken place, and where villages manage their own grazing lands. Because ACSI credit is given in kind in the form of chemical fertilizers and improved seed, increasing the proportion of participants can lead to increased intensification of crop production and, subsequently, increased production of crop residues that can be fed to livestock. With respect to land redistribution, the positive influence may be reflecting the increased reliance on crop residues for feed as a result of distribution of traditional grazing areas (mainly between 1996 and 1998) to newly formed households for cropping and tree-planting activities to reduce the growing incidence of landlessness. On the other hand, it may also reflect the positive effect of land redistribution on input use and crop yield by improving access to land by farmers who are more able and willing to use purchased inputs (Benin and Pender 2001). The positive association between villages managing their own grazing lands and increased use of crop residues may seem counterintuitive. However, as mentioned earlier, grazing lands managed at the village level are more likely to have grazing restrictions (e.g., grazing at certain times of the year only or for certain animals only) imposed on them and for those restrictions to be enforced. Therefore, farmers in such villages have to rely more on crop residues and other sources of feed for their animals during the period of no grazing or for those animals that are not allowed to graze.

Table 6.7 Determinants of perceived changes since 1991 in use of feed resources and availability and quality of grazing lands

	Sources of feed			Grazing lands	
Explanatory variable	**Private pastures**	**Crop residues**	**Homestead**	**Availability**	**Quality**
Annual rainfall (×1,000 millimeters)	0.278	–0.777	0.036	1.432	1.489**
Altitude (×1,000 meters above sea level)	0.290	–0.263	0.057	–0.654**	–0.563**
Change in proportion of area irrigated	269.7***R	–84.65	59.19	87.75	11.51
Distance (×100 kilometers) to *woreda* town	–0.363	–0.567	0.577	0.163	–0.353
Whether there is improvement in access to all-weather road	–0.586	–1.363***R	–0.219	0.082	–0.342
Change in household density (×100/km²)	–0.134	0.106	0.933	–3.757*R	–4.747***R
Change in proportion of households with:					
Credit from ACSI	0.077	1.971***	0.451	0.723	–0.070
Credit from BoA	–0.354	–0.790	0.557	–0.351	0.072
Credit from other formal sources	–0.353	–0.616*R	0.953**	0.082	–0.686*
Change in proportion of adult literates	–2.654*	0.590	2.982*	1.788*R	0.727
Whether there was land redistribution since 1991	0.554*	0.924***	–0.121	–0.719	–1.201***R
Whether village exclusively manages own grazing land	0.027	0.543**R	–1.893***R	0.705*	0.814***
Number of observations	86	86	86	86	86
F-statistic	2.40**	5.76***	2.99**	1.76*	2.66**

Note: Ordered probit regressions. Change in explanatory variable refers to difference between 1999 and 1991 levels. The dependent variables are ordinal indicators of perceived changes since 1991, where –2 = decreased significantly, –1 = decreased slightly, 0 = no change, +1 = increased slightly, +2 = increased significantly. Coefficients and standard errors are adjusted for stratification, weighting, and clustering of sample.

***, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.**

[R]Coefficient of same sign and significant at 10 percent level when predicted values used for changes in proportion of households using ACSI, BoA, and other formal credit, adult literacy, household density, and proportion of area irrigated.

Improvement in access to all-weather roads and increase in proportion of households obtaining credit from NGOs are associated with a decline in use of crop residues. Improvement in access to markets may induce farmers to produce more vegetables and other cash crops, whose crop residues may not be suitable for livestock, for sale. However, they can use part of the income to buy feed, as we find that improvement in access to all-weather roads is associated with increases in use of purchased feed. As mentioned earlier, there are many NGOs providing credit and extension for the development of backyard and improved forages. Therefore, the success of these programs may reduce use of crop residues as feed because the various feed resources are substitutes.

Increase in use of homestead sources of feed (prickly pear, backyard forages, etc.) is positively affected by increases in proportion of households obtaining credit from other formal sources and adult literacy. With respect to credit, there are many NGOs involved in the region who are providing credit as well as extension in development of backyard forages. This influence is likely more a result of the effects of extension than of credit, per se. Education, on the other hand, may increase farmers' awareness of the benefits of using prickly pear, which commonly grows wild in the homestead and, therefore, is free. However, decline in use of feed from the homestead is greater where villages manage their own grazing lands. These findings again highlight the relative profitability and substitutability of the various feed resources.

The regression models of changes in use of purchased feed, communal grazing lands, and woodlot or forest areas for fodder were not statistically significant at the 10 percent level. Therefore, they are not reported.

Changes in Availability and Quality of Grazing Lands

The determinants of changes in the availability and quality of grazing lands are also shown in Table 6.7. Change in availability of grazing lands is significantly affected by altitude and changes in household density and proportion of adult literates, and where villages manage their own grazing lands. We find that availability of grazing lands has declined more at higher altitudes and where household density has increased more but improved more where adult literacy has improved and where villages manage their own grazing lands. The negative effects of altitude and population growth are consistent with a neo-Malthusian notion regarding the negative effects of population growth. We also find that household density increases with altitude. Thus, population growth is not inducing sufficient investment in improvement of communal resources to overcome the negative effects of increased pressure on degrading resources. This is consistent with the finding from Tigray (Gebremedhin, Pender, and Tesfay 2004; Chapter 10) that community natural resource management is less likely to be successful in densely populated communities because of difficulties of maintaining collective action in maintenance and use of those resources.

Increased quality of grazing lands is positively affected by rainfall and is also seen where grazing lands are managed at the village level. Generally, ample and reliable rainfall intensity, as observed in the high-agricultural-potential areas of the western Amhara region, ensures adequate growth and quick regeneration of lush natural pastures. With respect to community resource management at the village level, because communal grazing lands managed at this lower level are more likely to have grazing restrictions imposed on them and for those restrictions to be enforced, their quality will tend to be higher. Quality of grazing lands, on the other hand, has declined more at higher elevations, where household density and use of credit from other formal sources have increased and where land redistribution has taken place. Generally, human settlement increases with altitude, and so the declining quality of grazing lands reflects the increasing pressure on grazing resources if population growth does not induce sufficient communal resource investment to improve the condition of those degrading resources. With respect to the negative effects of credit, involvement of NGOs in the development of backyard forages may be a contributing factor. There is additional increasing pressure on the already degraded grazing resources where there has been land redistribution because parts of traditional grazing areas (hillsides and waste lands) are distributed for cropping and tree-planting activities, and more farmers are able to own livestock, as discussed earlier.

Change in Use of Animal Health Services

The determinants of change in the proportion of households using animal health services (vaccine and treatment) are shown in Table 6.8. Increase in use of animal health services is negatively affected by rainfall but positively affected by increase in proportion of area irrigated, better access to the *woreda* town, increase in use of credit from BoA, and a history of local land redistribution.[16] The finding that higher use of health services is associated with lower-rainfall areas is counterintuitive. Nutrition may be a confounding factor in developing low resistance to diseases in lower-rainfall areas. However, lower-rainfall areas face less disease risk as well as lower agricultural potential and lower incomes. Thus, only some diseases may be more common in lower rainfall areas, and purchasing power to use health services will be less. Note, however, that the proportion of households using animal health services was greater in higher-rainfall areas in both 1991 and 1999, though the percentage increase was greater in lower-rainfall areas (Table 6.3). Poorly managed irrigation projects can become breeding grounds for animal disease vectors and

Table 6.8 Determinants of changes (1991 to 1999) in proportion of households using animal health services and adoption of improved breeds and stall feeding by communities since 1991

Explanatory variable	Use of animal health services	Adoption of: Improved livestock breeds	Adoption of: Stall feeding
Annual rainfall (×1,000 millimeters)	–1.034*	–2.735**	–2.824
Altitude (×1,000 meters above sea level)	0.260	0.613	0.161
Change in proportion of area irrigated	85.32***	309.2**	–56.83
Distance (×100 kilometers) to *woreda* town	–0.510***R	1.679*R	–0.079
Whether there is improvement in access to all-weather road	0.425	0.000	–0.207
Change in household density (×100/km^2)	1.503	8.062***R	3.422
Change in proportion of households with:			
Credit from ACSI	0.644	1.824	1.488
Credit from BOA	0.444*	0.841	1.447
Credit from other formal sources	–0.111	1.653***	2.510***
Change in proportion of adult literates	–2.084***	3.191	–1.089
Whether there was land redistribution since 1991	0.390*R	1.688***R	2.453***R
Whether village exclusively manages own grazing land	–0.034	–0.466	0.786
Intercept	0.886*	–2.491	–0.177
Type of regression	Censored MLE	Probit	Probit
Number of observations	85	79	86
F-statistic	4.47***	3.22**	2.85**

Note: Change in explanatory variable refers to difference between 1999 and 1991 levels. For the censored MLE regression, there are 70, 4, and 11 uncensored, left-, and right-censored observations, respectively. Coefficients and standard errors are adjusted for stratification, weighting, and clustering of sample.

***, **, and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent levels, respectively.**

[R]Coefficient of same sign and significant at 10 percent level when predicted values used for changes in proportion of households using ACSI, BoA, and other formal credit, adult literacy, household density, and proportion of area irrigated.

parasites (e.g., worms and ticks) and may therefore increase the incidence of related diseases and, consequently, demand for health care. On the other hand, people may use more health services in irrigated areas because they have more income and can better afford it.

Better access to the *woreda* town generally improves access to health services, either by walking animals to the clinic or going to seek advice or purchase drugs, especially with increased access to extension from BoA. With respect to the positive influence where there has been land redistribution, we find that redistribution increases the proportion of households owning livestock (discussed earlier) and, therefore, other things being the same, we would expect the proportion of households using health services to also increase.

The results show that an increase in adult literacy is associated with a reduction in use of animal health services. The reason for this result is not apparent, as we expect better-educated people to have higher nonfarm income that can contribute to financing and using more health services.

Adoption of Improved Livestock Breeds and Stall Feeding

The factors affecting adoption of improved livestock breeds and stall feeding are also shown in Table 6.8. Adoption of improved breeds is positively affected by an increase in the proportion of area irrigated, increase in household density, increase in proportion of households obtaining credit from other formal sources, and where there has been a land redistribution but negatively affected by access to the *woreda* town. These findings, except the effect of access to the *woreda* town, jointly suggest that the increasing pressure (population growth and diminishing plot sizes and grazing areas as a result of land redistribution) on already degraded grazing resources may be inducing farmers to replace part of their local stock with fewer improved breeds in order to reduce the pressure on resources while improving the productivity of their herd. Although substantial added investment may be required to replace a larger herd of local animals with a smaller herd of local and improved animals, evidence suggests that the return on investment can be very high. For example, crossbred cows used for production of both milk and traction can produce about six times more milk than local cows and plow a plot of farmland faster than local oxen, and the return on investment can be as high as 78 percent (GebreWold, Misgina, and Shapiro 1998). Providing the impetus for the change are increase in irrigation, which promotes development and use of private pastures (as discussed earlier), and increase in use of credit from NGOs to purchase improved breeds and associated extension on development of improved forages and provision of veterinary care. Household data, however, are needed to further test these hypotheses.

The reason for the negative association between better access to the *woreda* town and adoption of improved livestock breeds is not apparent. It may be that the credit and extension programs of those NGOs involved in the region are being targeted to more remote areas. In this case, the issue of sustainability (e.g., obtaining the necessary inputs and support services) when such projects come to an end needs to be addressed. Further research is, however, needed to explain the relationship.

The adoption of stall feeding,[17] which is also positively affected by an increase in the proportion of households obtaining credit from other formal sources and by a history of land redistribution, appears to complement the adoption of improved breeds, as we find that almost 80 percent of the communities that adopted improved breeds also adopted stall feeding.[18]

Conclusions and Implications

Using data from a survey conducted in northern Ethiopia, this chapter examined the trends since 1991 in the ownership of various types of livestock, use of various livestock feed resources and animal health services, and adoption of improved breeds and modern management practices. We found that ownership of various types of livestock has declined and that there have been significant changes in utilization of feed resources: although use of communal grazing lands, private pastures, woodlots, and forest areas as feed sources has declined, the proportion of households using crop residues and purchased feed has increased. In addition, the proportion of households using animal health services and the proportion of communities adopting improved livestock breeds and modern management practices (e.g., artificial insemination, stall feeding, and fattening) have increased. The factors contributing to the trends include agricultural potential, changes in access to markets and participation in credit and extension programs, population growth, land redistribution, and community natural resource management, as these factors influence the awareness, availability, costs, benefits, and risks associated with owning livestock and with the use of different feed sources, technologies, and practices.

Irrigation can influence the agricultural potential in the Ethiopian highlands, largely dependent on rainfall, to develop and improve private pastures while improving crop productivity. As irrigation, combined with improved seeds and fertilizer, lead to higher crop yields, other plots, especially the homestead, can be released for forage and pasture development. In fact, an ambitious program to tap the irrigation potential in the Ethiopian highlands was developed under the Sustainable Agriculture and Environmental Rehabilitation Program. In Amhara region alone, for example, the program initially planned to construct 540 microdams to irrigate 62,000 hectares over 10 years (CoSAERAR 1999). However, the plans have been scaled back as a result of capacity constraints and assessment of the availability of suitable sites. Given the limited opportunities for development of irrigation projects, the costs involved, and potential public health problems, as the data show that incidence of mosquitoes and malaria were more prevalent in communities with irrigation (see also Haile et al. 2003), their development should be considered on a case-by-case basis.

Better access to *woreda* towns significantly improves ownership of oxen and goats, whereas improvement in access to all-weather roads reduces ownership of oxen. Improving access to markets and communal management of grazing resources have complex interrelationships, which in turn have mixed influences on use of feed resources by influencing the relative importance (and profitability) of feed resources and condition of grazing lands, respectively. Further research on the complex cause–effect relationships is needed to derive policy implications, given that access to infrastructure has improved very little over the years. For example, in the early 1980s, it was found that about three-fourths of highland farm households lived more than a six-hour walk from an all-weather road (FAO 1986). Nearly two decades later, the average distance is about a five-hour walk (Pender et al. 2001a).

Better access to credit and extension, especially those offered by the Amhara Credit and Savings Institution (ACSI) and the Bureau of Agriculture (BoA), have not had positive influences across the board, probably because credit and extension targeting livestock started only recently. The finding of negative effects of ACSI credit on livestock ownership needs to be researched further, and alternative approaches to credit delivery and collection considered. However, the positive effects of the credit and extension given by NGOs suggests that the government credit and extension programs, by adopting the management and delivery strategies of those NGOs involved, can have similar positive but farther-reaching effects on livestock ownership because the government programs are implemented all over the region.

The negative effects of rapid population growth on ownership of livestock and availability and quality of grazing lands support the Malthusian perspective that rapid population growth contributes to poverty and resource degradation. Efforts to help farmers restock may be critical to poverty alleviation. However, in helping farmers to restock and get out of the downward spiral, replacing some local stock with fewer improved breeds to reduce herd size and stocking rate should be considered because this strategy can reduce the pressure on the already degraded resources while improving livestock productivity. To enhance the adoption process, priority should be given to investment in improving access to markets and credit and extension programs oriented toward livestock improvement.

Access to land seems to be a major factor affecting livestock ownership, as land redistribution, which enhanced access to land for many households, had significant positive effects on ownership of most types of livestock. However, ownership of more than two oxen (larger herd) was reduced, indicating the negative implications of land redistribution by reducing plot sizes and quality of grazing lands. Nevertheless, it is difficult to continue to use redistribution as a tool to address landlessness because of the very small size of farm holdings and diminishing traditional grazing areas (hillsides and waste lands) in the Ethiopian highlands. Thus, developing oxen sharing, lease arrangements, or other mechanisms for obtaining plow services will become important as farm sizes continue to decline.

Notes

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1. The share of livestock in total exports, however, declined from 21.3 percent in 1987–88 to 12.9 percent in 1995–96, with hides and skins contributing about 93 percent of total livestock exports within this period (Degefe and Nega 2000). There is similar evidence of the importance of livestock to the livelihoods of farmers in other Sub-Saharan African countries. For example, in the greater horn of Africa (comprising Ethiopia, Kenya, Somalia, Tanzania, and Uganda), it is estimated that livestock provide 20 to 30 percent of GDP and about 70 percent of farm cash income (Ndikumana et al. 2000). See for example ILCA (1987), USDA (1990), and Gittinger et al. (1990) for other estimates.

2. Poverty actually increased in urban areas by 11 percent within the same period (Woldehanna and Alemu 2002).

3. Peasant associations are the lowest-level local government in Ethiopia and usually consist of three to five villages.

4. Compared to other regions, Amhara stands first in number of goats; second in cattle, sheep, asses, horses, and poultry; and fifth in camels (CSA 1998).

5. Purchased feed includes oil-seed cakes, grain mill byproduct, straw, and *atella* (residue obtained from brewing local beer).

6. See Desta et al. (2000) for details on NGO activities in the region.

7. PADETES was launched in the country in 1994.

8. The first difference model eliminates unobservable fixed factors as a source of omitted variable bias.

9. These include mainly indigenous animals improved through breeding or selection as well as crossbred animals.

10. We had wanted to use the change between 1999 and 1991 in walking time to the nearest all-weather road. However, there were only two cases where the walking time had changed (decreased), although there were several cases where there was no "access" in 1991 but there was access in 1999. Therefore, we used instead a dummy variable to represent an "improvement in access to an all-weather road," where 1 refers to either a reduction in walking time between 1991 and 1999 or access in 1999 where access did not exist in 1991, and 0 otherwise.

11. ACSI started operating in the region in 1995, and so we used the proportion of households participating in 1999, which is equivalent to the change since 1991.

12. The instrumental variables used to predict the potentially endogenous explanatory variables, in addition to the exogenous variables in the regressions, include the values of each those endogenous variables in 1991: walking time to nearest bus station in 1991 and change since 1991, walking time to the nearest grain mill in 1991 and change since 1991, walking time to the nearest primary school in 1991 and change since 1991, and the proportion of households that were landless in 1991. The instruments predicted most of the potentially endogenous variables fairly well: $R^2 = 0.66$ for change in household density, 0.64 for change in proportion of households obtaining credit from other formal sources, 0.59 for change in proportion of households obtaining credit from BoA, 0.33 for change in adult literacy, 0.28 for proportion of households obtaining credit from ACSI, and 0.25 for change in proportion of area irrigated.

13. Note from the first difference econometric model described in equation (6.1) that the coefficient of fixed variables such as rainfall and elevation do not represent the same thing as a coefficient in a cross-sectional model; instead, the coefficient of fixed variables represent the change in coefficient that would apply at a given point in time. By contrast, the coefficients of changes in explanatory variables in the first difference model (such as changes in access to roads) should reflect the same coefficients as in a cross-sectional model, assuming that coefficients do not change between the two time periods in the first difference model.

14. As noted in the previous endnote, the coefficient of change in road access in a first difference model should be consistent with the coefficient of road access in a cross-sectional model, whereas the coefficient of a fixed variable such as distance to the nearest town would not be the same in cross-sectional and first difference models.

15. Generally, postharvest repayment of credit is a problem associated with most agricultural loans.

16. In Chapter 4, rainfall and market access were found to have insignificant association with use of vaccination services. The difference between that finding and ours could be for the same reason explained in note 14.

17. Stall feeding is commonly used when raising improved livestock breeds, especially dairy animals.

18. The positive association of stall feeding with access to some types of NGO credit contrasts with results in Chapter 4, where the authors found a negative association of NGO credit with improved feeding practices. This difference may reflect differences in the focus of NGO credit programs as well as differences in response variables (changes vs. levels), as noted previously.

Chapter 7

Strategies to Increase Agricultural Productivity and Reduce Land Degradation in Uganda: An Econometric Analysis

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Land degradation and low agricultural productivity are severe problems in Uganda. Although Uganda's soils were once considered to be among the most fertile in the tropics (Chenery 1960), problems of soil nutrient depletion, erosion, and other manifestations of land degradation appear to be increasing. The rate of soil nutrient depletion is among the highest in Sub-Saharan Africa (Stoorvogel and Smaling 1990), and soil erosion is a serious problem, especially in highland areas (Bagoora 1988). Land degradation contributes to the low and in many cases declining agricultural productivity in Uganda. Farmers' yields are typically less than one-third of potential yields found on research stations, and yields of most major crops have been stagnant or declining since the early 1990s (Deininger and Okidi 2001).

Finding ways to reverse these trends is an urgent need in Uganda and many other developing countries. In order to do that, information is needed to help identify strategies that will lead to more productive and sustainable land use. Because of the diverse agro-ecological and socioeconomic conditions in Uganda and the complex set of factors and interactions that influence farmers' land management decisions and their implications for productivity and land degradation, addressing this information need is a formidable challenge. This chapter addresses this challenge by developing and estimating a structural econometric model of household decisions regarding income strategies, participation in programs and organizations, crop choices, land management, and labor use and their implications for agricultural production and land degradation based on a survey of over 450 households and their farm plots in central and southern Uganda.

Conceptual Framework and Methodology

Empirical Model

The key outcomes of interest in this study are agricultural production and land degradation. We consider the proximate causes of each of these, including household choices regarding income strategies, land management, and other decisions, and the underlying determinants of these choices.[1]

Value of crop production. For agricultural production, we focus on the value of crop production. We assume that the value of crop production by household h on plot p (y_{hp}) is determined by the vector of shares of area planted to different types of crops (C_{hp}); the amount of labor used (L_{hp}); the vector of land management practices used (LM_{hp}); the "natural capital" of the plot (NC_{hp}) (biophysical characteristics and presence of land investments); the tenure characteristics of the plot (T_{hp}) (land rights category, how plot acquired, tenure security); the household's endowments of physical capital (PC_h) (land, livestock, equipment), human capital (HC_h) (education, age, and gender), and "social capital" (SC_h) (participation in programs and organizations); the household's income strategy (IS_h) (primary income source); village-level factors that determine local comparative advantages (X_v) (agro-ecological conditions, access to markets and infrastructure, and population density); and random factors (u_{yhp}):

$$y_{hp} = y(C_{hp}, L_{hp}, LM_{hp}, NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, IS_h, X_v, u_{yhp}) \quad (7.1)$$

Soil erosion. Many of the factors determining the value of crop production also are expected to influence land degradation. We use soil erosion as an indicator of land degradation, although this is certainly not the only form of land degradation occurring in Uganda. Because we have not been able to measure erosion on the plots studied in this research, we use predicted erosion based on the revised universal soil loss equation (RUSLE) (Renard et al. 1991). The RUSLE has been calibrated to soil conditions in Uganda by several recent studies (Tukahirwa 1996; Lufafa et al. 2003; Mulebeke 2003; Majaliwa 2003). The RUSLE estimates annual soil loss on the basis of several factors, including rainfall intensity, soil erodibility, topography (slope, slope length, and curvature), land cover, and land management practices. The RUSLE model is deterministic, providing deterministic predictions of erosion based on the factors mentioned above. As such, it is not so useful in estimating the statistical relationships between land management practices and actual erosion because these are predicted by the model. However, the predictions of RUSLE can be useful in estimating the relationships between underlying socioeconomic and biophysical factors that determine crop choice and land management and hence affect erosion. Considering the factors determining land management decision,[2] and assuming that the error term is additive,[3] we have the following expression for erosion:

$$e_{hp} = e(NC_{hp}, T_{hp}, PC_{h}, HC_{h}, SC_{h}, FC_{h}, IS_{h}, L_{fh}, X_{v}) + u_{ehp} \qquad (7.2)$$

Suppose that actual erosion is equal to erosion predicted by RUSLE (e^{p}_{hp}) plus a randomly distributed error term:

$$e_{hp} = e^{p}_{hp} + v_{ehp} \qquad (7.3)$$

Then substituting equation (7.3) into (7.2), we have:

$$e^{p}_{hp} = e(NC_{hp}, T_{hp}, PC_{h}, HC_{h}, SC_{h}, FC_{h}, IS_{h}, L_{fh}, X_{v}) + u_{ehp} - v_{ehp} \qquad (7.4)$$

Thus, we can estimate equation (7.2) using equation (7.4), as long as the prediction error (v_{ehp}) is not correlated with the explanatory factors. We maintain this as an assumption, recognizing that violation of this assumption would lead to biased estimates of the parameters in equation (7.2).

Explanatory variables. The village-level explanatory variables (X_{v}) include the agro-ecological and market access zone and the population density of the parish (the second lowest administrative unit, consisting of several villages). Ruecker et al. (2003) classified the agroclimatic potential for perennial crop (banana and coffee) production in Uganda, based on the average length of growing period, rainfall pattern (bimodal versus unimodal), maximum annual temperature, and altitude (Figure 7.1; see color insert). Potential for maize production was also mapped, and this map was found to be very similar. Thus, the zones in Figure 7.1 are representative of agroclimatic potential for the most important crops in Uganda.[4] Seven zones were identified: the high-potential bimodal rainfall area (BH) at moderate elevation near Lake Victoria (the "Lake Victoria crescent"), the medium-potential bimodal rainfall area (BM) at moderate elevation (most of central and western Uganda), the low-potential bimodal rainfall area (BL) at moderate elevation (lower-elevation parts of southwestern Uganda), the high-potential bimodal rainfall southwestern highlands (SWH), the high-potential unimodal rainfall eastern highlands (EH), the medium-potential unimodal rainfall region at moderate elevation (parts of northern and northwestern Uganda), and the low- and very-low-potential unimodal rainfall region (unimodel) at moderate elevation (much of northeastern Uganda).

A classification of Uganda into areas of low and high market access, using an index of "potential market integration" based on estimated travel time to the nearest five markets, weighted by their population, is shown in Figure 7.2. Market access in Uganda is highest in the Lake Victoria crescent (especially close to the major urban centers of Kampala and Jinja), in parts of the densely populated highlands, and near to the highway network in the rest of the country.

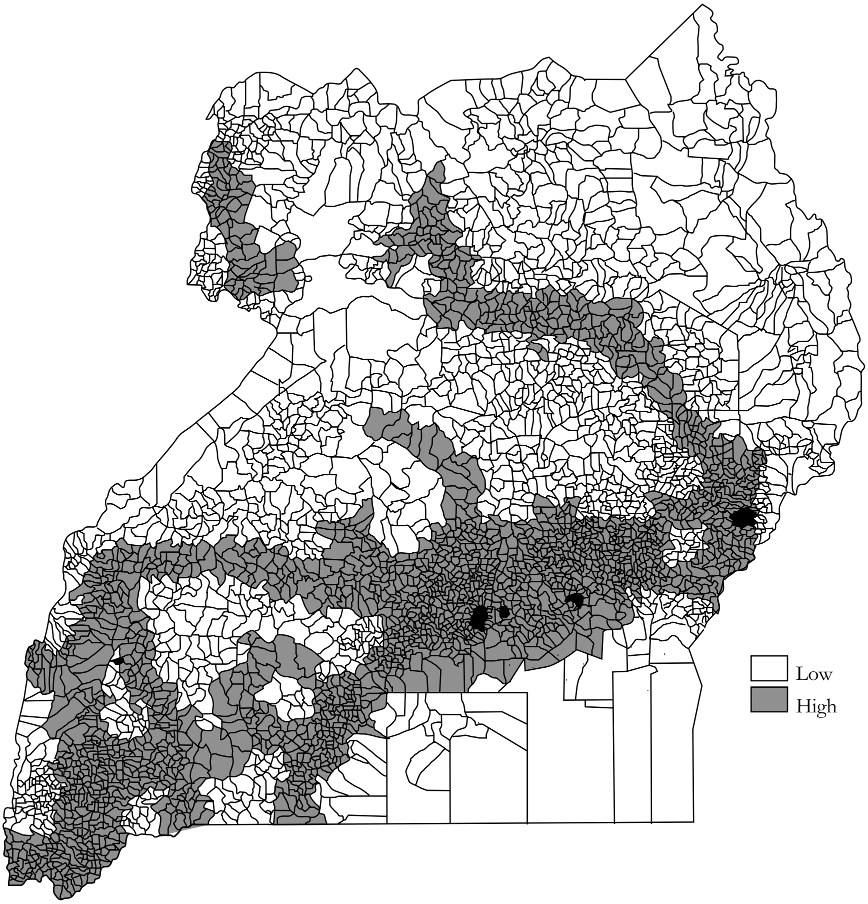
Household-level factors include income strategy (primary income source of the household); ownership of natural and physical capital (area of land, value of livestock and farm equipment); human capital (education, age, and gender of household head); the family labor endowment (size of household and proportion of dependents); financial capital (access to formal or informal credit);[5] and social capital (participation in technical assistance programs [longer-term training and shorter-term extension programs] and in various types of organizations). Plot-level factors include the size, tenure, and land rights status of the plot, whether the plot has a formal title, whether the household expects to have access to the plot in 10 years, the altitude of the plot; the distance of the plot from the farmer's residence, roads, and markets; the investments that have been made on the plot (presence of irrigation, trenches, grass strips, live barriers, and planted trees; share of area planted to perennial crops); and various plot quality characteristics (slope, position on slope, soil depth, texture, color, and perceived fertility).

Hypotheses

Hypotheses about the effects of most factors on land management and outcomes were discussed in Chapter 2. Here we focus only on the hypothesized influences of land tenure systems in Uganda, which have not been discussed in any detail in other chapters.

Land tenure. There are four types of land tenure in Uganda: customary, *mailo,* freehold, and leasehold. Owners of freehold land have complete rights to use, sell, lease, subdivide, mortgage, or bequeath this land; formally, this is the most complete and secure form of tenure. Customary land is subject to customary laws and regulations and is the most common form of tenure. Owners of customary land generally have secure rights to use, lease, and bequeath this land, but sales are sub-

Figure 7.2 Classification of market access in Uganda



Source: Ruecker et al. (2003).

ject to approval of clan leaders and family members. Customary landholders are encouraged by the 1998 Land Act to apply for freehold status or to acquire a certificate of customary ownership, both of which are issued by the district land board. However, the process of getting the certificate of customary ownership or a title for freehold is costly and cumbersome, as it involves cadastre expertise. As a result, few customary owners have converted their land to freehold status, and even many owners of freehold land do not have titles. *Mailo* land is land that was provided by the British colonial government to the Buganda royal family and other nobles in units of square miles (*mailo*), and was regarded as freehold land under colonial law. However, most of this land is occupied by long-term tenants, whose rights have been increasingly protected by the government of Uganda since the end of colonial rule, and the 1998 Land Act provides long-term *mailo* tenants the right to acquire freehold title to *mailo* land. Leasehold land is private or public land leased from the landlord for a specific period of time. Under the leasehold, the landlord grants the tenant exclusive possession of land during the lease period, and in return the tenant pays rent or service under specified terms and conditions that vary widely (Republic of Uganda 1998).

The extent of tenure insecurity among these different tenure systems is debatable. Customary landholders have had access to these lands for a long time, though in some areas the power of traditional authorities has been undermined in the past by actions of the government (Place, Ssenteza, and Otsuka 2001), which may have contributed to insecurity. The 1998 Land Act seeks to ensure tenure security on customary land by recognizing the jurisdiction of local authorities and customary laws over this land. *Mailo* tenants generally have strong rights (Place, Ssenteza, and Otsuka 2001), and the 1998 Land Act increases these. Holders of leasehold land generally have long-term leases of public land from the state or individual landlords. However, in some cases such leases have been provided to elites without regard to other occupants of the land, contributing to risks of insecurity and conflict (Place, Ssenteza, and Otsuka 2001). Thus, tenure security may be a concern for occupants of leasehold or public land.

Ownership of a formal title may amplify the influence of greater tenure security and complete land rights associated with freehold by providing proof of freehold status. In particular, formal title may facilitate access to credit and help to prevent or resolve land disputes (Feder et al. 1988). Thus, we investigate the influence of a title, per se, in addition to the land tenure status. We also investigate the effects of households' perception of perceived tenure security and the means of land acquisition, which may also influence incentives to invest in land management. For example, tenants on rented land are unlikely to invest in soil and water conservation measures if the lease is short term. Owners of purchased land and tenants using cash rental may have more incentive than owners of inherited land to produce cash crops and apply inputs in order to be able to recoup the costs of their investment. These differences may result in differences in crop production and land degradation.

Data. The above models were estimated using econometric analysis of survey data collected in 107 communities during 1999 to 2001. The study region included most of Uganda, including more densely populated and more secure areas in the southwest, central, eastern, and parts of northern Uganda, representing seven of the nine major farming systems of the country (Figure 7.3; see color insert).[6] Within the study region, communities (LC1s, the lowest administrative unit, usually a single village) were selected using a stratified random sample, with the stratification based on development domains defined by the different agro-ecological and market access zones shown in Figures 7.1 (see color insert) and 7.2, and differences in population density (Pender et al. 2001b). One hundred villages were selected in this way. Additional communities were purposely selected in areas of southwest and central Uganda, where the African Highlands Initiative and the International Center for Tropical Agriculture (CIAT) are conducting research.

A community-level survey was conducted with a group of representative people from each selected community to collect information on access to infrastructure and services, local markets and prices, and other factors. A random sample of 451 households was selected (four households per community in most cases). For each household selected, a household-level questionnaire collected information about household endowments of assets, household composition, income, expenditures, and adoption of agricultural and land management technologies. A plot-level survey was also conducted to collect information on all of the plots owned or operated by the household, including information about land tenure, plot quality characteristics, land management practices, use of inputs, and outputs from the plot in the year 2000. The survey information was supplemented by secondary information collected from the 1991 population census and available geographic information.

Analysis. The analysis conducted was similar to that discussed in detail in Chapter 5.[7] We used econometric analysis to analyze the determinants of income strategies, participation in programs and organizations, and land management practices and the influences of these factors on crop production and soil erosion. We used instrumental variables (IV) estimation to address the endogeneity of decision variables such as income strategies, participation in programs and organizations, and land management decisions when these are used as explanatory variables (e.g., in the crop production regression).[8] We investigated the robustness of the regression results by comparing the results of ordinary least squares (OLS), instrumental (IV), and reduced form (RF) approaches.[9] We also conducted Hausman (1978) tests comparing the OLS and IV models.

We used a log-log specification for equations (7.1) and (7.4) (logarithm of the dependent variable and of all continuous uncensored explanatory variables). Because there are zero values for some household assets (land, livestock, and equipment) for some households, it was not possible to use a simple logarithmic transformation for these variables. Instead, we included a dummy variable for positive asset ownership to allow for an intercept shift for households with zero values for some assets as well as the logarithm of assets for households that have positive asset levels. These transformations reduced problems with nonlinearity and outliers, improving the robustness of the regression results (Mukherjee, White, and Wuyts 1998).

In all models we tested for multicollinearity and found it not to be a serious problem (variance inflation factors < 5) for almost all explanatory variables (except for some assets when the logarithmic specification with the intercept shift dummy variables were used). All parameters were corrected for sampling stratification and sample weights. Estimated standard errors are robust to hetereoskedasticity and clustering (nonindependence) of observations from different plots for the same household. Outliers were detected, and errors corrected where found.[10]

As in Chapter 5, we predicted the effects of changes in selected variables using simulations based on the regression results. This analysis was conducted for the sample as a whole and separately for highland versus lowland subsamples (based on separate regressions for each of these subsamples), to investigate the extent to which responses and effects differ in different regions of Uganda.

Income Strategies and Land Management in Uganda

The primary sources of household income reported by the sample households in the study region include production and sale of agricultural products in general; production and sale of cereals (especially maize, sorghum, and millet), export crops (mainly coffee, but also including cotton, sugar cane, and tobacco), root crops (sweet potatoes, yams, Irish potatoes, and cassava), bananas, legumes, and horticultural crops (fruits and vegetables); livestock production; forestry and fishing activities; off-farm work for wages or salary; brewing beer; and various other nonfarm activities (e.g., petty trade, masonry, carpentry, butchery) (Table 7.1). The most common crops grown include cereals, legumes, root crops, vegetables, coffee, and bananas.

These income strategies and crop choices vary across regions of Uganda. Production of Robusta coffee is primarily in the Lake Victoria crescent region, and Arabica coffee in the eastern highlands around Mt. Elgon and some other highland areas (Pender et al. 2001b). Banana production was historically associated with coffee production in the Lake Victoria region but has been shifting to the southwest in recent years (Gold et al. 1999). Cereal production is important in most regions, and root crop production is particularly important in the northern part of the country (Pender et al. 2001b). Cattle keeping is most important in the lower-rainfall "cattle corridor," which ranges from lower-elevation zones in the southwest through parts of central Uganda to the northeastern Karamoja region (Pender et al.

Table 7.1 Descriptive statistics of variables used in econometric analysis

Variable	Mean	Standard error	Number of observations	Minimum	Maximum
Household/village-level variables					
Primary income source (proportion of households)					
General agricultural production	0.351	0.035	446	0	1
Gifts/donations	0.005	0.003	446	0	1
Wages/salary	0.066	0.019	446	0	1
Livestock	0.066	0.020	446	0	1
Nonfarm activities	0.080	0.020	446	0	1
Forestry/fishing	0.015	0.007	446	0	1
Brewing beer	0.040	0.012	446	0	1
Legumes	0.035	0.009	446	0	1
Horticultural crops	0.011	0.005	446	0	1
Bananas	0.072	0.013	446	0	1
Cereals	0.121	0.020	446	0	1
Root crops	0.038	0.006	446	0	1
Export crops	0.101	0.020	446	0	1
Household income (×1,000 Ush)	1,440.185	179.786	446	–1,795.1	11,519.17
Income per capita (×1,000 Ush)	147.272	17.128	446	–212.6	1,570.136
Agroecological zone (proportion of households)					
Unimodal rainfall	0.137	0.017	451	0	1
Bimodal low rainfall	0.091	0.007	451	0	1
Bimodal medium rainfall	0.189	0.012	451	0	1
Bimodal high rainfall	0.460	0.020	451	0	1
Southwest highlands	0.084	0.005	451	0	1
Eastern highlands	0.039	0.006	451	0	1
Market access zone (proportion of households)					
Low market access	0.256	0.014	451	0	1
High market access	0.744	0.014	451	0	1
Population density (persons/km^2)	219.518	7.145	451	10	962
Physical capital					
Area owned (acres)	10.400	2.117	451	0	640
Value of livestock owned (×10,000 Ush)	5.646	0.631	451	0	267
Value of equipment owned (×10,000 Ush)	1.612	0.233	451	0	80.55
Human capital					
Age of household head (years)	46.146	0.875	451	20	90
Household size	11.198	0.387	451	1	32
Proportion of dependents	0.540	0.012	451	0	1
Highest education of household head (proportion of households)					
Not completed primary	0.521	0.035	451	0	1
Primary	0.331	0.033	451	0	1
Secondary	0.071	0.018	451	0	1
Higher	0.077	0.020	451	0	1

(*continued*)

Table 7.1 (continued)

Variable	Mean	Standard error	Number of observations	Minimum	Maximum
Sex of household head (proportion of households)					
Male	0.895	0.026	451	0	1
Female	0.105	0.026	451	0	1
Participation in organizations (proportion of households)					
Agriculture/environment	0.241	0.032	451	0	1
Credit	0.356	0.032	451	0	1
Poverty reduction	0.107	0.021	451	0	1
Community services	0.464	0.033	451	0	1
Participation in technical assistance (proportion of households)					
Training	0.500	0.034	451	0	1
Extension	0.312	0.032	451	0	1
Availability of credit in village (proportion of households)					
Formal credit	0.260	0.023	451	0	1
Informal credit	0.698	0.024	451	0	1
Plot-level variables					
Crop choice (proportion of plot area)					
Cereals	0.210	0.011	1,436	0	1
Legumes	0.129	0.008	1,436	0	1
Root crops	0.191	0.009	1,436	0	1
Vegetables	0.094	0.005	1,436	0	1
Coffee	0.115	0.010	1,436	0	1
Bananas	0.198	0.011	1,436	0	1
Land management practices (proportion of plots)					
Slash and burn	0.113	0.015	1,785	0	1
Inorganic fertilizer	0.017	0.003	1,786	0	1
Manure/compost	0.176	0.014	1,876	0	1
Incorporation of crop residues	0.251	0.025	1,786	0	1
Crop rotation	0.406	0.020	1,786	0	1
Mulch	0.079	0.010	1,788	0	1
Household residues	0.136	0.011	1,786	0	1
Preharvest labor input (person-hours)	366.549	19.141	1,874	0	10344
Value of crop production (Ush)	188,146	18,606	1,876	0	2.61×10^7
Soil loss (metric tons/hectare per year)	5.758	0.626	1,584	0.02002	127.0776
Altitude (×100 meters above sea level)	13.224	0.383	1,572	10.12	42.09
Distance of parcel (kilometers) to:					
Residence	0.538	0.062	1,854	0	32
All-weather road	2.505	0.195	1,854	0	77
Market	4.494	0.268	1,854	0	37

Table 7.1 (continued)

Variable	Mean	Standard error	Number of observations	Minimum	Maximum
Tenure of plot (proportion of plots)					
Freehold	0.283	0.033	1,861	0	1
Leasehold	0.044	0.014	1,861	0	1
Mailo	0.185	0.027	1,861	0	1
Customary	0.488	0.031	1,861	0	1
Formal title of plot held (proportion of plots)	0.038	0.011	1,861	0	1
How plot acquired (proportion of plots)					
Purchased	0.507	0.032	1,665	0	1
Leased in	0.047	0.013	1,665	0	1
Borrowed	0.035	0.008	1,665	0	1
Inherited	0.404	0.029	1,665	0	1
Encroached common land	0.006	0.005	1,665	0	1
Expect to operate plot in 10 years? (proportion of plots)					
No	0.038	0.009	1,861	0	1
Yes	0.933	0.011	1,861	0	1
Uncertain	0.029	0.007	1,861	0	1
Plot area (acres)	2.352	0.635	1,604	0.1	636

2001b). Cotton used to be an important cash crop in parts of eastern, northern, and western Uganda but has declined over the past few decades because of low world prices, marketing problems, and conflict (You and Chamberlin 2004). Nonfarm activites such as trading, charcoal making, and brick making are generally more common in areas of better market access (Pender et al. 2001b).

The most common land management practices used by farmers in the study villages are crop rotation, incorporation of crop residues, application of household residues, application of manure or compost, use of slash and burn to prepare fields, and application of mulch (Table 7.1).[11] Slash and burn, crop rotation, and incorporation of crop residues are most often associated with extensive annual crop production systems in the east and north (Pender et al. 2001b). Use of manure, compost, and mulch is most often associated with perennial crop systems in the Lake Victoria crescent and the highlands (Pender et al. 2001b). Use of fallow has declined, and use of inorganic and organic sources of soil fertility is still very limited, contributing to perceived declines in soil fertility and crop yields in most areas (Deininger and Okidi 2001; Pender et al. 2001b). Average estimated soil erosion levels are less than 10 tons/hectare per year but are much higher in steeply sloping areas of the highlands.

Results of Econometric Analysis

In this section we present results of the econometric estimation of determinants of the value of crop production and soil erosion and simulations of the effects of selected interventions.[12]

Value of Production

The value of crop production is substantially higher on plots where bananas are grown than where cereals and many other types of crops are grown, controlling for labor use, land management, agro-ecological potential, and other factors (Table 7.2).[13] We do not find statistically significant differences in the value of production among other types of crops.

Crop rotation reduces the value of production significantly, at least in the short run. In the longer term, however, crop rotation may contribute to productivity by helping to restore soil fertility and reducing problems of pests and diseases. We find no statistically significant and robust effects of other land management practices on the value of production, controlling for labor use and other factors.

Not surprisingly, the value of crop production on a plot increases with both plot size and labor use. The elasticities of production value with respect to plot size (0.580 in the OLS regression) and labor (0.385) imply that production is an approximately constant return to scale: sum of elasticities = 0.965 (standard error = 0.055), which is not statistically different from 1.000 ($P = 0.52$).

Other factors that significantly affect the value of crop production include agro-ecological zone (highest in the high-potential EH), primary income source of the household (higher for households with primary income from production of legumes, horticultural crops, cereals, export crops, livestock, or nonfarm activities than for general agricultural producers and lowest for households with primary income from forestry or fishing), age of the household head (negative effect), amount of land owned (negative effect), value of livestock owned (positive effect), participation in agricultural extension and training programs (positive effect), and how the plot was acquired (lower for inherited than purchased plots).

The negative effect of farm size on value of crop production is consistent with most of the literature on farm size–productivity effects (e.g., Berry and Cline 1979; Deolalikar 1981; Carter 1984; Heltberg 1998), indicating that management, labor, or other constraints limit the ability of larger farmers to be as productive as smaller farmers. Because we find higher value of crop production even controlling for labor input, equipment availability, land quality, and other factors, our findings suggest that smaller farmers attain higher total factor productivity and not only higher land productivity, a finding that is not well established in the literature. This finding implies that reallocation of land toward smaller farms, whether through

Table 7.2 Determinants of output value and predicted erosion

	ln(Output value) (USh)			ln(Erosion [metric tons/hectare per year])		
Variable[a]	Ordinary least squares	Instrumental variables[b]	Reduced form	Ordinary least squares	Instrumental variables[b]	Reduced form
Crop choice (share of area)						
Legumes	–0.068	0.752				
Root crops	–0.468*	1.553				
Vegetables	0.525	2.523				
Coffee	0.098	1.097				
Bananas	0.988***	2.090***				
Land management practices						
Slash and burn	–0.048	–0.140				
Inorganic fertilizer	0.276	0.028				
Manure and compost	0.103	–1.384*				
Crop residues	0.043	0.483				
Crop rotation	–0.201*	–0.892**				
Mulch	–0.171	–0.152				
Household residues	–0.093	0.103				
Pesticides	0.059	0.620				
Integrated pest management	0.158	–1.369				
ln(Preharvest labor use)	0.385***	0.563**				
Primary income source (cf. general agricultural production)						
Gifts/donations	0.230	–1.026		–1.189		
Wages/salary	0.169	0.348		0.007		
Livestock	0.626**	0.457		–1.006		
Nonfarm	0.549***	0.775***		–0.184		
Forestry/fishing	–0.732***	–0.720**		0.328		
Brewing beer	0.279	0.244		0.061		
Legumes	0.490**	0.600*		0.076		
Horticultural crops	1.676***	1.159***		–0.239		
Bananas	0.164	0.105		–0.299		
Cereals	0.484***	0.575**		0.058		
Root crops	0.117	–0.047		–0.030		
Export crops	0.483***	0.197		0.168		
Agro-ecological zone (cf. unimodal)						
BL	0.295	0.149	–0.009	0.611	0.354	0.322
BM	0.054	–0.033	–0.065	0.151	0.037	0.062
BH	0.291	0.031	0.303	0.084	–0.187	-0.162
SWH	0.014	–0.232	–0.505*	1.951***	2.114***	1.510***
EH	0.672**	0.661	1.008***	1.160***	1.659***	0.940**
Altitude	–0.450**	0.254	–0.289	–2.380*	–2.774*	-2.612
High market access	0.013		0.122	–0.085		-0.109

(*continued*)

Table 7.2 (continued)

	ln(Output value) (USh)			ln(Erosion [metric tons/hectare per year])		
Variable[a]	Ordinary least squares	Instrumental variables[b]	Reduced form	Ordinary least squares	Instrumental variables[b]	Reduced form
Distance (kilometers) to:						
Residence	–0.093*	0.002	–0.056	0.063		0.067
All-weather road	0.007	0.018*	–0.002	0.016		0.008
Nearest market	-0.012	-0.015	-0.011	0.011		0.023**
ln(Population density)	0.014		0.001	0.152**	0.004	0.077
Assets						
Own land	0.305	0.365	0.031	–0.341		
ln(Area owned)	–0.097*	–0.260**	–0.133**	–0.007		
Own livestock	–0.828*	–0.437	–1.904***	0.355		
ln(Value of livestock)	0.068*	0.062	0.156***	–0.014		
Own equipment	0.010		–0.747	–0.097		
ln(Value of equipment)	0.001		0.060	–0.011		
Education of household head (cf. not completed primary)						
Primary	–0.155	–0.276*	–0.139	0.146	0.117	0.091
Secondary	0.129	0.071	0.095	0.441*	0.661*	0.357*
Higher education	0.117	0.040	–0.087	0.541*	0.541*	0.390
ln(Age of head)	–0.359**	–0.044	–0.615***	–0.271	0.243	–0.200
Female head	–0.152		–0.176	0.469*		0.292
ln(Size of household)	0.011		0.043	0.291**		0.315**
Proportion of dependents	–0.266		0.039	0.088		–0.120
Participation in organizations						
Agriculture/environment	–0.168			–0.349**	–0.709***	
Credit	0.129			–0.162	–0.546*	
Poverty reduction	0.229			–0.219*	–0.733	
Community services	–0.038			–0.182	0.287	
Participation in technical assistance programs						
Training	0.271***	0.331		0.047	–0.300	
Extension	0.287***	0.629		0.167	0.551**	
Credit availability in village						
Formal credit	0.001		0.248	–0.234		
Informal credit	0.055		0.175	–0.097		
Tenure of plot (cf. freehold)						
Leasehold	–0.436		–0.273	0.273	0.140	0.551
Mailo	0.217		0.092	–0.424*	–0.535**	–0.334
Customary	0.133		0.271*	–0.108	–0.133	–0.003
Formal title to plot	–0.306		0.150	–0.157		–0.295

Table 7.2 (continued)

	ln(Output value) (USh)			ln(Erosion [metric tons/hectare per year])		
Variable[a]	Ordinary least squares	Instrumental variables[b]	Reduced form	Ordinary least squares	Instrumental variables[b]	Reduced form
How plot acquired (cf. purchased)						
Leased in	–0.138	–0.403	–0.525	–0.636		–0.605
Borrowed	–0.414	–0.663*	–0.620*	–0.327		–0.230
Inherited	–0.288***	–0.253*	–0.371***	–0.088		–0.014
Encroached	–0.331	–1.108**	0.178	–0.061		–0.155
Expect to operate plot in 10 years? (cf. no)						
Yes	–0.008		–0.454	–0.423		–0.267
Uncertain	0.213		0.040	–0.052		0.133
Area of plot	0.580***	0.648***	0.876***	–0.046	–0.052	–0.023
Investments on plot						
Irrigation	0.790	2.426**				
Trenches	–0.009	0.115				
Grass strips	0.046	0.499				
Live barriers	–0.330	–0.376				
Trees	0.030	0.096				
Intercept	11.461***	6.986***	15.905***	6.030	6.417*	6.635
Number of observations	930	920	937	1,295	1,284	1,295
R^2	0.565	0.308	0.456	0.563	0.493	0.541

Note: Least-squares regressions.

A Hausman test failed to reject OLS model for value of crop production ($P = 1.000$).

***, **, *** mean reported coefficient is statistically significant at 10 percent, 5 percent, and 1 percent level, respectively.**

[a]Coefficients of plot quality variables (slope, position on slope, soil depth, texture, color, and perceived fertility) and ethnic groups in reduced form not reported because of space limitations. Full regression results available on request.

[b]Variables that were jointly statistically insignificant in the OLS regression were excluded from the IV regression.

land reform or the operation of land markets, would be expected to increase productivity in Ugandan agriculture.

The significant influences of income sources, controlling for land quality, crop choice, land management, labor use, and many other factors, suggest that households pursuing different income strategies acquire skills or have access to information or markets that translate into higher value of production and indicates the importance of considering income strategies to better understand how to increase agricultural production and incomes in Uganda. Many types of specialized crop producers and households dependent on livestock or nonfarm activities earn higher returns from crop production than general agricultural producers or households more dependent on extractive activities (forestry and fishing), suggesting that there are gains from specialization in crop production and also that there may be complementarities between livestock or nonfarm activities and crop production. However, specialization exposes farmers to increased production and price risks. Thus, many farmers may prefer to remain diversified in agricultural production despite lower expected returns.

Participation in agricultural training and extension programs has a positive and statistically significant effect on value of production in the OLS regression, but the effects are not statistically significant in the IV regression. This could mean that these programs tend to work with people who are more productive anyway (because the IV regression controls for this selection issue), though the coefficients in the IV regression are similar or larger in magnitude (which would not be the case if a selection bias were the only reason for the significant effect), and regressions predicting participation in these programs do not show clear tendencies in this regard.[14] Insignificance of the coefficients of these variables in the IV regressions may simply be a result of the difficulty of identifying these influences as a result of the limited number of suitable instrumental variables. Thus, agricultural training and extension programs appear to be having a positive effect on the value of crop production, though we are not certain of this because of limitations in the instrumental variables available. Participation in other organizations did not have a statistically significant influence on the value of crop production.

In summary, the regression results for value of crop production suggest that promotion of several income strategies and agricultural technical assistance programs can help to boost the value of crop production significantly. There appears to be potential for profitable expansion of banana production in the study region, whereas livestock development and nonfarm development appear to be complementary to increased crop production. The potential effects of improved land management on the value of crop production are less clear, however.

Erosion

Erosion varies across the development domains in Uganda. Erosion is highest in the intensively cultivated steeply sloping highlands (SWH and EH zones) and greater in areas of higher population density (though the effect of population density is significant only in the OLS regression). Consistent with the effect of population density, we find that erosion is higher for larger households, controlling for the amount of land owned by the household.

The positive effect of population density and household size on erosion supports neo-Malthusian concerns about population-induced land degradation, consistent with findings of recent studies in Ethiopia (Grepperud 1996; Pender et al. 2001a). However, this finding is not consistent with optimistic arguments about "more people, less erosion" cited by Tiffen, Mortimore, and Gichuki (1994a) for the Machakos district of Kenya. In that study, the reduction in erosion was influenced by factors other than rural population growth, such as the presence of technical assistance programs promoting conservation and access to the Nairobi market, which favored production of high-value cash crops and thus increased the value of investment in land conservation. It is essential to control for such factors in a multivariate analysis, as we have done, to more properly assess the effects of population pressure (or any other factor) on land degradation.

Participants in organizations focusing on agriculture and environment have lower levels of erosion on their plots than other households, suggesting that such organizations are effective in helping to reduce land degradation.

Predicted erosion is lower on *mailo* land than land under freehold tenure (in the OLS and IV regressions). This likely is caused by a tendency of *mailo* land to be planted with perennial rather than annual crops, however, and may not be related to the tenure characteristics of *mailo* land, per se. The fact that there is no statistically significant difference between erosion on *mailo* and freehold plots in the reduced form regression, in which ethnicity is included in the explanatory factors, suggests that the differences found in the other two models result from cultural factors leading to different cropping choices in *mailo* areas.

Most other factors considered, including income sources, household assets, education, participation in technical assistance programs, access to markets, infrastructure, credit, land title, and tenure security have a statistically insignificant influence on predicted erosion. Consequently, the evidence presented here does not support use of policy interventions affecting these factors as a means of addressing this form of land degradation. It appears that efforts to reduce population pressure and organizations focusing on agriculture and environment concerns are likely to be more effective than interventions related to income diversification, infrastructure, education, credit, or land titling in reducing soil erosion in Uganda. Of course, there may be indirect effects of some of these interventions on erosion; for example, if education were to increase participation in agricultural and environmental organizations, it could indirectly contribute to reducing erosion.

Potential Effects of Selected Interventions

Several interventions may be considered as possible means of increasing agricultural production and reducing land degradation. We focus in this section on factors that are found to have statistically significant and robust influences on at least one of the outcome variables (value of crop production, erosion). Among these are population growth, improved access to all-weather roads, improved access to education, participation in agricultural technical assistance programs, and participation in nongovernmental organizations. We explore the potential effects of such interventions on crop production and erosion using the predicted relationships from the econometric model, considering both the direct effects of such interventions based on the results reported in Table 7.2 as well as indirect effects of such interventions via their effects on households' choice of income sources, participation in programs and organizations, crops planted, land management practices, and labor use. We consider effects for the full sample, as well as those on highland and lowland zones separately, in case there are differential effects.[15]

Population growth of 10 percent is predicted to have a small and statistically insignificant influence on the mean value of crop production, but it would increase predicted erosion by about 2 percent (Table 7.3). The effect of population growth on erosion is mainly in the highland zones (SWH and EH), with small and statistically insignificant effects of population growth on predicted erosion in the lower-elevation zones (Table 7.4). This is not surprising, given the steep slopes and dense population in the highland zones, creating substantial land degradation pressure in these areas. This suggests that priority should be given to reducing population pressure in the highlands to help reduce soil erosion.

Improved access to all-weather roads is predicted to have a small and statistically insignificant influence on the value of crop production and erosion, considering the entire sample. However, when the highlands and lowlands are considered separately, improved access has differential effects on erosion, with a weakly statistically significant negative effect on erosion (–5 percent) in the lowlands but a significant and robust positive effect on erosion (+5 percent) in the highlands. It may be that greater road access reduces labor intensity of land management, which may cause more erosion in the steeply sloping highlands, where labor-intensive investments in soil and water conservation measures are critical, but less erosion is found in the lowlands as a result of less intensity of crop production. Whatever the reason, improved road access appears to have different effects on land degradation in the lowlands and the highlands.

Universal primary education is predicted to result in an average reduction in value of crop production and an increase in erosion in the full sample, though neither of these results is statistically robust. In the lowlands, education is more strongly associated with both lower value of crop production and higher erosion. In the highlands, by contrast, improved education is predicted to lead to higher crop production. As with population pressure and road access, the influences of education are location-specific but may involve trade-offs between income and agricultural production and sustainability.[16]

Table 7.3 Simulated impacts of changes in selected variables on outcomes

Variable	Scenario	Mean of selected variable		Value of crop production (plot level) (percent change)		Predicted soil erosion (percent change)	
		Before change	After change	Direct effects	Total effects	Direct effects	Total effects
Population density (persons/km^2)	10 percent increase	220	242	+0.1	+0.4	+1.6**	+1.6
Distance to all-weather road (kilometers)	All households next to an all-weather road	2.250	0.000	–2.2$^-$	–0.9	–3.5	–3.2
Primary education (proportion of households)	Universal primary education	0.480	1.000	–8.2$^-$	–7.7	+8.1	+8.2
Postsecondary education (proportion of households)	Higher education for all heads with secondary education	0.078	0.149	–0.1	–0.7	+0.5*	+0.3
Agricultural training (proportion of households)	All households receive training	0.502	1.000	+13.1***	+12.2	+2.5	+2.5
Extension (proportion of households)	All households receive extension	0.311	1.000	+18.5***	+13.7	+11.5	+11.5
Agricultural/environment NGOs (proportion of households)	All households participate	0.241	1.000	–11.8	–8.7	–23.1**$^{---}$	–23.1

Note: Percentage change in mean predicted values. Simulation results for direct effects based on predictions from OLS model regressions reported in Table 7.2. Results of regressions predicting choices of income sources, crops, land management practices, and labor use were used to predict indirect impacts.

***, **, *** mean direct effect is based on a coefficient that is statistically significant in the OLS regression at 10, 5, or 1 percent level, respectively. Statistical significance of indirect effects not computed.**

$^+$, $^{++}$, $^{+++}$ and $^-$, $^{--}$, $^{---}$ mean direct effect is of the sign shown and statistically significant in the IV regression at 10 percent, 5 percent, or 1 percent level, respectively.

[R]Coefficient is of the same sign and statistically significant in the reduced form regression. Because participation in agricultural training, extension, and organizations were excluded from the reduced form regressions, the robustness of the total effects for these variables could not be shown.

Table 7.4 Simulated impacts of changes in selected variables on outcomes, lowlands versus highlands (total effects)

		Lowlands (BL, BM, BH, and U zones)				Highlands (SWH and EH zones)			
Variable	Scenario	Before	After	Value of crop production (percent change)	Soil erosion (percent change)	Before	After	Value of crop production (percent change)	Soil erosion (percent change)
Population density (persons/km^2)	10 percent increase	207.9	228.7	+1.1	+0.6	308.6	339.5	–5.0**	+2.8**R
Distance to all-weather road (kilometers)	All households next to an all-weather road	2.161	0.000	–0.9	–5.3*–	2.915	0.000	–2.9	+4.5***+R
Primary education (proportion of households)	Universal primary education	0.483	1.000	–11.1**–––	+6.7*	0.462	1.000	+42.1*++	+12.5
Postsecondary education (proportion of households)	Higher education for all heads with secondary education	0.077	0.155	–0.7	–0.5	0.078	0.106	+0.3	+0.4R
Agricultural training (proportion of households)	All households receive training	0.508	1.000	+12.5***+++	+1.9	0.457	1.000	–16.9	+13.3**
Extension (proportion of households)	All households receive extension	0.321	1.000	+10.8***	+14.6	0.227	1.000	+12.0	+33.4***
Agricultural/environment NGOs (proportion of households)	All households participate	0.254	1.000	–10.7**	–19.5***–––	0.154	1.000	+115.9**	–29.4***

Note: Percentage change in mean predicted values. Simulation results for direct effects based on predictions from separate OLS model regressions for highland and lowland subsamples. Results of regressions predicting choices of income sources, participation in programs and organizations, crops, land management practices, and labor use were used to predict indirect impacts.

***, **, *** mean direct effect is based on a coefficient that is statistically significant in the OLS regression at 10 percent, 5 percent, or 1 percent level, respectively. Statistical significance of indirect effects not computed.**

+, ++, +++ and –, ––, ––– mean direct effect is of the sign shown and statistically significant in the IV regression at 10 percent, 5 percent, or 1 percent level, respectively.

R Coefficient is of the same sign and statistically significant in the reduced form regression. Because participation in agricultural training, extension, and organizations was excluded from the reduced form regressions, the robustness of the total effects for these variables could not be shown

Agricultural technical assistance, whether through longer-term training programs or short-term extension visits, is predicted to increase the value of crop production significantly. For the full sample, universal participation in agricultural training programs would lead to a predicted 12 percent increase in the value of crop production, while universal participation in extension increases predicted production by 14 percent. The positive influence of these programs are greater in the lowlands. In the highlands, the effects on production are statistically insignificant, and such programs are associated with more soil erosion. Thus, agricultural technical assistance programs appear to have had more beneficial effects in the lowlands.

Trade-offs between environmental and production objectives may result from participation in nongovernmental organizations (NGOs), but this is also location-specific. Universal participation in NGOs focusing on agriculture and environmental issues is predicted to reduce soil erosion in the full sample by 23 percent, with significant effects in both the highlands and lowlands, though with a larger influence in the highlands. However, such participation is predicted to reduce the value of crop production in the lowlands but increase it in the highlands. By emphasizing labor-intensive technologies to conserve soils, such organizations are able to reduce soil erosion, but apparently at the expense of crop production in the near term in the lowlands. Although such near-term losses may be recouped in the longer term, they undoubtedly contribute to the low adoption of conservation practices by most small farmers. In the highlands, the technologies being promoted have more beneficial immediate effects on production, probably by helping to conserve soil moisture as well as soil. In steeply sloping highland areas, soil moisture is usually a more important constraint on production than in lowland areas, and measures to conserve soil moisture may thus have more immediate influence (Shaxson 1988).

Other interventions that may contribute to increased value of crop production, based on the regression results reported in Table 7.2, include promotion of specialized crop production, livestock keeping, and nonfarm activities as income strategies, investments in irrigation, and improved access of small farmers to land (given the inverse farm size–productivity relationship). Some factors that are commonly thought to be important were found to have mostly insignificant influences, including access to markets and credit, land tenure, and ownership of a title. However, it appears that development of land markets can contribute to more intensive and higher-value production (since we find higher value of output on purchased than inherited plots).

Conclusions and Implications

The results of this study generally support the Boserupian model of population-induced agricultural intensification but do not support the optimistic "more people–less erosion" hypothesis (Tiffen, Mortimore, and Gichuki 1994a). Households in more densely populated communities and smaller farms were found to be more likely to adopt some labor-intensive land management practices (Nkonya et al. 2004), and smaller farms obtain higher value of crop production per hectare. However, population pressure contributes to soil erosion and lower crop production in the highlands. Efforts to reduce population pressure in the highlands may thus produce "win-win" outcomes, helping to both increase agricultural productivity and reduce land degradation.

Agricultural technical assistance programs have important effects on agricultural production and land degradation, contributing to higher value of crop production (especially in the lowlands) but also to soil erosion in the highlands. By contrast, NGO programs focusing on agriculture and environment are helping to reduce erosion but have mixed influences on production. The effects of technical assistance thus can be very location specific and involve trade-offs between agricultural production and land degradation. This suggests the importance of a demand-driven community-based approach to such programs, in order to ensure that location-specific factors and trade-offs can be adequately considered. Development and promotion of combination technologies that can enhance agricultural productivity and conserve soils and that are suited to local conditions should be a high priority for such programs.

We find little evidence of effects of access to markets, roads, and credit on agricultural intensification and crop production, though road access appears to contribute to land degradation in the highlands, again emphasizing the location specificity of effects. This is not to say that such factors will be unimportant in the longer-term. As agricultural modernization and commercialization proceeds in Uganda, access to markets and credit are likely to become much more important.

Land tenure and land title were also found to have limited influences on agricultural production and land degradation. This is because the most common forms of tenure are relatively secure and transferable, and access to credit is not a critical factor affecting agricultural production, as noted above. As agriculture becomes more commercialized, the demand for formal titles in order to increase access to formal-sector credit is likely to increase, however.

Improving education is critical for increasing household incomes (Nkonya et al. 2004), but this is not solving problems of low agricultural productivity and land degradation. By increasing household members' income opportunities off the farm, education may reduce small farmers' effort to produce agricultural output or to conserve soil. Such potential trade-offs do not mean that investments in improved education should not be pursued, but other means may be needed to address low productivity and land degradation. Including teaching on principles of sustainable agricultural production in educational curricula might help to minimize negative effects or even have positive effects on agricultural production and sustainable land management.

We do not find evidence of a poverty–land degradation trap, given that erosion does not depend significantly on asset ownership. Asset poverty has mixed effects on agricultural productivity depending on the type of assets considered: smaller farms obtain higher value of crop production per hectare, and households with fewer livestock obtain lower value of crop production. These findings suggest that development of factor markets (e.g., for land and livestock) can improve agricultural efficiency. Also consistent with this is the finding that owners of purchased land obtain higher value of crop production than owners of inherited land.

Several other factors that contribute to increased value of crop production, without significant effects on land degradation, include specialized crop production, livestock and nonfarm income strategies, and irrigation. The effect of income strategies on value of crop production suggests the importance of development of human and social capital required to pursue such strategies in increasing households' ability to identify and exploit market opportunities in agriculture. Interventions to promote livelihood diversification as well as investments in irrigation thus can contribute to agricultural growth.

In general, the results imply that the strategies to increase agricultural production and reduce land degradation must be location-specific and that there are few "win-win" opportunities to simultaneously increase production and reduce land degradation. Interventions must be tailored to local circumstances, and trade-offs among different outcomes may often occur. There is no "one-size-fits-all" solution to the complex problems of small farmers in the diverse circumstances of Uganda. Thus, a demand-driven approach to development programs will be crucial.

Notes

1. This empirical model is derived from a theoretical dynamic household model, which is presented in Nkonya et al. (2004). The empirical model is quite similar to the model presented in Chapter 5, but there are some important differences (e.g., inclusion of annual crop choice in the model and estimation of determinants of erosion). Hence, we present the model in an abbreviated form, focusing only on the outcome variables discussed in this chapter. A complete exposition of the model can be found in Nkonya et al. (2004) and Pender et al. (2004b).

2. These factors are explained fully in Nkonya et al. (2004) and Pender et al. (2004b) and are very similar to the determinants of land management discussed in Chapter 5.

3. In the empirical work we use the logarithm of erosion as the dependent variable; thus the assumption that the error term in equation (7.2) is additive is equivalent to assuming a multiplicative error in the level of erosion. This assumption is consistent with the multiplicative form of the RUSLE.

4. Although soil conditions are also important in determining agricultural potential, no attempt was made to include soils in the classification because of limitations in the available soil data and the high degree of spatial variability in soil quality. Thus, the map in Figure 7.1 does not fully represent "agricultural potential," though it represents agroclimatic zones.

5. Credit access was measured at the village level to address concern about endogeneity of household level use of credit.

6. The districts included in the project study area include Kabale, Kisoro, Rukungiri, Bushenyi, Ntungamo, Mbarara, Rakai, Masaka, Sembabule, Kasese, Kabarole, Kibale, Mubende, Kiboga, Luwero, Mpigi, Nakasongola, Mukono, Kamuli, Jinja, Iganga, Bugiri, Busia, Tororo, Pallisa, Kumi, Soroti, Katakwi, Lira, Apac, Mbale, and Kapchorwa.

7. The analytic approach is described fully in Nkonya et al. (2004).

8. The ethnicity of the household was used as an instrumental variable to predict income strategies and participation in programs and organizations. Other instrumental variables were identified by hypothesis testing: variables that were jointly statistically insignificant in the full version of the models for equations (7.1) and (7.4) were dropped from the regression and used as instrumental variables.

9. The reduced form regressions exclude endogenous decision variables such as income strategies, participation in programs and organizations, and land management practices. The coefficients in these regressions thus reflect total effects of exogenous or predetermined factors on the outcome variables, allowing for indirect impacts that such factors have on the outcomes by affecting the endogenous decision variables as well as direct impacts. The coefficients of exogenous and predetermined factors in the structural OLS and IV regression models reflect only their direct effects on the outcomes, controlling for the endogenous decision variables that are also included in the models. Thus, the coefficients in the reduced form models are not expected to be the same as those in the OLS or IV models because they are reflecting different effects. Nevertheless, it is instructive to investigate robustness of results across all three models.

10. Two households were dropped from the analysis because they own more than 300 acres of land and are not representative of the vast majority of farmers in Uganda. All remaining households owned less than 100 acres of land, and the average farm size for these was 8.2 acres.

11. Household residues include kitchen waste and other residues from the household. Compost includes vegetative wastes (usually from crop production) combined with manure.

12. Other econometric results are presented in Nkonya et al. (2004).

13. Variables that were jointly statistically insignificant in the OLS regression were dropped from the IV regression ($P = 0.57$), and multicollinearity is a problem only for the equipment and livestock variables in the OLS and RF regressions (maximum VIF = 20 for ln[equipment value]). A Hausman test of the OLS versus IV models could not reject the hypothesis of no specification error in the OLS model ($P = 1.000$), which is thus preferred.

14. The only factors found to have a statistically significant impact on participation in extension programs are distance to a tarmac road (more participation further from a road) and ethnicity. The only factor having a statistically significant impact on participation in agricultural training programs is education (higher participation for more educated household heads). These findings do not clearly indicate that participants in technical assistance programs are households that would tend to be more productive in the absence of extension because these factors are found to not have significant direct effects on the value of crop production. Regression results are available on request.

15. As noted previously, separate regressions were run for highland and lowland subsamples but are not reported here to save space. These regression results are available from the authors on request.

16. Influences of education on household income are shown to be positive in Nkonya et al. (2004).

Chapter 8

Agricultural Enterprise and Land Management in the Highlands of Kenya

Frank Place, Jemimah Njuki, Festus Murithi, and Fridah Mugo

This chapter focuses on the management of agricultural land by smallholder households in the highlands of Kenya. It draws mainly from several recent studies from the central highland areas near to the south and west of Mt. Kenya and the western highland areas to the north and west of Kisumu, which were led by the authors. The chapter also draws from a set of studies under the KAMPAP project.[1] See the appendix for a description of the key papers used in this synthesis. The main purpose of this synthesis is to understand constraints and opportunities for improving agricultural productivity in a sustained manner. The comparison between the central and western highlands offers considerable insights because one area consists of relatively dynamic and productive agricultural systems (central), and the other is relatively stagnant and unproductive (western).

The fact that very diverse agricultural and livelihood outcomes emerge from fairly similar initial physical-climate conditions is not unique to Kenya but occurs throughout the highlands of east and central Africa. It is hoped that this detailed synthesis and analysis will help to indicate research, development, and policy steps that can bring about positive changes in the areas beset by poverty. Specifically, this chapter attempts to:

1. describe agricultural systems in the Kenya highlands including enterprise choice, investment behavior, and impact on productivity and income,

2. identify factors behind different agricultural strategies pursued by households, and

3. develop feasible recommendations that can benefit the development of poor communities and poor households.

The Study Sites

In this study, we focus on the central and western Kenya highlands (see Figure 8.1 in the color insert for a map of the study sites). The reason for this is that they are similar in terms of rainfall and population density. In both cases, rainfall is ample (mainly between 1,400 and 1,800 millimeters) and can accommodate two cropping seasons. Population density ranges between 350 and 1,000 persons per square kilometer in most of the central and western highlands so that average farm sizes are between 0.5 and 2 hectares. The highland areas lying between the central and western parts (i.e., those in the Rift Valley Province) are different in that they are comprised of a disproportionate number of larger commercial farms.

Central Highlands

The central highlands lie between Nairobi and the slopes of Mt Kenya with an altitude ranging from 1,500 to 2,000 meters above sea level. Rainfall is bimodal and averages from 1,300 to 1,800 millimeters per year. There are two cropping seasons, with the long rain season starting from mid-March through July and the short rain season from mid-October through December. Our data are principally from Embu and Kirinyaga Districts, which are positioned to the south and west of Mt. Kenya. Most of the area is covered by clay soils except for a small area that is covered by loam soils. The soils are deep and well drained and are of good fertility. The average annual maximum temperature is as low as 20°C in the upper portions of the districts.

The Tea–Dairy Zone is located at higher elevations with precipitation rates of 1,800 millimeters per year, a very long cropping season, and good yield potential. The Coffee–Tea Zone at a slightly lower altitude has an average annual rainfall of 1,400 to 1,800 millimeters with a long cropping season and a medium-length cropping season. The Main Coffee Zone has a medium and a short to medium cropping season with an average rainfall of 1,200 to 1,500 millimeters. Finally, the Marginal Coffee Zone is at the lowest altitude of the districts and has a medium to short and a short cropping season and an annual average rainfall of 1,000 to 1,250 millimeters.

Population densities are high throughout the two districts, averaging over 400 persons per square kilometer in the more favorable agricultural zones. There is a high-quality tarmac road cutting through the districts and eventually leading to Nairobi. There are few other tarmac roads in the districts, however. Most roads are dirt and are generally of good quality but, because of their high clay content, can become problematic during the rainy season. Piped water is not uncommon in the districts, but telephone and electricity are generally not available in the rural areas. The trade and marketing sector is quite active and innovative in central Kenya, encouraging the growth of commercial enterprises. All in all, central Kenya enjoys a relatively low rate of poverty compared to other provinces, with rural poverty rates ranging between 30 and 40 percent of the population (Republic of Kenya 1997).

Western Kenya

Similarly to central Kenya, there are two cropping seasons in western Kenya: the long rains from March to July and the short rains from September to November, with rainfall amounts ranging between 1,500 and 1,900 millimeters per annum. During the past decade, rainfall in the western Kenya highlands has been very reliable, perhaps the most favorable in all of Kenya. The altitude in the main study areas of Vihiga and Siaya Districts is between 1,400 and 1,700 meters above sea level. The topography has frequent ridges and valleys with a large area of moderately sloping land. Soils are deep and well drained. The area is considered to be of medium to high potential for agriculture, but soils are highly degraded from agricultural activities.

There is less variation in rainfall among our western Kenya sites than in central Kenya because of the influence of Mt. Kenya near the central Kenya sites. Although a sizable portion of the study area could accommodate tea or coffee as in central Kenya, these are largely absent from the landscape with the exception of sites near the single tea factory in Vihiga District. Instead, the predominant production system is production of seasonal crops during two seasons each year.

Rural population densities in some areas of western Kenya (e.g., Vihiga) are the highest in all of Kenya (at over 1,000 per square kilometer). Two main ethnic groups are found in the area, the Luhya (Vihiga) and the Luo (Siaya). There is a fairly dense road network, but the roads are of poor quality, including tarmac roads that are in disrepair. Other infrastructure such as telephone lines, water, and electricity is equally lacking. The potential for accessing markets is high, but actual commercialization of agriculture is lower in these areas than in nearby districts. The districts host a large number of NGOs that are active in agriculture. In terms of poverty rates, Vihiga and Siaya rank as among the very poorest of the districts with relatively high agricultural potential, with poverty rates of 58 percent and 62 percent, respectively (Republic of Kenya 1997).

Much of the data from western Kenya are derived from studies in 17 villages in Siaya and Vihiga Districts. Some results are from a census of over 1,600 households, whereas others are from smaller subsets of them. The locations are very representative of most of Vihiga: very small farms and predominance of maize/bean farming.[2] Siaya District contains both highland and midland areas, but our sample is derived exclusively from the higher potential highland areas. There have been numerous studies in these villages, and sampling procedures have differed depending on the objective of the research. The individual studies are cited in the text so that more details of the data and households can be found by the reader. In central Kenya, our samples are drawn mainly from the coffee- and tea-growing areas, where dairy farming is also common. Two of the studies, however, do include some households in the lower-potential areas where maize production becomes more important. Most of the households in these studies were selected at random, although some have used different stratification methods. Again, these are cited in the text.

Household Resources and Agricultural Enterprises

Household Resources

Nuclear households are the main decisionmaking units over farming (in the sense that sons and their wives form their own household and manage their affairs without much influence of the parents) in both the central and western highlands.[3] These independent households are becoming increasingly diverse and complex as a result of the ravaging of HIV/AIDS and the pursuit of alternative livelihood options because of the small farm sizes. Western Kenya households seem to be much more affected, as for many years the number of female-headed households (in which the husband was working off-farm) has been high, around 30 percent of the population (Wangila, de Wolf, and Rommelse 1999). The mobility of individuals along with the effects of high death rates has led to the observance of many households headed by widows or composed of nonnuclear members. On the other hand, monogamous male-headed households are the majority in the central Kenya sites, as shown by recent studies (Murithi 1998; Njuki 2001).

The large outflow of men from households, especially in western Kenya, not only results in loss of male labor but increases the difficulty for households to make certain types of decisions regarding farm investment. Mugo (1999) shows that when husbands are away, there is considerable variation in the extent to which women are able to make decisions over land management. In terms of labor, men generally provide important roles in land preparation, cutting of trees, and caring for livestock. Women can assume these roles too, but their time is squeezed by other demands. The presence of two adults also enables households to simultaneously practice good husbandry on their own land while earning cash by working off the farm. With a single adult, there are more serious trade-offs in selecting one or the other option.

In terms of available labor, given the high population densities in the highland areas, there is a large aggregate pool of local labor. But this does not translate directly into available labor for agriculture. First, many of the individuals are of school-going age and have only limited hours during the day to assist on the farm. Second, many of the educated young adults show relatively little interest in agriculture.[4] Last, agricultural wages must compete with other types of employment to attract workers. Where wages are attractive, there do not appear to be cases of observed labor shortages in Kenya, even when demand is high or seasonal. Thus, the relatively attractive piece rate wages for tea and coffee[5] harvesting lead to sufficient labor supplies in the central highlands. In western Kenya, there appears to be poor management of farm enterprises despite the presence of high man–land ratios. The reasons seem to be multiple, including lack of interest in working the land by the youth, lack of cash on the part of farmers, and low returns to the predominantly cereal-based production system.

The high population densities in both highlands imply that farm sizes will be small. The average farm size near the slopes of Mt. Kenya is between 1.0 and 2.0 hectares. Murithi (1998) found a mean of 1.9 hectares in the coffee zone. In nearby districts, a mean of 1.3 hectares was reported by Argwings-Kodhek et al. (1999). In most areas of the western Kenya highlands,[6] average farm size is somewhat lower, at between 0.6 and 1.0 hectares (Argwings-Kodhek et al. 1999; de Wolf and Rommelse 2000). As in most places in Africa, there is a noticeable variation in holding size, but there are very few large farms. For example, in the western Kenya sites, the range in farm sizes within a village is generally from 0.2 to 5 hectares. In both regions, farms consist mainly of a single parcel of land that is often in a narrow strip running from the top of a ridge (where the road and house are) down slope, possibly to a valley bottom. Land is acquired mainly through inheritance, but land purchases also occur, and tenure is considered to be secure. One difference is that in central Kenya most farmers hold titles to land, but in western Kenya, many farmers do not bother to update titles that are often in the name of their father.

Although both land and labor are limiting in certain cases, most farmers mention lack of cash as the most critical constraint. This stems from lack or irregularity of income, weaknesses in credit markets, and high demands for expenditures, both anticipated and unexpected. Expenditure needs are relatively high in Kenya because of the need to contribute to education and health services through cost sharing. In addition, unexpected expenditures related to increased numbers of funerals have stretched capacities of many households. Significant amounts of credit are available only through membership in coffee or tea cooperatives. Other sources are informal, for example, through small community-based groups that generally provide modest resources. Income sources and sizes vary considerably across the highlands of Kenya, and these are analyzed in more detail in a later section. The net result of all these factors is that cash flow is often the main focus of management of households. Cash flow management leads to the foregoing of purchase of inputs, the hiring out of one's labor rather than working on one's land, and the searching for water and firewood over long distances rather than buying the resources on the market.

Current Agricultural Enterprises

Crops. Data on crop enterprises in western Kenya comes from a 1997 survey of all households (about 1,600) residing in a pilot area for agroforestry testing. Maize was the most predominant crop in these 17 villages, with only 10 households not growing any. Other common crops include local beans, bananas, cassava, sweet potatoes, kale/cabbages, and napier. Another set of crops, sorghum, tomatoes, and groundnuts, were grown by fewer than 50 percent of farmers. Sugar cane, which is the major crop produced purely for income, was grown by 31.2 percent of the households. Among the crops in Table 8.1, the mean and median number grown per farm is six.[7] Despite the large number of crops found on a given household, maize or maize–bean intercrops dominate the area under cultivation. For example,

Table 8.1 Crop production in western Kenya for 17 villages in Siaya and Vihiga districts

Crop	Number of valid responses	Percentage of households growing	Percentage mainly for own consumption	Percentage mainly for market
Maize	1,714	99.4	91.4	7.9
Hybrid maize	1,714	14.6		
Local beans	1,714	96.3	89.6	6.7
Bananas	1,713	84.5	68.9	15.5
Cassava	1,711	74.5	70.0	4.4
Sweet potatoes	1,710	74.2	71.7	2.5
Kale/cabbages	1,712	56.5	42.2	14.1
Sorghum	1,713	36.8	35.4	1.4
Tomatoes	1,712	12.1	8.6	3.3
Groundnuts	1,152	5.3	3.7	1.1
Sugarcane	1,147	31.2	23.5	7.5
Woodlots	1,697	79.8	57.9	21.6
Napier	1,710	42.0	36.7	5.2
French beans	1,701	2.1		2.1
Tea	1,607	0.1		0.1

Source: Wangila, de Wolf, and Rommelse (1999).

Owuor (1999) found that 66 percent of cultivated area was under maize in the western highlands.

In central Kenya, the major crops on farms are maize, beans, potatoes, vegetables (kales, tomatoes, spinach, onion, among others), french beans, and yams among annuals and coffee, macadamia, bananas, avocado, mango, tea, passionfruit, sugar, *miraa,*[8] and papaya among perennials. Njuki and Verdeaux (2001) found that farmers were growing an average of six different crops in the coffee and tea zones of Embu and Kirinyaga. This was more than the average number of crops in the adjacent lower zones (with lower rainfall and population density). With respect to the type of crops grown, farmers in the uplands grow crops more for the market than those in the lowlands. Market-oriented crops include tea, coffee, and horticultural commodities such as tomatoes, kales, cabbages, and fruit. Owuor (1999) found that a large portion of area was devoted to traditional industrial crops such as coffee and tea (27 percent) and to horticultural crops (19 percent). On the slopes of Mt. Kenya, the proportion of area under coffee was similar (26 percent) to that of maize monocrop or intercrops (28 percent) (Murithi 1998).

Thus, it is found that farmers throughout the western and central highlands produce a variety of crops, even on small farms, as population pressure intensifies.[9] Commercialization does not appear to alter the number of crops grown by smallholder farmers and indeed appears to increase the level of diversity according to area by reducing the "traditional" high allocation of land to cereals and substituting an array of market-oriented crops in their place. We shall come back to this point later in the analytic sections.

Livestock. Livestock production in the western Kenya system is mainly based on a semi-intensive dairy-meat-draft-manure system. This is largely with indigenous animals, as only 3 percent of the nation's dairy animals are found in the Western Province. On the other hand, the Western Province has 10 percent of the national indigenous herd. Because of land scarcity, confined grazing on farms or roadsides is dominant. This makes it relatively easy to collect manure, and indeed, this is the most widely used crop nutrient source, though in modest amounts (Place et al. 2002a). Livestock production in the area is based on local cattle and poultry, with few sheep, goats, or pigs, as shown in Table 8.2. The livestock population is notably small in the area, most likely because of livestock diseases, lack of veterinary services, and shortage of browse caused by land scarcity. Herd sizes are also difficult to increase or maintain because of cultural obligations such as funerals.

A large majority of households own cattle in the central highlands, as many as 90 percent in some areas. Among the farmers who own cattle, the average number held is 2.3 per household (Murithi 1998), nearly all being improved breeds or

Table 8.2 Livestock numbers in highland households of Siaya and Vihiga Districts, western Kenya

Livestock type	Farms	Animals	Percentage of farms with animals	Average herd/flock size (all households)	Average herd/flock size (households with animals)
Improved cows	1,702	178	4.3	0.11	2.41
Local cattle	1,703	2,051	53.3	1.20	2.26
Sheep and goats	1,703	771	16.9	0.45	2.68
Pigs	1,699	8	0.3	0.01	1.60
Poultry	1,642	7,738	72.3	4.71	6.52

Source: Wangila, de Wolf, and Rommelse (1999).

crossbreeds. All but about 6 percent are managed in zero grazing units (Murithi 1998). Cattle are raised mainly for milk production, with manure being the second most important reason. Farmers in the midlands have the highest number of goats: 1.06 compared to 0.92 in the uplands (the tea zone). Improved dairy goat breeds are increasing in number over recent years, spurred on by the Dairy Goat Association of Kenya. As is common throughout the highlands, central Kenya farmers keep a large number of poultry, and there are more cases of commercial enterprises than in western Kenya.

Tree growing. Western Kenya is characterized by three types of tree-growing practices. The first is the management of small private woodlots by farmers. As shown in Table 8.1, 80 percent of Siaya and Vihiga highland farmers had a woodlot on their farm. The woodlots consist overwhelmingly of *Eucalyptus* spp., which are popular with farmers because of their fast growth, straight trunks, and coppicing ability (regrowth from the stump). Eucalyptus trees are considered to be best for poles, but their use for fuelwood is also growing (as other species become rarer). In addition to eucalyptus woodlots, other timber trees such as cypress and *Markhamia* are grown on boundaries or near homesteads. The other common trees are tropical fruit species such as papaya, mango, and avocado. These are also found on most farms near homes, but are few in number, one or two per household. On average, farmers in Vihiga District had about 160 trees on their farms (Mugo 1999).

In central Kenya, the dominant tree on the landscape is *Grevillea robusta,* which was found to be grown by 86 to 94 percent of households on their boundaries (indeed, it is used to demarcate boundaries) (Mugo 1999; Njuki 2001). On average, there are fewer trees per farm in central Kenya, mainly because of the lack of woodlots as a result of the strong competition with other profitable enterprises. The average reported by Mugo (1999) for Kirinyaga was about 130 per household, and Njuki (2001) found about 90 trees for wood on farms in the same farming zone.

Apart from *Grevillea,* fruit and nut trees are also common and have been reported on about 64 percent of farms. Among these, macadamia trees are the most well known and provide a good income. Macadamia was first introduced in the 1970s on a very small scale, and later they became more and more popular as an alternative cash crop. The traditional varieties were replaced by the grafted, shorter maturing, and more productive varieties as the market for macadamia grew. Avocado is also common in the central highlands, as are mango, papaya, and guava. Fodder trees are increasing in popularity because of the relatively large proportion of dairy farmers in central Kenya. In one area studied, Murithi (1998) showed that about 20 percent of dairy farmers had planted some type of fodder tree.

Agricultural Investment

In traditional agricultural development models, at low levels of population density and rudimentary access to markets, households would produce a wide variety of foods for subsistence needs. As markets developed, households would specialize into fewer commodities, generating surpluses in some, and obtain desired consumption baskets through market exchanges. In the central Kenyan highlands, this model has not followed to form (see above on the lack of specialization). First, the degree of specialization for the subsistence-oriented households in the highlands is more than might be predicted because maize is the primary staple food, dominating dietary intake. For instance, Rommelse (2001a) found that over 73 percent of energy consumed by households in Vihiga and Siaya comes from maize alone. Thus, a subsistence-oriented household will devote much of its land to maize with small amounts for complementary vegetables.

As population pressure intensified and farm sizes fell, there were essentially four options for households: (1) increase landholdings through purchases, (2) intensify production and increase yields from maize or other existing staples, (3) substitute into new agricultural enterprises, or (4) diversify livelihood strategies off farm. The first option is possible in the highlands, but finding additional land in close proximity to existing landholdings is not simple, and moreover, the poorest households would not afford the selling prices for land. Thus, it is a very limited option viable only for a minority of households.

The second option has been available for many years through the use of improved seed varieties and fertilizer, but high costs and lack of credit have limited the use of this option. More recent organic nutrient management systems have also been developed and disseminated in many highland areas. A major limitation of these components of the second option is that even with an increase in yields, households with farms of 1 hectare or less will struggle to produce enough maize. Moreover, the low value of maize per hectare means that its exchange value for other needed items (e.g., medicines, schooling) is very low. This option has been emphasized primarily by Rift Valley farmers who still retain relatively large farms (this is the prime maize-growing belt of Kenya with many medium-scale farmers).

The third option of diversifying into higher-value agricultural enterprises is a strategy pursued by many farmers in the central highlands of Kenya. It is a strategy that requires good access to markets and the ability to produce a range of higher-value crops at a profit. As shown in the following section, Njuki and Verdeaux (2001) show that central Kenya farmers have adopted many new enterprises over recent decades.

The fourth option of diversifying out of agriculture is one that is pursued to some degree in almost all rural areas of Kenya. Argwings-Kodhek et al. (1999) report that nonfarm income is important in all regions. The nature and level vary across districts, and there is evidence that higher absolute levels of nonfarm income are positively associated with higher absolute levels of farm income. Thus, option 4 may be complementary with options 2 and 3.

All four options may be mutually reinforcing. Which one is likely to drive the other and under what circumstances is an important but generally unexplored area of analysis. Investments in education have clearly helped reduce poverty rates among households later formed by the recipients (Republic of Kenya 1997). There are examples of agriculture-led and non-agriculture-led poverty reduction from both regions. In the past, it could be argued that commercialization of agriculture was a major driving factor in poverty reduction in central Kenya. Now, there are increasing examples of retired or retrenched urban workers investing their savings or pensions in agriculture. Which option is best appears to be partly driven by locational factors (e.g., climate, market access) but also by household-level factors because there remains significant heterogeneity in resources and capabilities among households (see Jayne et al. 2003b for the inequality of landholdings in Kenya). We shall now explore some of the agriculture-based opportunities in more detail, including the extent to which they are accessible to the different regions and different households within each.

New crops or crop mixes. One of the strategies farmers have used to cope with reduced land sizes and changes in livelihoods has been crop diversification. In the central highlands, Njuki and Verdeaux (2001) found that farmers were growing between six and seven crops because of reduction in land size, loss of market for old crops, and opening of new markets for new crops. Area under annual crops can be altered seasonally, but some of the important cash crops are perennials, and their area changes more slowly. Currently, there is little current investment in coffee because of a decline in coffee prices and mismanagement of the coffee cooperatives. Coffee output has thus fallen dramatically, but the area under coffee much less so. There is relatively high investment in tea in the upper lands and horticultural crops.

A recent study has documented the changing patterns of agricultural enterprises in the central highlands (Njuki and Verdeaux 2001). Table 8.3 presents a summary of the major changes in crop production in Embu, comparing the current situation to that at the time of independence (1963). Tea and potatoes were introduced at the time of independence. A large number of trees were introduced during the 1970s. A few crops, climbing beans, sweet potatoes, and passion fruit have all been introduced since the 1980s. Two of the most important crops, coffee and maize, had been cultivated in both periods, though there were strict marketing limitations facing African coffee producers prior to independence. This diversification into higher-value crops at the same time as average farm size is shrinking serves as a cushion against risky markets and testifies to a recognition by farmers that farming is a business and not just as a way of life.

There is much less known about changes in crop mix in the western highland areas. The response to market opportunities appears to be more uneven than in the

Table 8.3 Changes in crop cultivation before and after independence on the southern slopes of Mt. Kenya

Type of crop	Cultivated before 1963 but not now	Cultivated now but not before 1963	Time of introduction
Legumes	Pigeon peas	Climbing beans	1992–93
	Njabi		
	Cowpeas		
	Green grams		
Grains	Millet	Baby corn	
	Sorghum		
Root crops		Irish potatoes	1963
		Sweet potatoes	2000
Stem and fruit crops		Bananas	1970s
		Mangoes	1960s
		Avocado	1970s
		Tree tomato	1970s
		Passion fruits	1980s
		Pawpaws	1970s
Crops exclusively for sale		Tea	1963
		Macadamia	1970s

Source: Njuki and Verdeaux (2001).

central highlands. This may be because of its poorer access to the Nairobi processor and consumer markets, and therefore farmers face keener competition for the smaller regional market. For instance, informal market surveys have found that much of the vegetables found in Siaya markets come not from nearby farmers but from farmers in Nandi or Uasin Gishu Districts (more commercialized districts located along the western edge of the Rift Valley) (Rommelse 2001b). In areas where farmers are not well linked into market opportunities, there has been little incentive to alter production patterns. Within villages in Vihiga and Siaya, there do not appear to be strong differences in crop mix across households of different size or households at different stages of life cycle. That is, there are no apparent patterns of diversification or specialization emerging.

What drives the process of diversification, and which households can join the process? The chronology of agricultural development in the central highlands suggests that government investment in tea and coffee marketing and processing enabled a large number of households to establish these commercial crops. With these founding commercial enterprises, huge investments in improved dairy animals occurred, and with them additional horticultural crops and heavy input use. In the western highlands, there was no similar successful government investment (though some attempts failed). Yet, similar patterns of diversification into dairy and other commercial enterprises are found in the few areas where tea has been promoted. With recent troubles in the cooperative sector (tea excluded), more recent investments in diversification may have been funded from nonfarm sources. However, studies of farm and nonfarm interactions are lacking for rural Kenya.

Livestock types and inputs. At independence in the Mt. Kenya highlands, most people kept large numbers of livestock, cattle, sheep, goats, and poultry. The cattle were originally zebu and were grazed in paddocks. In the 1980s, there was introduction of crossbred and exotic cattle and a shift from paddock grazing to zero grazing. This was accompanied by a reduction in the number of cattle that farmers kept. The reduction of livestock numbers is best illustrated by the livestock numbers held by different generations of households (Table 8.4). Njuki and Verdeaux (2001) traced the number of cattle through three generations of households. The oldest generation had the highest number of cattle at the time of study and also had the highest number of cattle ever held. Moreover, all generations now have fewer livestock than they once had.

The lower numbers among the current generation have three main reasons. The exotic breeds were high producing and input intensive. In some cases, desired output levels could be achieved with fewer animals, and in other cases, high feed

Table 8.4 Difference in livestock numbers among farmer generations in Embu District

Generation	Number of cows	Largest number of cows ever held	Number of goats	Largest number of goats ever held
Generation 1	1.40	10.19	1.20	21.13
Generation 2	0.61	2.64	0.54	7.88
Generation 3	0.33	1.00	1.33	3.33
F value	5.688	11.184	3.225	1.183
Significance level	0.004	0.0001	0.43	0.315

Source: Njuki and Verdeaux (2001).

costs limited the number of exotic cattle that farmers could keep. The second reason is the reduction in farm size and lack of area for producing feed. Last, increased labor spent on nonfarm activities will tend to reduce agricultural investment across the board. The pattern for goats is somewhat different. Though current herds are smaller than those once held by households, today sizes are similar for different-aged households. Goats are becoming popular among the young in good part because new high-quality dairy goats are being promoted by NGOs using schemes that require little cash. Discussions with farmers also indicate that investment in goats may partly compensate for an inability to establish a dairy cattle system.

Nonetheless, the numbers of improved dairy animals held by smallholder farmers is impressive. It is estimated that there are slightly more than 2.5 million dairy cattle on 600,000 smallholder dairy farms in Kenya, the most in all of Sub-Saharan Africa (Peeler and Omore 1997). Central Province, with 27 percent of the stock, is home to the second largest number of improved dairy animals in Kenya. There are many accompanying investments that follow the improvement of cattle breeds. Some of the recent investments among central Kenya dairy farmers are in feeding regimens. Murithi (1998) found that among dairy farmers, 98 percent had planted napier grass, 18 percent had fodder trees, and 16 percent had planted high-quality pastures.

In western Kenya, as indicated in Table 8.2, one striking difference from the central highlands is the lack of investment in higher-grade cattle and accompanying investments in zero grazing. Very few households have such animals in the sample from Vihiga and Siaya. On the other hand, there is quite a significant investment in napier grass (Table 8.1). Some is used to feed local cows, but some is produced for sale by households without cattle. For instance, 7.4 percent of poor farmers were found to produce napier for the market as compared to only 2.5 percent of the nonpoor. There appears to be a reduction in livestock numbers across generations, similar to the results from the central highlands. The youngest household heads (below the age of 30) had on average 0.87 head of local cattle. Those between

40 and 50 had 1.09 head, and those above 60 had 1.49 head on average. The difference is highly significant, and the number of goats follows the same pattern.

Land investments and inputs. There is evidence to suggest that farmers in the central highlands make significantly more investments in soil management than their counterparts in the western highlands. First, Owuor (1999) found that fertilizer use intensity was highest in the central highlands (106.0 kg/acre). Fertilizer use on the higher-value crops was 194 kg/acre as compared to 58 kg/acre on the lower-value crops, so the mix of crops plays a key role in overall fertilizer rates. However, farmers apply nutrient inputs on most of the crops. Table 8.5 shows that a high proportion (75 to 92 percent) of farmers apply fertilizer on maize, potato, and coffee, and over half of farmers applied manure to all their crops (except for beans, which are normally not fertilized because of their nitrogen-fixing capability). Indeed, farmers placed the purchase of inputs among their top four expenditure categories in over 80 percent of cases in central Kenya, and about 30 percent of farmers felt that input investments ranked first or second (Murithi 1998).

In the western Kenya highlands, the amount of investment in land is much more varied across different sites, with our Vihiga and Siaya sites exhibiting little investment. Only about 20 percent of 1,636 households use fertilizer on a regular basis (Place et al. 2002a), and the amounts used per hectare are calculated to be about one-fifth (28 kg/acre) of those in the central highlands (Owuor 1999). There is somewhat more concentration on higher-value crops (40 kg/acre) as compared to 17 kg/acre for cereals. This low investment level is clearly linked to the relatively low use of industrial crops, horticultural crops, and high-yielding varieties of maize. Only 15 percent of 1,636 households reported the use of hybrids in 1997. Rommelse (2001a) found that the median annual expenditure on farm inputs (crops and livestock together) in western Kenya was about $15. On the other hand, organic nutrient input systems are currently being tested by a large number of households in western Kenya in good part because of a high concentration of NGOs in the

Table 8.5 Nutrient investments on major crops in the central highlands

Crop	Percentage of farmers growing	Percentage of farmers who apply fertilizer	Percentage of farmers who apply manure
Coffee	99	74	89
Macadamia	87	38	60
Bananas	59	11	56
Maize	89	92	57
Beans	82	27	17
Potatoes	69	90	69

Source: Murithi (1998).

region. Over 70 percent use animal manure, and about 40 percent use composting methods in Siaya and Vihiga. New agroforestry techniques for soil fertility management are also being tested by a good number of households (10 to 30 percent) where they have been introduced.

Comparing across the regions, Owuor (1999) reports that average fertilizer amounts per acre for the upper quartile of farmers in western Kenya is below the mean level of the lower half of farmers in central Kenya. These differences in nutrient investments are perceived by farmers to have had long-term effects on the soils as well. A study by Migot-Adholla, Place, and Oluoch-Kosura (1990) found that farmers in the central highlands overwhelmingly perceived their soils to be of higher quality than when they acquired the land (positive changes were reported by around 90 percent of farmers). The exact reverse was found among farmers in the western highlands. Thus, there is strong evidence of vicious poverty–environmental cycles at work in some regions while virtuous cycles exist in others.

Labor. One recent detailed study of labor has been undertaken in the central highlands. Njuki (2001) collected labor data by gender and by major crop during 1998, and some results are summarized in Table 8.6. Two major conclusions are evident:

1. Men and women both invest more labor in cash crops than in food crops.

2. Women invest more labor than do men in both food crops and cash crops.

The only activity where men contribute more labor than women is livestock raising. But even in this case, women's labor contribution nearly equals that of men. These results demonstrate the clear priority that households place on cash crops over food crops. Moreover, the idea that men are interested in commercial crops and women are interested in subsistence crops is dispelled by the fact that the ratio of female to male labor is similar for both types of crops. Because women often manage farms, either on a temporary basis when the husband is away, or because of death or divorce of a husband, the fact that women are active in the higher-value crops is very positive.

Driving Factors Underpinning Agricultural Investment

Macro and Meso Factors

In this section we highlight the major factors that could explain the remarkable differences in agricultural development between the western and central highlands.

Table 8.6 Allocation of labor by major crop in Kirinyaga and Embu Disticts

Activity/enterprise	Percentage of all labor allocated to the activity/enterprise (column percentage)	Women's labor as a percentage of total labor for each activity/enterprise (row percentage)
Food crops	13.8	70.2
Maize	4.4	68.8
Cash crops	49.9	67.6
Coffee	30.3	61.0
Tea	19.6	77.8
Livestock	10.6	47.6
Other resource management	3.8	96.5
Domestic	21.9	92.1

Source: Njuki (2001).

The key factors are highly linked to government policy and public investment. As a proximate factor, commercialization seems to be the most important. Throughout the previous discussion, the influence of markets and higher-value enterprises in central Kenya has been paramount. How did this occur? One obvious reason for relatively higher commercialization in central versus western Kenya is its proximity to Nairobi, where virtually all major agricultural processing firms are located. Also of great importance was government investment in tea and coffee factories in central Kenya. Because these had ready international markets, there was a steady inflow of income into the rural areas. Moreover, the tea and coffee associations provided credit to farmers, which helped to maintain high productivity levels. As global competition in these commodities has heightened, liberalization and the reduction of transaction costs may prove to be important in the future. Liberalization was certainly the most important policy change for the dairy industry. The role of culture is not clear, but there is more dynamism of individuals and groups in the central Kenya highlands (Place et al. 2002b). Whether this is inherent in culture or built from earlier successes is not clear. Last, it may also be useful to highlight the factors that are not important because of their similarity in both sites: rainfall, extension, and land tenure. In the following paragraphs we provide some illustrated examples of these factors.

There is a strong relationship between commercial orientation and agricultural development. Owuor (1999) shows that throughout all regions of Kenya there is a strong link among the proportion of crops marketed, the crop mix, and the value of crop production. For example, in central Kenya, the upper quartile of households according to value of crop production sells on average 63 percent of crops. On the other hand, the lower half of households sell only 38 percent of crops. The favorable crop mix has pronounced effects (direct and indirect through incentives for investment in other areas) on crop income. Households apply much greater concentrations of fertilizer and other nutrients on their higher-value crops. The end result is that households with higher-value crops earn significantly more than do households with lower-value crops.

Expansion of market opportunities in Kenya has been strong throughout the dairy sector. With the relinquishing of control of purchasing and processing by a monopoly parastatal in the early 1990s, there was a mushrooming of private firms in the dairy sector. These firms innovated a range of new products and brands of cheese, yogurt, butter, and ice cream. Added to this was the already strong demand for milk by nearby rural consumers (consumers of fresh milk and milk-based tea). At lower levels of the chain, a variety of buyers for milk emerged, including the large dairy producers cum processors. By 1998, Murithi (1998) found that smallholders were utilizing a range of outlets for their milk, including local trading centers, their farms, neighbors, the government parastatal, and dairy cooperatives.

Complementing the influence of markets for outputs has been the availability of credit for farmers in the central highlands. This is one success of the government-supported cooperative sectors in coffee and tea. Murithi (1998) found that 76.8 percent of households in Embu had received credit through their membership in coffee cooperative societies. A further 23.2 percent received credit from the Agricultural Finance Corporation. These outlets are largely unavailable to smallholders in the western highlands, and there are no other major sources that might fill this gap.

Household Factors

In this section we highlight the roles that household factors have in farmer investment patterns. In central Kenya, there are certainly differences in agricultural practices among households. However, these differences are not so apparent in the types of enterprises adopted, as evidenced in Table 8.5, but rather in the management of and investment in these enterprises. Unfortunately, the factors that explain differences in such investments are not well studied in the region. Therefore, this section draws on detailed microstudies from western Kenya.

Household wealth is positively associated with the presence of many of the investments discussed above. Using a wealth indicator driven by criteria identified by villagers, we classified households in Vihiga and Siaya into groups of "very poor," "poor," or "nonpoor." The nonpoor households have:

- larger farms (2.5 acres compared to 1.4 acres for the very poor),
- more cattle (1.7 compared to 0.6 for the very poor),

- a higher proportion cultivating high-value crops (67.1 percent compared to 51.9 percent of the very poor growing kale; 13.2 percent compared to 8.1 percent of the very poor growing tomatoes),

- a higher proportion growing hybrid maize (25.2 percent compared to 6.8 percent for the very poor), and

- a higher proportion using fertilizer (33.6 percent compared to 8.3 percent for the very poor).

In terms of overall expenditure on agricultural inputs, one study found that the nonpoor spent approximately $100 per year, whereas the very poor spent only $5 (Rommelse 2001a). However, Place et al. (2002a) found that poor households do invest in labor or land-using practices such as manuring, composting, and agroforestry techniques for soil improvement at rates similar to those of the nonpoor. For instance, the very poor had improved fallows on about 11 percent of their maize area as compared to 10 percent for the nonpoor.

In terms of the influence of gender of household head, the following relationships were found in western Kenya:

- Women grow slightly fewer crops than men (5.7 compared to 6.2 for men).

- Women are less likely to grow high-value crops than men (31.0 percent grow napier compared to 48.0 percent for men; 11.4 percent grow hybrid maize compared to 16.9 percent for men; 6.4 percent grow tomatoes compared to 14.4 percent for men).

- Women have similar land sizes as men.

- Women have similar numbers of local cows, goats, and poultry as men.

- Women are slightly less likely to use chemical fertilizer than men (17.4 percent compared to 22.6 percent for men).

Descriptive analyses found that farm size and education also feature in differences across households. The causal relationships are not determinate, but farm size in these areas is relatively fixed, with inheritance passing ownership of more than 90 percent of all land area. Farm size is positively correlated with cattle ownership, use of hybrid maize, and use of chemical fertilizer. But it is not linked to whether cash crops are grown. Farm size is also positively associated with education level, and education appears to be similarly critical in use of chemical fertilizer (e.g., fertilizer is used by 33 percent of those with secondary education and 11 percent of those with no education), use of hybrid maize, and the number of local cows owned. Education is also strongly linked to obtaining important off-farm income, and it is likely that the complementarities among education, agricultural assets, and off-farm income are key to household investment in western Kenya, if not throughout rural Kenya.

Effects of Investment and Land Management Choices on Income and Poverty

The purpose of this section is to assess the extent to which the abovementioned differences in agricultural investment translate into significant differences in income and poverty reduction. The first piece of evidence reported is a comparison of gross margins for different agricultural enterprises in central Kenya. Njuki (2001) measured outputs, inputs, and labor for 40 farmers during the 1998 growing season, and an analysis is presented in Table 8.7. In terms of gross margins (excluding own labor), it is clear that in the late 1990s coffee and tea were far superior to food crops such as maize, potato, and beans. Gross margins per hectare were between two and eight times those for the food crops. Returns from livestock farming were also relatively high. So shifts in relative enterprise mix can have a large influence on agricultural revenue. As demonstrated above, many households recognize these profitable opportunities and devote a high proportion of labor to them. However, households do not specialize in the highest expected return activities for several reasons. The key reason is economic risk both of finding markets for outputs and of obtaining a favorable price. Imperfect factor markets, especially for credit, hamper farmers' ability to access the necessary resources for the high input–high output farming systems.

The implications of this microanalysis are confirmed in a national study by Owuor (1999). In that study, a comparison is made between percentage area under cereals, industrial crops (coffee, tea, sugar), and horticultural crops and the percent of crop revenue that each contributes. Table 8.8 shows the results not only for the central and western highlands but for several other agricultural zones in Kenya. In most zones, the contribution of industrial and horticultural revenue to total crop revenue greatly exceeds the share of land under these crops. This is very evident in the central highlands, where the share of land area under industrial and horticultural crops is 46.2 percent, but their share of revenue is a staggering 71.1 percent. Thus, the central highlands have not only diversified into higher-value crops but have selected very profitable ones. On the contrary, though there is some diversification

Table 8.7 Seasonal gross margin for farm enterprises in central Kenya

Indicator	Coffee	Tea	Maize	Beans	Potato	Livestock
Output value (per farm)	258	272	32	31	35	135
Output value (per hectare)	947	1,035	65	52	137	—
Input costs (per farm)	22	48	14	4	10	43
Input costs (per hectare)	81	181	28	7	39	—
Hired labor costs (per farm)	12	25	6	13	—	
Hired labor costs (per hectare)	46	97	12	21	—	—
Gross margin (per farm)	223	199	13	14	25	92
Gross margin (per hectare)	819	757	25	24	98	

Source: Njuki (2001).

in the western highlands (28.0 percent of land under noncereal crops), these particular industrial and horticultural crops (e.g., sugar cane, cabbage) are not providing an incremental gain in revenue. The figure for average labor productivity summarizes this well. The productivity level in the central highlands is 3.5 times that in the western highlands, reflecting differences in crop mix, technical efficiency in crop production, and relative prices of inputs and outputs.

Do these differences in agricultural productivity translate into differences in household incomes? Argwings-Kodhek et al. (1999) show clearly that crop and livestock income play vital roles in total rural household income. It appears that farm and nonfarm income sources are complementary, providing investment funds for each other or at least secure bases that enable farmers to take risks in other ventures. In the central highlands, average total household income was estimated at $2,819. Of this, 39 percent or $1,099 came from crops, 24 percent from livestock, and 37 percent from nonfarm sources. Households in the western highlands earned 32 percent of income from crops, 29 percent from livestock, and 39 percent from nonfarm sources, which do not differ significantly from the pattern in the central highlands. However, total income for western highland households averaged only $1,014 (36 percent of the figure for the central highlands). Adjusting for farm size differences, central highland farmers earn 2.5 times the amount of crop income per person as western highland farmers. Similarly, livestock and nonfarm income are multiples of those earned by western highland households. In addition, average earnings for agricultural wage labor and nearly all other nonfarm occupations are higher in the central highlands than in the western highlands (Argwings-Kodhek et al. 1999). It seems that the high agricultural incomes from the central highlands play a significant role in stimulating the wider local economy.

So in aggregate, the investment in new enterprises and in intensifying crop, livestock, and tree production systems have led to significantly greater incomes for

Table 8.8 Contribution of different crop types to revenue generation

Crop	High-potential maize	Central highlands	Western transitional	Western highlands	Western lowlands
Share of land (percent)					
Cereals	93.1	53.7	51.0	72.0	84.1
Industrial	3.6	26.9	43.4	16.6	14.3
Horticulture	3.3	19.3	5.5	11.4	1.6
Share of revenue (percent)					
Cereals	84.7	28.9	36.8	71.4	58.9
Industrial	7.2	45.7	51.0	24.1	34.7
Horticulture	8.1	25.4	12.2	4.2	6.4
Land productivity (ksh/acre)	188	289	146	110	90
Labor productivity (ksh/adult)	257	262	142	74	60

Source: Owuor (1999).

central Kenyan farmers compared to their counterparts in other regions. In western Kenya, enterprise diversification has not yet been as extensive or profitable as in central Kenya. Consequently, intensification of production is lagging too, and low agricultural incomes are the norm. These general results mask important intra-regional differences between households, however. Jayne et al. (2003b) find that despite regional disparities, there exists substantial variation in household incomes within regions, districts, and villages. In line with the meso- and microanalyses in previous chapters, this shows that although getting the market economy right is an important antipoverty intervention, it by no means guarantees that all households can be uplifted. Special attention is still required for those households unable to seize opportunities in the agricultural or nonagricultural sectors.

Summary and Ways Forward

This synthesis began by demonstrating the significant gap in poverty levels between the relatively poor western highlands and the relatively better off central highlands of Kenya. It further tried to show the extent to which historical and current agricultural practices have influenced this divergence. Finally, policies and investments that have underpinned positive changes in the agricultural sector have been noted. A brief summary of this is shown in Table 8.9. In this section, we summarize those analyses and offer suggestions as to how agriculture could become more productive in the poverty hot spots.

In the Kenyan highlands, market development of higher-value agricultural enterprises is a strategy that has paid off for a large number of smallholder farmers. To reinforce the point that in the relatively market-oriented highlands of Kenya,

Table 8.9 Summary of comparative analysis

Indicator	Central Kenya	Western Kenya
Poverty rates	Low	High
Agricultural incomes	High	Low
Nature of agricultural enterprises	Diverse, commercial enterprises including perennials and high-grade dairy	Diverse, staple crops, local livestock breeds
Level of investment	Moderately high fertilizer use	Very little
Availability of credit	Mainly through cooperatives	No significant sources
Soil fertility management	Good, fertility improving	Poor, fertility declining
Public investment in agriculture	Tea, coffee, and dairy sectors with generally favorable results	Cotton and sugar mainly with mixed success
Private sector investment in agriculture	Dairy marketing, contract farming	Contract farming tried but not successful

food security is mainly about income generation (and not producing one's own food), Table 8.10 provides some data on sources of food consumed from western Kenya. The first striking fact is that households demand and consume a wide range of food products, and it is infeasible for households to produce all of these at sufficient levels. Second, it is easily seen that households are relying on market purchases, at least at times during the year, for most of the items, including maize. Rommelse (2001a) found that about 70 percent of household expenditures in the western highlands were for food. It is therefore clear that household food security would benefit significantly from enhanced income sources, whether from agricultural or nonagricultural sources.

Clearly, there are many examples of successful intensification from the central highlands. For this region, a key foundation has been either coffee or tea, both export crops with a ready buyer and supplier of inputs on credit. With these pillars in place, other commercial-oriented enterprises such as dairy, macadamia, pyrethrum, vegetables, and fruit trees were easy to accommodate.

This type of development pathway has escaped the majority of the western highlands. One factor has been the lack of parallel development of infrastructure for processing coffee and tea and to service high-quality animals. Proximity to Nairobi cannot be discounted as a factor. The end result is that much of western Kenya has focused on the development strategy of diversifying into off-farm activities. For the poor, this often means seeking jobs as agricultural laborers or relocating to Nairobi to work in the low-paying informal sector. These nonfarm strategies have yet to pay off for the majority of rural households.

Most households have invested considerable funds and foregone labor in the education of their children. Not only is this done on moral grounds, but it is expected to provide economic and social rewards to parents. In prior decades,

Table 8.10 Percentage of food consumption from own-farm production in Siaya and Vihiga

	Percentage of consumption from own production (range two visits)	
Food item	**Luhya**	**Luo**
Maize	19–46	59–66
Kales	38–56	71–75
Banana, cooking	83–87	88–96
Sweet potato	65–68	84
Beans	53–66	61–86
Cowpea leaves	83–96	76–92
Milk	24–31	24–27
Mango	44–78	87
Beef	0	0
Avocado	65–79	64–81
Banana, ripe	51–56	76–85
Cabbage	0–2	3–7
Chicken	51–78	97–98
Pawpaw	66–78	89–94
Egg	64–65	85–97
Rice	0	0
Cassava	0–33	53–75
Millet	20–38	8
Irish potato	0	1–11
Pumpkin leaves	51–55	68–88
Groundnut	28–36	21–40
Sorghum	41–59	20–66
Tomato	11	11

Source: Rommelse (2001a).

educating children to high levels was a poverty-alleviation strategy with a relatively high probability of success, even if after a long payback period. But now, education is only a necessary but not sufficient condition for a successful livelihood because job growth is poor if at all positive, and there are increasing numbers of educated job seekers. Furthermore, the costs of education at secondary levels and beyond are enormous. Thus, even this strategy requires the generation of funds for school fees. Where can funds for this or other large investments come from?

In central Kenya, it is clear that many households are able to generate significant sums of cash with which to meet such investments. It is thus more critical to explore possible ways to generate investment capital in the western highlands. We cannot explore all the potential nonfarm opportunities in this chapter, so we offer a few immediate prospects within agriculture. In the Siaya-Vihiga food production area, the 10 most commonly sold items are: (1) vegetables, (2) chickens, (3) fruits, (4) poles and timber, (5) milk, (6) maize, (7) fuelwood, (8) beans, (9) eggs, and (10) cattle and goats (Rommelse 2001a). Of these, some are feasible for households with little cash. These would include short-term enterprises such as certain types of vegetables (e.g., kales, but not tomatoes) and chickens (starting on a small scale). Longer-term investments in trees for fruits, poles and timber, and fuelwood are also feasible in terms of requiring little cash (but require land and the ability to bear lengthy payback periods). But even these small investments may be difficult for the poorest households. There are several "first steps" that households could take to generate small sums of cash without having to invest cash. These include better husbandry practices with existing crops including an expansion in the use of organic nutrients. Thes major question is whether these incremental gains can be used to fuel further investment in agriculture because the competition for cash from different consumption needs is acute. Many integrated interventions would be required for rapid and widespread improvements in agricultural productivity to take place in poverty hot spots. In a place like western Kenya, with good potential for commercial production but small farms, increasing credit opportunities will be essential.

Appendix: Description of Key Studies Synthesized

Author	Topics covered	Geographic area covered
Murithi (1998)	Farming system description, especially dairy	Central Kenya 100 hhs
Mugo (1999)	Female and male decisionmaking and tree planting	Central and western Kenya 200 hhs
Wangila, de Wolf, and Rommelse (1999)	Description of farming practices	Western Kenya 1600 hhs
Owuor (1999)	Farm enterprises, inputs use, and productivity	All of Kenya 1500 hhs
Argwings-Kodhek et al. (1999)	Farming systems and income	All of Kenya 1500 hhs
Njuki (2001)	Female and male labor allocation, enterprise profitability	Central Kenya 200 hhs
Njuki and Verdeaux (2001)	Historical change in farming systems	Central Kenya Focus groups
Rommelse (2001a)	Farm investment, consumption and expenditure	Western Kenya 120 hhs
Place et al. (2002)	Soil management	Western Kenya 1600 hhs

Note: All studies reflect data collected in the period 1995–2000.

Notes

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1. The Kenya Agricultural Marketing and Policy Analysis Project of Tegemeo Institute, Kenya Agricultural Research Institute, and Michigan State University.

2. There is one tea factory in the north of the district, and the immediate surrounding area is more prosperous than elsewhere. Our data do not include these households.

3. Two corollaries to this are (1) the influence of seniority among Luo men living together on a single compound and (2) cases where land given to sons has not been officially confirmed as permanent by the father.

4. Young males in the Siaya and Vihiga are often maligned by local leaders as being lazy if not delinquent (Wangila 2000).

5. For coffee, this may have changed during the downturn in coffee prices in the early 2000s.

6. Including the high-rainfall areas of Kakamega, Vihiga, and Siaya. Exceptions are former resettlement areas (e.g., in Kakamega) and the drier areas to the west (Busia, Bungoma).

7. This may underestimate the true diversity because yams, tobacco, millet, onions, cow peas, groundnuts, finger millet, coffee, sisal, sesame, and soybeans are also grown in the area.

8. A woody species grown as a bush whose main product is a stimulant that is sold in Somalia and the Middle East.

9. The high potential maize zone spanning the edges of the Rift Valley is an exception whereby cereals account for 93 percent of cultivated area on more medium- or large-scale farms (Owuor 1999).

Chapter 9

Policies and Programs Affecting Land Management Practices, Input Use, and Productivity in the Highlands of Amhara Region, Ethiopia

Samuel Benin

Increasing agricultural productivity is an important challenge in Sub-Saharan Africa (SSA). Since the 1960s, agricultural production in SSA has failed to keep up with population growth. The situation is severe in Ethiopia, particularly in the highland areas, where agriculture is primarily rain fed (about 95 percent); soil loss rates average 21 to 42 tons per hectare per year on cultivated lands (Hurni 1988; Kebede 1996); many soils show large negative nutrient balances (Stoorvogel, Smaling, and Janssen 1993; Elias, Morse, and Belshaw 1998); cereal yields are less than 1 ton per hectare in many places; and up to 2 percent of total crop production is lost annually from soil erosion alone (Kappel 1996).

Since 1991, the federal and regional governments of Ethiopia, within the framework of the Agriculture Development Led Industrialization (ADLI) strategy, have undertaken a massive program of natural resource conservation and huge investment in infrastructure (e.g., roads, irrigation), agricultural extension and credit, education, and other services to reduce environmental degradation, increase agricultural productivity, reduce poverty, and increase food security. Fundamental empirical evidence based on sound scientific methodology on the contribution of these public investments and programs to agricultural production is lacking. Also important is the relative contribution of the public investments and programs to agricultural productivity in low- versus high-agricultural-potential areas. Filling these knowledge gaps is the main objective of this chapter.

Data from household- and plot-level surveys conducted between 2000 and 2001 in the highlands of Amhara region are utilized in this chapter to examine the contributions (and implications) of land redistribution and tenure, infrastructure (irrigation, roads, markets), education, and agricultural extension to land management practices, input use, and land productivity (crop yield) in low- versus high-agricultural-potential areas. In contrast to many studies, several other factors including land investments, household structure and endowments, plot quality, population pressure, and natural factors that may affect land management practices, inputs, and land productivity are controlled for. The analysis is similar to that presented in Chapters 5 and 7 but focused on a different region.

The next section of this chapter presents the conceptual framework and hypotheses for examining the effects of policies and programs on adoption of land management practices, amount of inputs used, and land productivity. The study area and data are presented in the third section. The econometric approach, results, and discussion are presented in the fourth section, and conclusions and implications in the last section.

Conceptual Framework and Hypotheses

The underlying conceptual framework for the econometric analysis is similar to that presented in Chapter 5, though we present the framework here because of some important differences. It draws from the literature on agricultural household models (Singh, Squire, and Strauss 1986; de Janvry, Fafchamps, and Sadoulet 1991). In addition, the hypotheses about how land redistribution and tenure contracts may influence land management, inputs, and productivity draw from the literature on property rights and investment incentives (Barrows and Roth 1990; Feder and Feeny 1993; Place and Hazell 1993; Besley 1995; Gavian and Fafchamps 1996; Pender and Kerr 1999; Place and Swallow 2000; Otsuka and Place 2001a) and land rental markets and agricultural efficiency (Cheung 1969; Otsuka and Hayami 1988; Otsuka, Chuma, and Hayami 1992; Ahmed et al. 2002; Pender and Fafchamps 2006, forthcoming). The effects of other policies derive from theories of induced technical and institutional innovation in agriculture (Boserup 1965; Hayami and Ruttan 1985; Pender 1998; Fan and Hazell 2000).

Crop output is given by equation (9.1):

$$\text{CROP OUTPUT}_{h,p,t} = f(\text{LAND INVESTMENTS}_{h,p,t}, \text{INPUTS}_{h,p,t}, \text{LAND MANAGEMENT PRACTICES}_{h,p,t}, \text{EXTENSION}_{h,t}, \text{CROP}_{h,p,t}, \text{LAND QUALITY}_{h,p,t}, \text{TECHNICAL KNOWHOW}_{h,t}, \text{NATURAL FACTORS}_{v,t}) \quad (9.1)$$

In equation (9.1), crop output of household *h* on plot *p* in year *t* is expressed as a function of the stock of land investments (or indicators of long-term investments) on the plot, especially soil and water conservation structures (e.g., stone terraces, soil bunds) and irrigation, amount of inputs used on the plot (e.g., labor, animal draft power, seeds, chemical fertilizers), land management practices used on the plot, especially soil-fertility practices (e.g., crop rotation, crop residues, manure), extension, type of crops planted, and the operator's technical knowledge, which is enhanced through education and farm experience.[1] Other factors affecting crop output include characteristics and quality of the land (e.g., size, slope, soil depth) and natural factors (e.g., rainfall, elevation). Amount of inputs used, land management practices, extension, and type of crops planted are in turn given by equation (9.2), where *X* represents the vector of the above endogenous variables.

$$\begin{aligned} X_{h,p,t} = f(&\text{LAND INVESTMENTS}_{h,p,t}, \text{LAND QUALITY}_{h,p,t},\\ &\text{TECHNICAL KNOWHOW}_{h,t}, \text{NATURAL FACTORS}_{v,t},\\ &\text{LAND POLICY}_{v,t}, \text{LAND TENURE}_{h,p,t},\\ &\text{ACCESS TO INFRASTRUCTURE AND CREDIT}_{h,t},\\ &\text{ENDOWMENT OF ASSETS}_{h,t}, \text{SOCIAL CAPITAL}_{v,t},\\ &\text{POPULATION DENSITY}_{v,t}) \end{aligned} \tag{9.2}$$

Here, the assumption is that inputs, land management practices, extension, and type of crops planted depend on the factors determining profitability of crop production. They depend also on the land policy and land tenure status (which affect the future returns from current practices); household access to roads, markets, and credit (which affect the ability to purchase or hire inputs); household endowments of land, labor, oxen, and other assets, and social capital (which are important for labor, draft power, manure, credit, etc., where markets for such inputs do not function properly or do not exist); and population density and other village-level factors (which affect the value of land relative to labor).

Note that equation (9.1) is a production function and so excludes those factors that do not have a hypothesized direct effect on crop production. Inputs, land management practices, extension, and type of crops planted, on the other hand, depend on additional factors that influence the awareness, availability, costs, benefits, and risks associated with them. Once the equations are estimated, the estimated coefficients can be used to predict the effect of the policy and program variables on crop output, for example, directly as specified in equation (9.1) or indirectly via the effects of land management practices, inputs, extension, and crop choice. For example, irrigation can affect crop output directly as well as indirectly via its influence on land management, inputs, or crop choice decisions, whereas the effect of market access on crop productivity can be measured indirectly via its influence on land management, inputs, and crop choice decisions.

Research Hypotheses

There are potentially a large number of testable hypotheses that can be considered concerning the relationships between the dependent and explanatory variables, as specified in the conceptual framework in equations (9.1) and (9.2). Many of these hypotheses have already been discussed in Chapters 2, 5, and 7. In this section, we focus on the effects of land redistribution and tenure, providing more local context than was possible in Chapter 2.

The nature of tenure on a plot of land can affect land management and productivity on that plot for several reasons. If land tenure is insecure, then the household operating the plot may have less incentive to invest in land improvement (Feder and Feeny 1993). However, the household may increase investment if the investment can in turn increase security of tenure (Besley 1995). Thus, there may be more investment in land improvement on plots with insecure tenure.

In Ethiopia, and particularly the Amhara region, one source of tenure insecurity derives from land redistribution, which has been frequent and ongoing since 1975 (instituted by the military government) to reduce landlessness and equalize landholding size and quality across households. Although land redistribution was stopped in many regions of Ethiopia in 1991 (with the current government coming to power), it continued in many parts of the Amhara region. A major recent redistribution exercise in the region took place in 1996–97, raising the proportion of farmers who owned land to about 72 percent (547,087 out of the total 756,809) (GEA 1997). However, actual implementation, type and amount of land affected, and population affected were not uniform across the region, as the exercise was left to local officials for needs assessment and implementation. In general, newly married couples (and the youth), widows, single women, and the poor were the main beneficiaries, and those classified as bureaucrats (associated with the feudal system or the previous military government and religious leaders), who were believed to hold excessive amounts of land, were the losers. See Ege (1997), Yigremew (1997), Gelaye (1999), and Ege and Aspen (2003), for example, for accounts of the implementation in specific parts of the region. Generally, the redistribution exercise drew a massive reaction, both against and in support of it, which was expressed through rallies and demonstrations (UNDP 1997) as well as songs and poetry (Gelaye 1999). Very few studies, however, have examined the effects of land redistribution on land management and productivity in Ethiopia. Although land redistribution may cause tenure insecurity (Holden and Yohannes 2002), it may have mixed influences on farmers' land management and productivity through short- and long-term effects

(Benin and Pender 2001). On one hand, by improving access to land of households that have relative surpluses of other important factors of production, such as labor, oxen, or cash to purchase inputs, particularly in the context of prohibited land sales and restricted lease markets as exist in Ethiopia, land redistribution may increase intensity of land management and use of purchased inputs, which may in turn increase productivity. On the other hand, land redistribution could also lead to inefficient factor ratios by forcing households with greater access to those other important factors of production to have the same landholding size as their poorer counterparts. Furthermore, expectations of future land redistribution may undermine farmers' incentive to invest in land improvements and soil fertility because farmers' ability to reap the benefits of such investments is undermined, adding to the ambiguity of the effect of land redistribution. Although the notion that a farmer may increase investment if the investment can in turn increase security of tenure or prevent one's land from being redistributed is not as evident in Ethiopia as it is in West Africa (for example, Besley 1995; Quisumbing et al. 2002), it can contribute to the ambiguity because farmers are entitled to compensation for any investments made on their redistributed lands, even if certain long-term investments such as planting trees on farmland are discouraged from the start.

Also responding to the problem of unequal landholding is the practice of transferring land through temporary leases in the form of sharecropping, fixed-fee rentals, or borrowing. The ability to temporarily transfer land can help households who own little or no land to overcome land constraints and also help those with little or no inputs (especially oxen and labor) to lease out the land and obtain capital to engage in other income-generating activity. However, the efficiency of alternative land tenure contracts has generated a lot of discussion in the past (Johnson 1950; Cheung 1969; Otsuka and Hayami 1988) and is still very much debated (Otsuka, Chuma, and Hayami 1992; Otsuka and Place 2001a; Ahmed et al. 2002; Pender and Fafchamps 2006, forthcoming). Underlying the debate about the inefficiency of alternative land contracts is the incentive that the contracts provide to the tenant. With perfect markets and no risk, fixed-fee or cash rental should result in an efficient resource allocation, as in the case of owner cultivation, because the fixed-fee rental would induce the tenant to produce the optimal level of output, where the marginal product of the tenant's extra effort equals the marginal cost of putting that effort. However, cash constraints (inability to pay the rent up front) or risk considerations may hinder the ability or preference of tenants in using fixed-fee rental. In this case, potential tenants may prefer sharecropping. However, because the share tenant receives as marginal revenue only a fraction of the value of his or her marginal product of labor, sharecropping limits the tenant's incentive to supply labor or other inputs at the optimum level, resulting in lower yields. If effort, however, can be easily monitored (or is costlessly enforceable), then a sharecropping arrangement can be as efficient as owner-cultivated or fixed-fee tenancy (Johnson 1950; Cheung 1969). The same result holds if there is mutual trust between the landowner and the tenant, as often exists in small communities where farmers know each other and lease markets are not restricted (Otsuka and Hayami 1988; Pender and Fafchamps 2006, forthcoming). To the extent that perfect markets for other factors of production exist, achieving allocative and productive efficiency may not require land rental markets to function (Pender and Fafchamps 2006, forthcoming).[2] However, imperfections in credit and input markets are important in developing countries' agriculture (Holden, Shiferaw, and Pender 2001), and they may be the main motive for the choice of sharecropping and the inefficiency surrounding alternative land tenure systems (Ahmed et al. 2002).

Given imperfections in factor markets, then whether or not the cost of monitoring and enforcement are low enough to result in efficient sharecropping remains an empirical question. The results can provide useful information, especially for the development by the regional government of the modalities of land leasing in the administration and use of land that has been ongoing in the region since 2000 (ANRSC 2000b).

Study Area and Data

Survey

The study is based on analysis of household and plot level surveys that were conducted in the highland areas (above 1,500 meters above sea level) of the Amhara region of Ethiopia in 2000 and 2001. These follow community surveys in 98 villages (*gots*) conducted in 1999 and 2000. At the community level, a stratified random sample of 49 peasant associations (PAs, usually consisting of three to five villages)[3] and two villages randomly selected from each PA were selected from highland areas of the region. Using district (*woreda*)-level secondary data, the stratification was based on indicators of agricultural potential (low or high),[4] market access (access or no access to an all-weather road), and population density (1994 rural population density greater than or less than 100 persons per square kilometer) (see Figure 9.1 in the color insert).[5] Two additional strata were defined for PAs where an irrigation project exists (in low- versus high-potential areas), resulting in a total of 10 strata. Five PAs were then randomly selected from each stratum (except the irrigated drought-prone stratum, in which there were only four PAs), for a total of 49 PAs and 98 villages. From each village, initially five households, and later four to speed up the data collection, were randomly selected to give a total of 434 households. In addition, all plots (1,422 in total) operated by the household were surveyed.

Information collected through structured surveys includes presence of programs and population in the community, household structure and endowments, household access to infrastructure and services, plot characteristics (mode of acquisition, size, slope, quality, crops cultivated, etc.), land investments, land management practices, inputs, and agricultural production in 1999. Recall methods were also used to obtain information before 1999, specifically 1991. Data on altitude were collected using a global positioning system (GPS). The primary data were supplemented by secondary information on amount of rainfall in 1999, obtained from the Meteorological Services Agency for weather stations located in the districts where the surveys were carried out.[6]

Data

Plot acquisition, tenure contracts, and land rights. In 1975, land was nationalized, and households were given use rights only, with occasional redistribution of farmland to accommodate landless households. Since 1991, households have been given the right to use the land indefinitely, lease it out temporarily to other farmers, and transfer it only to their children. However, they cannot sell or mortgage the land. In the Amhara region, land redistribution to address the increasing problem of landlessness and equalize landholding and quality of farmland has been common. There has been at least one land redistribution in about 73 percent of the villages since 1991, with the average number being three.[7] One of the villages interviewed had experienced as many as 14 land redistributions since 1975.

About 89 percent of the plots surveyed were cultivated by their owners, that is, by those receiving the land directly from the government or through gift, inheritance, or permanent exchange. These plots are referred to as owner-cultivated plots. The remaining 11 percent of the plots were mainly obtained through temporary farmer-to-farmer exchanges in the form of rental, mostly sharecropping. Renting in and out of plots of land is also common in other parts of the country, about 14 percent in Tigray region (Pender, Gebremedhin, and Haile 2002) and 11 percent in Oromiya region (Jabbar and Ayele 2002). Contracts for rented plots were very short (one season or year on average), and *equal* sharecropping (one-half of crop output to landowner) was the common practice. For fixed leases, rents were about 250–550 birr per hectare, depending on the quality of the land.[8]

Land rights associated with exchange, transfer, and making long-term investments were exclusive to owner-cultivated plots. There seems, however, to be a high level of restriction on rented plots even for simple activities such as crop choice and grazing animals. Tenants could not choose what type of crops to plant on 50 percent of the rented plots, and they could not graze their animals on 28 percent of the rented plots. Expectations to operate the plot over the next 5 or 10 years or to bequeath the plot were almost 100 percent on owner-cultivated plots but were between 20 and 28 percent on rented plots.[9] The main reason for expecting not to operate the plot in the future was fear of land redistribution on owner-cultivated plots and termination of rental contract or uncertainty of renewal of contract on rented plots.

Land investments and adoption of management practices and modern inputs. The presence of long-term land investments on plots was generally low. The most common types of investment were drainage ditches, occurring on 39 percent of all plots (Table 9.1). Stone terraces, fences, and live fences were next, ranging from 12 to 22 percent of all plots. Check dams, soil bunds, grass strips, and tree planting accounted for between 1 and 5 percent of all plots. There were some statistically significant differences in investments by land tenure. The incidence of stone terraces, live fences, trees, and check dams was significantly higher on owner-cultivated plots compared to rented plots, whereas the incidence of drainage ditches was higher on rented plots. In fact, there were no trees or check dams on rented plots. Possibly, owners of rented plots identify those as less productive or too far away and so did not invest in them before renting out, whereas those renting them have little or no incentive to invest in them. Note that it is not possible in the data to link

Table 9.1 Percentage of plots with investment by land tenure and redistribution in the highlands of Amhara region, Ethiopia

		Land tenure		Land redistribution in village since 1991	
Type of investment	**All plots**	**Owner-cultivated**	**Rented**	**No**	**Yes**
Stone terrace	21.9	23.5*	9.3*	26.4	19.9
Soil bund	3.2	3.2	3.6	1.2*	3.8*
Check dam	1.4	1.6*	0.0*	1.5	1.4
Drainage ditch	39.2	37.5*	52.6*	18.6*	47.4*
Irrigation canal	3.3	3.5	1.6	5.1	2.7
Grass strip	4.9	5.2	2.7	2.1*	5.8*
Planting trees	2.8	3.1*	0.0*	1.1*	3.3*
Fence	16.2	15.3	23.0	9.1*	18.8*
Live fence	12.5	13.7*	2.8*	11.4	13.0
Number of plots	1,187.0	1,057.0	130.0	346.0	841.0

Note: Rented plots include sharecropped and fixed-fee rented plots. Sample means are adjusted for stratification, weighting, and clustering of sample.

***Sample means in the relevant category are different at the 10 percent level of significance.**

Table 9.2 Percentage of plots using land management practice by land tenure and redistribution in the highlands of Amhara region, Ethiopia

		Land tenure		Land redistribution in village since 1991	
Type of investment	All plots	Owner-cultivated	Rented	No	Yes
Reduced tillage	25.2	25.7	21.1	22.5	25.1
Contour plowing	69.3	69.6	67.4	82.8*	64.9*
Crop rotation	62.4	63.7*	53.6*	64.4	60.8
Crop residues	64.0	64.0	59.6	73.9*	59.2*
Household refuse	17.4	19.4*	3.7*	17.6	17.5
Manure	9.0	9.8*	2.7*	10.6	8.4
Chemical fertilizers	34.5	32.1*	53.3*	10.6*	44.3*
Improved seeds	13.0	11.7*	22.7*	2.4*	17.0*
Number of plots	1,187.0	1,057.0	130.0	346.0	841.0

Note: Rented plots include sharecropped and fixed-fee rented plots. Sample means are adjusted for stratification, weighting, and clustering of sample.

*Sample means in the relevant category are different at the 10 percent level of significance.

rented plots to their respective owners in order to verify this. Where there were statistical differences by land redistribution, the incidence of investments on plots was higher in villages that have experienced at least one land redistribution since 1991. Villages experiencing land redistribution tended to be located more in the high-potential areas where such investments are more profitable.

Table 9.2 shows the most common land management practices used on the plots, including contour plowing (occurring on 66 percent of all plots), plowing in crop residues (64 percent), and crop rotation (62 percent). Reduced tillage was used on 25 percent of all plots, and chemical fertilizer, household refuse, and improved seed and manure were used on 35, 17, 13, and 9 percent of all plots, respectively. The low incidence of manure use on plots is likely because it is also used as fuel. However, increased use of chemical fertilizers under implementation of the massive agricultural package program, which led to a substantial increase in the cultivated area under chemical fertilizers, may have also reduced the need for manure. Here too, there were some differences by land tenure and land redistribution. Applying household refuse and use of manure were more common on owner-cultivated than rented plots. On the other hand, using fertilizers was more common on rented plots. This may reflect the relative long-term versus short-term return on investment in different inputs, where those with immediate (one season) benefits are preferred on rented plots. It is likely that renters have more resources including access to credit to finance the purchase and use of chemical fertilizers. However, most of the rented plots are sharecropped, where sharing of chemical fertilizer cost is a common feature. Thus, the cost (and risk) of applying chemical fertilizer is reduced for each party, which increases the likelihood of using chemical fertilizers on rented plots. Moreover, several of the rented plots were planted to maize on which chemical fertilizers are commonly applied. Looking at the differences by land redistribution shows that use of chemical fertilizers and improved seeds was greater in villages that have experienced land redistribution, whereas use of contour plowing and crop residues was less. As mentioned earlier, villages experiencing land redistribution were located more in the high-potential areas, where use of chemical fertilizers and improved seeds is more profitable.

Land use, inputs, and crop production. A majority of the plots (76 percent) were located in the fields, as opposed to those cultivated on the compound of the household (homestead, 24 percent). With very little irrigation (about 4 percent of all plots) and unreliable small rains (*belg*), crop production was restricted to the main rainy season, which is normally from June to October. Cereals dominated the crops cultivated. *Teff,* barley, wheat, and maize were the dominant monocropped cereals, taking up 50 percent of all plots. Other cereals (sorghum, millet, and oat), either monocropped or mixed with other cereals, made up 14 percent of the plots, and cereals mixed with other noncereal crops made up 16 percent. Legumes cultivated as monocrops made up 11 percent of all plots. The remaining 9 percent of the plots were cultivated with other crops or combinations of crops, excluding cereals.

The amounts of inputs used are shown in Table 9.3. For all plots, 287 man-days, 54 animal-days, and 256 birr of labor, draft power, and seed were used per hectare of land, respectively. With the exception of labor, the use of which was statistically significantly higher on owner-cultivated than on rented plots, use of other inputs was not statistically different by land tenure or land redistribution. It is puzzling why labor was much lower (about 50 percent) on rented plots than on owner-cultivated plots. Possibly, renters underestimated or did not report the contribution of landowners. Recall that most of the rented plots were sharecropped where landowners often contributed labor. The average value of crop yield for all plots was 2,829 birr per hectare (Table 9.3).[10] Consistent with the higher use of inputs on owner-cultivated plots or in villages that have had at least one land redistribution since 1991, average yield was also higher, although the difference is not statistically significant.

Production and sociocultural environment. The highlands of Ethiopia are typically very densely populated. The highlands account for about 45 percent of the total area of the country, but they are home to about 80 percent of the total human

Table 9.3 Amounts of inputs used and value of output by land tenure and redistribution in the highlands of Amhara region, Ethiopia

		Land tenure		Land redistribution in village since 1991	
Type of investment	All plots	Owner-cultivated	Rented	No	Yes
Labor (man-days/hectare)	286.8	304.3*	157.6*	257.3	297.5
Draft animal (animal-days/hectare)	54.3	54.7	51.6	50.3	55.8
Seed (birr/hectare)	255.8	258.8	233.7	273.7	249.4
Value of crop yield (birr/hectare)	2,829.1	2,887.6	2,407.1	2,703.4	2,874.4
Number of plots	1,187.0	1,057.0	130.0	346.0	841.0

Note: Rented plots include sharecropped and fixed-fee rented plots. Sample means are adjusted for stratification, weighting, and clustering of sample.

At the time of the survey, US$1 ≈ 8.50 Ethiopian birr.

*Sample means in the relevant category are different at the 10 percent level of significance.

population and 75–80 percent of the cattle and sheep (Degefe and Nega 2000). The survey data show an average of about 45 households per square kilometer in each village. Rapid population growth has increased the demand for farmland and contributed to farming on fragile lands, especially on hillsides with steep slopes, which are traditional grazing areas. Compared to Tigray region and others, the region has relatively good rainfall, with an average annual rainfall of 1,408 millimeters.[11] The average elevation was 2,172 meters above sea level, and the average distance to the district town was 34 km. When these characteristics were examined by agricultural potential, population densities and rainfall amounts were higher in high-potential areas. Villages in high-potential areas also had better access to their respective district towns (less than one-half of the average distance in low-potential areas) and were also located at relatively lower altitudes.

The sociocultural environment is shaped by the evolution and historical distributions of population settlement norms and, particularly in this context, those that affect attitudes and behavior toward organization of agricultural production. The administrative zones (North and South Gondar, Awi, East and West Gojjam, Wag Hamra, Oromia, North and South Wollo, and North Shewa) best capture the major sociocultural differences in the population across the region.[12] The North and South Gondar (representing about 30 percent of the sample) and North Shewa (14 percent) zones are evenly distributed as low and high agricultural potential. The Awi (3 percent) and East and West Gojjam (33 percent) zones are mostly of high potential, whereas North and South Wollo (20 percent) zones are mostly of low potential.

Econometric Approach and Results

Econometric Approach

Econometric techniques were used to estimate equations (9.1) and (9.2) presented in the conceptual framework. Specifically, we estimate and present regression results for (1) whether various land management practices, including use of reduced tillage, contour plowing, crop rotation, crop residues, household refuse, manure, chemical fertilizers, and improved seeds, were used by farmers on their farm plots in 1999;[13] (2) amount of labor and draft animal power and value of seed used by farmers per hectare in 1999; and (3) value of crop yield (total output per hectare) in 1999.

Table 9.4 shows detailed description and summary statistics of the dependent and endogenous variables. The econometric models used to estimate them depend on how they are measured. For land management practices, probit models were used to explain the probability of the management practice being used on the plot. Least-squares models were used to explain the amount of labor, draft animal, and seed used per hectare and value of crop yield obtained. Although not reported, the determinants of extension visits and crop choice were also estimated, and the results used to enrich the discussion of the chapter. Ordered probit and multinomial logit models were used to estimate the probability of receiving extension and planting a particular crop or mix of crops, respectively.[14]

The explanatory variables used in the regressions are operational measurements of the factors discussed in the conceptual framework. Detailed description and summary statistics of the explanatory variables are also shown in Table 9.4, grouped first by those used in estimating both equations (9.1) and (9.2) and those excluded from the value of crop yield equation. How the variables were partitioned will be explained shortly under estimation procedure. Then, within the two categories, they are grouped by plot-, household-, village/district-, and subregional-level factors. Among the plot-level factors, the variables include whether the plot is owner-cultivated or not and whether the farmer expects to operate the plot in the next five years or not. Others include size, slope, perception of soil depth, soil color, and waterlogging problems, presence of gullies, irrigation, stone terraces, and soil bunds or fences, location of plot (homestead versus field), and walking time from plot to residence. Household factors include endowments of human capital (gender and age structure, size, and education), physical capital (size of farm operated, number of oxen, and total stock of livestock measured in tropical livestock units),[15] financial capital (exogenous income and access to credit), and access to infrastructure and services. The village/district-level factors include whether there was a land redistribution since 1991 or not, population density, altitude, rainfall, distance to the district town, availability of inputs, and social capital (presence of various local associations). For ease of estimation, the region is divided into four subregions: the northern part (North and South Gondar zones), the western part (Awi and East and West Gojjam zones), the eastern part (North and South Wollo zones), and the southern part (North Shewa zone).

Estimation Procedure

As the conceptual framework specified in equations (9.1) and (9.2) shows, land management practices, inputs, extension, and crop choice are endogenous in the crop production function. This endogeneity problem can be addressed by estimating the value of the crop yield equation by a two-stage procedure in which land management practices, inputs, extension, and crop choice are predicted from the first stage and used in the second-stage estimation of the value of crop yield regression. Some of the explanatory variables used in the first-stage estimation are excluded from the second-stage estimation. This procedure is similar to estimating the value of the crop yield equation by instrumental variables (IV), where the excluded explanatory variables in the second stage are the instruments. Finding appropriate instruments can be challenging because one needs to find variables (at least one for each explanatory endogenous variable) that are correlated with the endogenous explanatory variables being instrumented (i.e., land management practices, inputs, extension, and crop choice) but not correlated with the dependent variable (i.e., value of crop yield after controlling for the explanatory variables in equation [9.1]).

First, potential exogenous variables that were hypothesized to have an influence on land management practices, inputs, extension, and crop choice but no hypothesized direct effect on value of crop yield, in addition to the exogenous and endogenous explanatory variables specified in equation (9.1), were used directly in the value of crop yield model. The variables finally selected for exclusion from the value of crop yield regression model were those exogenous variables that had a zero effect (separately and jointly) on value of crop yield.

Ordinary least squares (OLS) and IV were used to estimate value of crop yield. Then endogeneity bias, potentially resulting from using the actual values of the endogenous explanatory variables (OLS method) rather than their predicted values (IV method), was tested for using a Hausman test (Hausman 1978; Greene 1993).[16] Exogeneity of land management practices, inputs, extension, and crop choice in the cereal yield regression was not rejected, suggesting that the OLS gives consistent and efficient estimates. Thus, only the OLS results are reported and discussed.

Recall that several of the factors specified in equation (9.2) with important potential policy implications (e.g., access to infrastructure and services) for increasing cropland productivity may in theory have only indirect effects on value of crop yield via their effect on land management practices, inputs, extension, and crop

Table 9.4 Detailed description and summary statistics of variables, by agricultural potential

Variable name	Variable description	Total sample		Low-potential areas		High-potential areas		
		Mean	S.E.	Mean	S.E.	Mean	S.E.	*t*-test
Endogenous variables								
Value of crop yield	Value of total crop output per hectare (Ethiopian birr/ha)	2,829.110	285.285	3,252.907	322.046	2,576.460	412.893	
Crops (cf. other crops)	Proportion of plot allocated to crops (compared to noncereals)							
Barley only	Barley only	0.135	0.013	0.197	0.026	0.097	0.015	*
Maize only	Maize only	0.079	0.010	0.039	0.011	0.105	0.016	*
Wheat only	Wheat only	0.086	0.010	0.120	0.017	0.064	0.012	*
Teff only	*Teff* only	0.197	0.015	0.164	0.021	0.218	0.022	*
Other cereals	Other cereal crops or combination of cereal crops	0.142	0.016	0.116	0.016	0.159	0.023	
Cereal and other crops	Cereals mixed with other crops	0.158	0.015	0.143	0.020	0.167	0.020	
Legumes only	Leguminous crops only	0.114	0.013	0.157	0.019	0.088	0.018	*
Extension (cf. 0 visits)	Number of visits by an extension agent (compared to no visit)							
1–5 visits	1–5 visits	0.305	0.038	0.362	0.048	0.269	0.055	
6–10 visits	6–10 visits	0.193	0.035	0.140	0.033	0.227	0.053	
More than 10 visits	More than 10 visits	0.163	0.031	0.137	0.032	0.179	0.047	
Use of reduced tillage	Dummy variable equal to 1 if reduced tillage is used, 0 otherwise	0.244	0.029	0.389	0.043	0.154	0.040	*
Use of contour plowing	Dummy variable equal to 1 if contour plowing is used, 0 otherwise	0.697	0.029	0.757	0.033	0.659	0.042	*
Use of crop rotation	Dummy variable equal to 1 if crop rotation is used, 0 otherwise	0.618	0.028	0.490	0.041	0.698	0.038	*
Use of crop residues	Dummy variable equal to 1 if crop residue is plowed in, 0 otherwise	0.631	0.035	0.640	0.048	0.625	0.050	
Use of household refuse	Dummy variable equal to 1 if household refuse is used, 0 otherwise	0.175	0.010	0.155	0.017	0.188	0.014	
Use of manure	Dummy variable equal to 1 if manure is used, 0 otherwise	0.090	0.010	0.102	0.018	0.082	0.012	
Use of chemical fertilizers	Dummy variable equal to 1 if chemical fertilizer is used, 0 otherwise	0.353	0.029	0.107	0.017	0.507	0.042	*
Use of improved seeds	Dummy variable equal to 1 if improved seed is used, 0 otherwise	0.131	0.022	0.040	0.010	0.188	0.034	*
Amount of labor	Amount of total labor used (excluding harvest and postharvest) (man-days/hectare)	286.854	32.592	297.530	38.237	280.177	47.252	
Amount of draft power	Amount of total draft animal used (excluding threshing) (animal-days/hectare)	54.379	4.378	49.385	4.745	57.502	6.485	
Value of seed	Value of total seed used (Ethiopian birr/hectare)	255.880	31.663	233.012	17.820	270.184	50.174	

Exogenous variables (for all endogenous variables)								
Plot-level factors								
Owner-cultivated	Dummy variable equal to 1 if plot is cultivated by the owner, 0 otherwise	0.880	0.020	0.956	0.014	0.833	0.030	*
Expectation to operate	Dummy variable equal to 1 if plot is expected to be operated within the next 5 years, 0 otherwise	0.885	0.021	0.964	0.013	0.836	0.032	*
Size	Size of plot (x10 m^2)	0.335	0.017	0.295	0.021	0.359	0.025	*
Slope	Average slope of the plot (degrees)	5.735	0.347	7.032	0.550	4.923	0.425	*
Soil depth (cf. deep)	Farmers' perception of depth of the soil on plot (proportion, compared to "deep" soil)							
Medium	Medium	0.595	0.025	0.564	0.032	0.615	0.035	
Shallow	Shallow	0.228	0.019	0.301	0.027	0.183	0.025	*
Soil color (cf. black)	Farmers' perception of color of the soil on plot (proportion, compared to "black" soil)							
Brown	Brown	0.297	0.027	0.337	0.035	0.272	0.038	
Gray	Gray	0.076	0.013	0.093	0.023	0.066	0.017	
Red	Red	0.342	0.031	0.180	0.026	0.442	0.046	*
Presence of gullies	Dummy variable equal to 1 if there are gullies on the plot, 0 otherwise	0.042	0.008	0.066	0.014	0.028	0.010	*
Waterlogging problem	Dummy variable equal to 1 if water logging is a problem on the plot, 0 otherwise	0.078	0.012	0.095	0.020	0.068	0.016	
Investments on plot								
Irrigation	Dummy variable equal to 1 if plot is irrigated, 0 otherwise	0.039	0.008	0.025	0.008	0.048	0.012	
Stone terraces	Dummy variable equal to 1 if there are stone terraces on plot, 0 otherwise	0.216	0.019	0.365	0.029	0.124	0.025	*
Drainage ditch	Dummy variable equal to 1 if there are drainage ditches on plot, 0 otherwise	0.397	0.034	0.160	0.030	0.546	0.052	*
Live fence	Dummy variable equal to 1 if there are live fences (e.g., living trees) on plot, 0 otherwise	0.126	0.013	0.094	0.020	0.146	0.019	*
Fence	Dummy variable equal to 1 if there are non-live fences on plot, 0 otherwise	0.162	0.023	0.106	0.020	0.197	0.034	*
Household-level factors								
Gender of head	Dummy variable equal to 1 if household head is male, 0 otherwise	0.964	0.012	0.976	0.016	0.956	0.018	
Average education	Average education of household members (years)	42.911	0.887	44.562	1.008	41.878	1.300	
Age of head	Age of household head (years)	1.887	0.187	1.756	0.174	1.969	0.283	
Size of farmland	Size of the total landholding of the household (x10 m^2)	1.278	0.062	0.935	0.061	1.492	0.088	*
Number of oxen	Number of oxen owned by the household	1.616	0.083	1.336	0.087	1.792	0.120	*
Tropical livestock units	Number of tropical livestock units owned by the household	3.918	0.216	3.547	0.281	4.151	0.301	

(*continued*)

Table 9.4 (continued)

Variable name	Variable description	Total sample		Low-potential areas		High-potential areas		
		Mean	S.E.	Mean	S.E.	Mean	S.E.	*t*-test
Village/district-level factors								
Land redistribution	Dummy variable equal to 1 if land redistribution occurred in village after 1991, 0 otherwise	0.734	0.031	0.627	0.044	0.802	0.043	
Household density	Number of households in the village per square kilometer	44.757	1.529	38.470	1.514	49.035	2.289	*
Altitude	Average altitude in the village (meters above sea level)	2,171.955	33.532	2,296.283	47.795	2,087.357	43.946	
Rainfall	Annual rainfall (millimeters)	1,407.815	33.931	1,049.204	15.281	1,632.131	47.761	*
Subregional location								
Location (cf. Southern)	Subregional location of household (compared to North Shewa Zone)							
Northern	Dummy variable equal to 1 if North/South Gondar Zones, 0 otherwise	0.297	0.033	0.331	0.028	0.276	0.052	
Western	Dummy variable equal to 1 if Awi/East/West Gojjam Zones, 0 otherwise	0.357	0.027	0.016	0.002	0.571	0.047	*
Eastern	Dummy variable equal to 1 if North/South Wollo Zones, 0 otherwise	0.197	0.016	0.509	0.032	0.002	0.000	*
Variables excluded from the value of crop yield equation								
Plot level								
Homestead plot	Dummy variable equal to 1 if plot is located in the homestead, 0 otherwise	0.240	0.012	0.238	0.018	0.241	0.015	
Plot to residence	Walking time in minutes from the plot to the household's residence	15.850	1.008	18.026	1.360	14.488	1.414	*
Household level								
Household size	Number of household members	6.855	0.206	6.553	0.204	7.043	0.306	
Proportion male	Proportion of household members that are male	0.542	0.012	0.507	0.016	0.563	0.016	*
Dependency ratio	Proportion of household members less than 15 years old or more than 59 years old	0.540	0.013	0.519	0.017	0.553	0.019	
Exogenous income	Sum of remittances, food aid, gifts, and pension (Ethiopian Birr)[2]	76.815	10.910	156.171	24.704	27.177	7.766	*
Access to markets or services	Walking time in minutes from the household's residence to the nearest market/service							
Drinking water	Drinking water source in the main cropping season	10.770	0.711	13.146	1.214	9.284	0.859	*
Grain mill	Grain mill	56.062	3.877	88.117	7.748	36.011	3.325	*
All-weather road	All-weather road	180.372	10.694	274.296	23.310	121.622	8.062	*

Development agent	Development agent's office	38.791	2.478	53.790	4.690	29.430	2.396	*
Bus service station	Bus service station	205.270	11.342	304.282	25.152	143.336	7.935	*
Fuelwood	Fuelwood source in main cropping season	54.212	4.516	68.714	6.909	44.996	5.866	*
Input supply shop	Input supply shop	145.704	8.347	211.117	13.708	104.768	8.768	*
Village/district-level factors								
Distance to district town	Average distance from the peasant association to the district town (kilometers)	33.536	1.936	51.058	3.851	20.926	1.115	*
Access to fertilizers	Dummy variable equal to 1 if chemical fertilizers are available in the village, 0 otherwise	0.972	0.008	0.929	0.022	1.000	0.000	*
Access to improved seeds	Dummy variable equal to 1 if improved seeds are available in the village, 0 otherwise	0.876	0.027	0.927	0.020	0.844	0.041	*
Access to purchased feed	Dummy variable equal to 1 if livestock feed can be purchased in the village, 0 otherwise	0.499	0.040	0.702	0.045	0.373	0.056	*
Access to credit	Dummy variable equal to 1 if credit from Amhara Credit and Savings Institution is available in the village, 0 otherwise	0.216	0.034	0.097	0.027	0.290	0.053*	
Presence of local association	Dummy variable equal to 1 if local association or organization or cooperative is present in the village, 0 otherwise							
Input cooperative	Input cooperative	0.397	0.039	0.151	0.028	0.550	0.055	*
Marketing cooperative	Marketing cooperative	0.044	0.011	0.114	0.028	0.000	0.000	*
Women's/youth	Women's/youth	0.955	0.012	1.000	0.000	0.927	0.020	*
Church	Church	0.944	0.009	0.858	0.025	0.998	0.000	*
Water users	Water users	0.536	0.040	0.452	0.048	0.589	0.056	*

Note: Agricultural potential is an adaptation of the classification used by the Ethiopian Disaster Prevention and Preparedness Commission, referring to non-drought-prone districts as high-agricultural-potential areas (located to the west and southern tip of the region) and drought-prone districts as low-agricultural-potential areas (located to the east) (see Fig. 9.1).

Sample means and standard errors are adjusted for stratification, weighting, and clustering of sample.

At the time of the survey, US$1 ≈ 8.50 Ethiopian birr.

***Sample means are different by agricultural potential at the 10 percent (or less) level of significance.**

choice. In order to examine the direct and indirect effects, a reduced-form model that excludes the endogenous variables as explanatory variables but includes the instruments (discussed earlier) is also estimated. The reduced-form specification allows estimation of the total effects of the exogenous explanatory variables on crop production. Furthermore, it eliminates the potential for endogeneity bias altogether.

In estimating the inputs (labor, draft animal power, and seed) and value of crop yield models, a logarithmic Cobb-Douglas specification was used.[17] This specification was chosen on empirical merit. For example, the translog specification, which is a more flexible form, was also attempted but not utilized because of severe multicollinearity problems introduced by the interaction and other terms. The logarithmic transformation also reduces problems resulting from outliers and nonnormality of the error term when an ordinary linear specification is used.

An attempt was made to examine the effect of interactions between some key variables on value of crop yield model, for example, the complementary effects of moisture-enhancing technologies and modern inputs. Various interactions among use of chemical fertilizers, improved seeds, irrigation, and stone terraces were tried. However, the interaction variables were dropped from the final regressions because there were too few observations (less than 2 percent in many cases) to warrant a reliable estimation, the results being very sensitive to a few positive observations. Finally, the models were estimated for the total sample and then separately for low- and high-agricultural-potential areas to provide information on the relative contribution of the policies and programs to technology adoption, land management, and productivity in the two production environments. Statistical test results show, except for use of reduced tillage, household refuse, and manure, significant differences in the effects of the explanatory variables between low- and high-agricultural-potential areas, suggesting that the observations should not be pooled in the regressions.[18] Thus, only results from estimation of the restricted models for use of reduced tillage, household refuse, and manure and the unrestricted models for the others are reported and discussed.

Generally, the different regression models were estimated and presented in order to provide as much information as possible as well as to generate a greater degree of confidence in the robustness of the econometric results. STATA software (StataCorp 2005) was used for the regression analysis, and the results are corrected for sample stratification, weighting, and clustering.

Regression Results

Detailed results of the econometric estimations are shown in Tables 9.5–9.7. Because of the large amount of output, which in turn is related to the large number of explanatory variables used,[19] discussion of the results is limited to those variables that are of interest in this chapter in order to conserve space. Thus, although all the estimated coefficients associated with the explanatory variables are reported for all the regression models, the discussion of results focuses on the effects of land redistribution and tenure, plot and farm size, household endowments (gender, education, oxen, and livestock ownership), population density, and access to infrastructure and services. The effects of irrigation, stone terraces, extension, land management practices, and use of conventional inputs (labor, draft animal, and seeds) and modern inputs (improved seeds and chemical fertilizers) on value of crop yield are also discussed.

Adoption of land management practices. Table 9.5 shows regression results for use of reduced tillage, household refuse, and manure on household farm plots for the total sample and for use of contour plowing, crop rotation, crop residues, chemical fertilizers, and improved seeds on household farm plots by agricultural potential.

With other factors controlled, owner-cultivated plots compared to rented plots were associated with a greater likelihood of using crop rotation and plowing in crop residues in high-potential areas only. Although it is meant to replenish soil fertility, Benin, Ehui, and Pender (2003b) argue that the concept of crop rotation as used in the Ethiopian highlands can be misleading because the rotation cycles practiced by farmers to incorporate legumes or fallow may not be long enough to be effective. In high-potential areas too, rented plots compared to owner-cultivated plots were associated with greater likelihood of using improved seeds, which is consistent with other observations that rented plots were planted more to maize for which improved seeds were used more. In general (i.e., in both low- and high-potential areas), incidence of manure use was lower on owner-cultivated plots than on rented plots, whereas in low-potential areas, incidence of use of chemical fertilizers and improved seeds was greater on owner-cultivated plots. Plots located in villages where there had been land redistribution were associated with lower likelihood of using several of the land management practices, especially in low-potential areas.

Larger plots were associated with greater likelihood of use of crop rotation in general and plowing in crop residues or using chemical fertilizers and improved seeds in high-potential areas in particular. Larger farms in low-potential areas were associated with greater likelihood of using contour plowing and improved seeds but lower likelihood of plowing in crop residues. In high potential areas, larger farms were associated with greater likelihood of using chemical fertilizers.

Irrigated plots were associated with greater likelihood of using household refuse but, surprisingly, lower likelihood of using chemical fertilizers in both low- and high-potential areas and lower likelihood of using improved seeds in low potential

Table 9.5 Probit regression results of use of land management practice by agricultural potential in the highlands of Amhara region, Ethiopia, 1999

	Reduced tillage	Contour plowing		Crop rotation	
	Total sample	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas
Plot-level factors					
Owner-cultivated	−0.396	−1.802***	0.189	−0.412	0.679*
Expectation to operate	0.445	1.534*	−0.314	−0.374	0.407
Ln Size	0.010	−0.058	0.018	0.220**	0.279***
Ln Slope	0.026**	0.126***	0.083***	−0.035**	0.031*
Soil depth (cf. deep)					
Medium	0.848***	0.380	−0.271	−0.361	−0.010
Shallow	0.783***	0.324	−0.168	−0.362	0.232
Soil color (cf. black)					
Brown	−0.415**	0.389	0.557	0.130	−0.120
Gray	0.033	0.193	0.625	0.016	−0.377
Red	0.134	0.367	0.245	0.356	0.366
Presence of gullies	0.274	1.041***	−0.579	−0.001	−0.087
Water logging problem	−0.165	0.261	0.970**	−0.508*	0.162
Investments on plot					
Irrigation	−0.100	−0.736	−0.159	0.170	0.870
Stone terraces	0.043	0.834***	1.525***	−0.072	0.203
Drainage ditch	0.015	0.289	0.644***	−0.408	−0.021
Live fence	−0.909***	0.011	0.039	−0.206	−0.039
Fence	−0.193	0.915***	0.634**	0.339	0.133
Household-level factors					
Gender of head	−1.065***	−0.793	0.314	−0.100	0.248
Ln Age of head	−1.276***	−0.686	0.045	−0.216	−0.358
Average education	−0.142***	−0.063	0.079	0.031	−0.140***
Ln Size of farmland	0.025	0.447**	0.034	0.025	−0.203
Number of oxen	0.332***	0.046	−0.123	−0.459***	−0.374*
Tropical livestock units	−0.128***	−0.022	0.026	0.159***	0.157*
Village/district-level factors					
Land redistribution	−0.004	−0.762**	−0.485	−0.625**	0.358
Ln Household density	−1.397***	−1.855***	0.091	−0.235	−0.037
Ln Altitude	1.108**	−1.259	1.438	0.415	−1.544
Ln Rainfall	1.991***	6.197***	2.159***	0.710	1.279
Subregional location					
Location (cf. Southern)					
Northern	−0.804***	0.767*	0.034	−0.091	−1.611**
Western	−5.156***	0.278	1.647	0.869	−1.624**
Eastern	1.457***	2.164***	2.312***	−0.754*	1.409
Variables excluded from the value of crop yield equation					
Plot level					
Homestead plot	0.070	0.480*	0.271	0.128	−0.613***
Ln Plot to residence	0.002	0.010*	0.000	−0.007	−0.011***

Crop residues		Household refuse	Manure	Use of chemical fertilizers		Use of improved seeds	
Low-potential areas	High-potential areas	Total sample	Total sample	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas
–0.156	0.874*	–0.103	–0.811**	0.692*	0.881	1.686*	–1.514***
1.079	–1.273***	–0.754*	0.935**	–0.552	–1.176**	–0.375	0.897
0.143	0.244*	–0.115	–0.070	0.111	0.674***	–0.127	0.440**
–0.002	–0.011	–0.068***	–0.031	–0.115***	–0.048***	–0.333***	0.023
0.457*	–0.372	0.367	0.052	0.228	0.035	0.730	–0.649
1.326***	–0.434	–0.532	–0.624*	0.408	0.610	0.318	–0.466
–0.303	0.956***	0.379	0.652***	0.110	–0.132	1.089***	–0.125
–0.453	1.210***	0.729*	0.731**	0.589	–1.013*	1.398***	–1.915**
0.329	0.934***	0.486	0.567*	–0.215	0.262	–0.934*	1.339***
–1.369***	–0.724	–1.656***	–0.438	–0.353	–0.226	2.405***	1.068**
0.783***	0.394	0.369	–0.311	–0.008	0.383	1.010***	–0.861
–0.228	–0.233	1.194***	0.479	–1.035***	–1.859***	–1.709**	0.892
0.463*	–0.081	–0.914***	0.069	0.827***	0.720*	0.405	0.315
0.267	0.819***	0.402	0.490***	0.112	0.763***	1.187***	0.159
–1.075***	–0.393	0.669***	0.821***	–0.778*	0.114	–0.033	–0.208
0.213	0.120	0.223	0.602***	–0.174	0.092	0.656	0.173
1.902***	1.572***	0.362	0.688	0.950	0.586	n.e.	–0.992
–0.643	–2.646***	0.862	–0.403	–1.147**	–3.281***	–1.222	–2.565***
0.049	–0.120**	0.015	0.036	–0.038	0.130*	0.098	0.246***
–0.357*	–0.351	0.276	–0.137	–0.350	0.803***	1.142***	0.155
0.463***	–0.219	–0.467***	–0.097	0.218	1.396***	0.451	0.466
–0.173***	0.079	0.204***	0.146**	0.019	–0.453***	–0.230*	–0.047
–0.965***	1.793***	–0.396	–0.535*	0.318	–2.728***	0.515	–0.476
1.859***	3.543***	–0.090	–0.184	–0.988**	0.148	2.718***	0.043
3.441***	–10.821***	0.203	0.529	2.160**	1.741	0.669	7.524*
2.143*	0.121	1.642***	1.829***	0.346	–1.399	1.585	0.779
–3.755***	–0.056	0.353	–1.445***	1.617**	4.838***	6.290***	7.766
–2.955***	–1.140	0.061	–1.094**	5.527***	5.453***	8.224	4.557
–3.734***	0.986	1.168	–0.134	2.884***	2.495*	2.639*	5.265
–0.014	–0.106	2.301***	0.825***	0.043	–0.198	–0.326	0.800**
0.014***	–0.011**	–0.168***	–0.081***	–0.005	–0.016**	–0.024	–0.021*

(*continued*)

Table 9.5 (continued)

	Reduced tillage	Contour plowing		Crop rotation	
	Total sample	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas
Household level					
Ln Household size	0.749***	0.612	–0.610	–0.015	1.067***
Proportion male	0.401	0.722	–1.596*	–1.611***	0.590
Dependency ratio	–0.736	–0.909	–2.582***	–0.037	–2.483***
Exogenous income	0.000	0.000	–0.001*	–0.001*	0.001*
Access to markets or services					
Ln Drinking water	–0.521***	0.019	–0.093	0.346***	0.405***
Ln Grain mill	0.144	–0.172	0.021	–0.114	0.053
Ln All-weather road	0.556***	0.312***	0.710***	–0.177	–0.380**
Ln Development agent	–0.067	–0.010	–0.599***	0.028	–0.102
Ln Bus service station	–0.606***	0.236	–0.416*	0.625***	–0.001
Ln Fuelwood	–0.002	0.007***	–0.002	–0.001	–0.007***
Ln Input supply shop	0.235**	0.247	0.220	–0.441***	0.415**
Village/district-level factors					
Ln Distance to district town	–0.432***	–1.208***	–0.685	–0.202	1.205***
Access to fertilizers	–1.123***	0.412	n.e.	n.e.	n.e.
Access to improved seeds	1.074***	–1.037	1.235**	0.837*	0.891*
Access to purchased feed	–0.841***	0.462	–0.448	–0.531*	–0.056
Access to credit	0.719***	–0.908*	0.489	–0.124	0.243
Presence of local association					
Input cooperative	1.631***	–1.387	–1.639*	–1.351***	0.796
Marketing cooperative	–1.221***	1.595*	n.e.	2.875***	n.e.
Women's/youth	–1.829***	n.e.	0.844	n.e.	n.e.
Church	–0.363	–2.521***	n.e.	–0.341	–1.665***
Water users	0.787***	1.167***	0.357	0.272	0.845**
Constant	–10.591*	–26.017***	–24.402*	–4.769	–0.775
Wald chi-square	258.470***	173.970***	183.860***	142.620***	159.310***
Pseudo-R^2	0.497	0.408	0.448	0.306	0.340
Likelihood ratio test[a]	48.304	149.92***		120.26***	

Note: See Table 9.4 for detailed description of variables. Coefficients and standard errors are adjusted for stratification, weighting, and clustering of sample.

***, **, and *** mean coefficient is statistically significant at the 10 percent, 5 percent, and 1 percent level, respectively.**

Ln means variable is transformed by natural logarithm. n.e. means coefficient was not estimated because the associated variable was dropped to avoid dummy variable trap or because it perfectly predicted the outcome.

Crop residues		Household refuse	Manure	Use of chemical fertilizers		Use of improved seeds	
Low-potential areas	High-potential areas	Total sample	Total sample	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas
1.713***	1.439***	–0.740***	–0.685**	0.378	0.887	–0.324	1.537**
–0.947	1.015	–0.980	–0.447	–1.517*	0.069	–3.939***	0.439
0.205	–1.467	0.116	0.811	–1.753*	–2.494***	1.226	–2.487*
0.000	0.000	–0.001	0.000	0.001	–0.001	0.005***	–0.002
0.204	0.212	0.151	0.354***	–0.123	–0.080	–0.227	–0.519**
0.689***	0.313*	–0.411***	–0.048	0.079	–0.170	0.528*	–0.422*
0.205	–1.369***	–0.250	0.090	0.269	0.033	0.497**	0.392
–0.813***	0.102	0.099	0.082	–0.491***	–0.690***	–0.344*	–0.410
–0.653***	0.435**	0.481**	0.156	0.101	–0.236	–0.650*	0.258
0.005**	0.012***	0.002	0.000	0.000	0.010***	0.004	0.002
1.050***	0.270	–0.007	0.331***	–0.112	0.286	–0.014	–0.185
0.333	2.486***	0.191	–0.517***	–0.299	–0.686*	0.423	–1.047
1.911***	n.e.	–0.110	–0.216	n.e.	n.e.	n.e.	n.e.
–1.037	–2.211***	–0.204	0.679*	–0.265	1.769***	n.e.	n.e.
–1.343***	0.014	–0.820***	–0.140	–0.056	1.535***	–0.124	1.520
–0.085	1.446***	–0.340	–0.032	–1.086*	1.094***	–2.174***	–0.242
1.288*	–0.481	–1.615***	–1.052***	–0.404	1.001*	n.e.	3.496***
0.821	n.e.	0.364	0.769	1.017	n.e.	0.204	n.e.
n.e.	–4.058***	0.464	–0.898*	n.e.	0.530	n.e.	–1.770
–1.524***	n.e.	0.297	–0.177	–0.179	n.e.	–2.644***	n.e.
–0.974***	–0.877*	–0.244	–0.049	0.464	1.535***	0.440	0.429
49.015***	73.876***	–17.730*	–15.739*	–12.239	–5.293	–35.157**	–63.165
365.02***	323.790***	257.500***	165.580***	189.810***	165.950***	124.990***	95.730***
0.699	0.648	0.691	0.502	0.324	0.545	0.569	0.485
356.67***		38.349	57.197	156.36***		128.80***	

[a]The likelihood ratio (LR) test, similar to a Chow test in a least-squares regression, is a test of equality of the coefficients in low- and high-potential areas, where LR = –2 [ln L_{LPA} + ln L_{HPA} – ln L_{pooled}] $\chi^2(k)$; ln L_i is the log likelihood in regression for low-potential areas only, high-potential areas only, and the pooled data, respectively, and k is the number of coefficients.

areas. Probably, manure is seen as a substitute for chemical fertilizers. As expected, the presence of stone terraces was associated with greater likelihood of using chemical fertilizers as well as contour plowing, although it was also associated with lower likelihood of using household refuse in low-potential areas.

Female-headed households in low-potential areas were more likely to use reduced tillage on their farm plots, which is expected given the customary prohibition of women using oxen to plow in many places in the highlands of Ethiopia. Better-educated households in high-potential areas were less likely to use crop rotation or to plow in crop residues, but they were more likely to use chemical fertilizers and improved seeds on their farm plots because education enhances the ability of individuals to utilize technical information associated with such modern inputs. Ownership of livestock in general, and of oxen in particular, had the opposite effects. For example, in high-potential areas, although greater ownership of oxen was associated with greater likelihood of using chemical fertilizers, greater ownership of livestock in general was associated with lower likelihood of using chemical fertilizers. However, the magnitudes (in absolute value terms) of the effects associated with ox ownership are larger, indicative of the relative importance of oxen within the household.

More densely populated villages were associated with a lower likelihood of using reduced tillage and greater likelihood of plowing in crop residues in general but greater likelihood of using improved seeds and lower likelihood of using chemical fertilizers in low-potential areas. These findings are mixed regarding the Boserupian (Boserup 1965) perspective about the responses of households to population pressure. However, some of the findings may be caused by the negative effect of population pressure on ownership of oxen and livestock (Benin, Ehui, and Pender 2003a; Chapter 6), thereby reducing the capability of households to plow while easing the demand on crop residues for livestock feed and increasing the likelihood of recycling them in the soil.

Amount of labor, draft animal power, and seed used. Regression results with respect to the amount of labor, draft animal power, and seed used on farm plots by agricultural potential are shown in Table 9.6. Owner-cultivated farms were associated with greater amounts of labor per hectare in high-potential areas and lower amounts of animal draft power and seed per hectare in low-potential areas. Villages in which land redistribution had taken place were associated with lower amounts of labor and animal draft power in low-potential areas. It seems that in an attempt to equalize the quality of landholding among households, especially in the low-potential areas, land redistribution may have made farms more fragmented, and, consequently, more resources (especially time spent to and from the different plots) are required per unit of area to manage the farm efficiently, reducing the actual amount of time spent on a particular plot.

As expected, larger plots were associated with lower amounts of labor, draft animal power, and seed per hectare. Irrigated plots were associated with greater use of labor and seed in high-potential areas and greater use of animal draft power in low-potential areas. Plots with stone terraces were associated with greater amounts of labor in low-potential areas only, reflecting additional labor input necessary for their maintenance. The other investments also were positively associated with some of the inputs, although the effects were different in low- versus high-potential areas.

Female-headed households were associated with smaller amounts of labor and animal draft power on their farm plots, which is consistent with the earlier result that they use more reduced tillage. However, they were associated with greater amounts of seed used in low-potential areas. Households with more educated members were associated with smaller amounts of labor and seed in high-potential areas and low-potential areas, respectively. Households with more oxen were associated with using less labor on their farm plots in high-potential areas, suggesting replacement of labor with animal draft power. Greater exogenous (nonfarm) income was associated with greater use of labor and animal draft power in both low- and high-potential areas, showing the positive influence of the nonfarm sector in promoting on-farm investment.

Access to infrastructure and services had mixed and varying effects on the amounts of the three inputs used in low- versus high-potential areas. For example, households that were closer to the district town or to an all-weather road were associated with lower amounts of labor and animal draft power in high-potential areas. This likely reflects higher opportunity costs of labor and capital assets among households with better access to towns where nonfarm employment opportunities are higher. Availability of formal credit in a village, on the other hand, had opposite effects and was associated with greater use of labor in low-potential areas but less use of labor in high-potential areas, which suggest use of credit for different purposes in the two areas.

Value of crop yield. Table 9.7 shows regression results with respect to value of crop yield (value of total output per hectare) in low- and high-agricultural-potential areas. The first two sets of results show the direct effects of the explanatory variables estimated by OLS. The other two show results of the reduced-form model (i.e., excluding extension, crop choice, land management practices, and inputs), which measures the total (direct and indirect) influence of the explanatory variables included. The discussion is based on the OLS model, the preferred model,

Table 9.6 Regression results of amounts of inputs used by agricultural potential in the highlands of Amhara region, Ethiopia, 1999

Explanatory variable	Amount of labor (Ln [man-days/hectare])		Amount of draft power (Ln [animal-days/hectare])		Value of seed (Ln [birr/hectare])	
	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas
Plot-level factors						
Owner-cultivated	–0.200	0.426***	–0.561***	0.245	–0.472**	0.052
Expectation to operate	0.277	–0.193	0.687***	–0.188	0.805*	–0.126
Ln Size	–0.723***	–0.684***	–0.771***	–0.542***	–0.522***	–0.572***
Ln Slope	–0.009	0.008	0.000	–0.004	0.024***	–0.017
Soil depth (cf. deep)						
Medium	–0.142	0.020	0.001	0.000	–0.304**	–0.265
Shallow	–0.182	0.038	–0.065	0.116	–0.374**	–0.041
Soil color (cf. black)						
Brown	0.024	0.019	–0.025	0.194	–0.382***	–0.048
Gray	0.191	–0.055	–0.078	–0.036	–0.129	0.284
Red	0.111	0.139	0.026	0.092	–0.030	–0.009
Presence of gullies	0.211	0.298	0.011	0.075	–0.176	–0.001
Waterlogging problem	–0.347***	0.073	0.092	–0.320**	–0.066	–0.128
Investments on plot						
Irrigation	0.426	1.168***	0.581***	0.258	0.609	1.974***
Stone terraces	0.581***	0.218	0.035	0.212	0.201	–0.340
Drainage ditch	0.289***	–0.004	0.422***	0.206*	0.387***	0.090
Live fence	0.192	0.319***	–0.122	0.081	0.183	0.242
Fence	0.459***	0.249***	0.081	0.278**	0.443***	–0.064
Household-level factors						
Gender of head	1.077***	0.333	0.322*	0.299*	–0.670*	–0.210
Ln Age of head	–0.034	–0.272	–0.266*	–0.449**	–0.435	–0.301
Average education	–0.048	–0.048*	–0.025	–0.003	–0.063*	–0.020
Ln Size of farmland	–0.154*	0.179*	0.131*	–0.111	–0.051	–0.078
Number of oxen	0.073	–0.217***	0.067	–0.141	0.125	0.277
Tropical livestock units	0.022	0.054	0.008	0.054	–0.008	0.009

Village/district-level factors						
Land redistribution	–0.237*	0.363	–0.316***	0.016	0.097	0.286
Ln Household density	0.336*	–0.087	–0.053	0.119	0.055	–0.531**
Ln Altitude	–0.597*	0.580	–0.516*	0.518	0.995***	1.691**
Ln Rainfall	–0.633	–0.316	–0.119	0.246	1.124*	–1.064*
Subregional location						
Location (cf. Southern)						
Northern	0.566***	–0.543	0.159	–0.810***	–0.338	1.143***
Western	0.568	–0.688*	0.207	–0.137	–0.961*	0.930**
Eastern	0.359	0.196	0.314*	–0.061	–0.153	0.764
Variables excluded from the value of crop yield equation						
Plot level						
Homestead plot	0.106	0.200**	0.079	–0.190	–0.332*	–0.375**
Ln Plot to residence	0.000	0.000	0.003*	–0.001	0.002	0.004
Household level						
Ln Household size	–0.142	0.034	–0.095	0.136	0.469	–0.095
Proportion of males	0.029	0.609**	0.216	0.872***	0.327	0.729
Dependency ratio	0.180	–0.822***	0.038	–0.325	0.023	0.468
Exogenous income	0.001***	0.001***	0.001***	0.001***	0.000	0.000
Access to markets or services						
Ln Drinking water	–0.023	0.015	0.026	0.026	–0.127	–0.071
Ln Grain mill	0.009	–0.001	0.001	–0.012	0.050	–0.089
Ln All-weather road	–0.083	0.101	0.007	0.162*	0.049	0.060
Ln Development agent	0.012	–0.014	0.015	0.117*	0.030	0.145
Ln Bus service station	0.015	–0.235***	–0.063	–0.158	0.053	–0.160
Ln Fuelwood	0.001	–0.002**	0.000	0.002*	0.001	–0.001
Ln Input supply shop	0.050	0.075	0.041	0.009	–0.275***	–0.021

(*continued*)

Table 9.6 (continued)

Explanatory variable	Amount of labor (Ln [man-days/hectare]) Low-potential areas	Amount of labor (Ln [man-days/hectare]) High-potential areas	Amount of draft power (Ln [animal-days/hectare]) Low-potential areas	Amount of draft power (Ln [animal-days/hectare]) High-potential areas	Value of seed (Ln [birr/hectare]) Low-potential areas	Value of seed (Ln [birr/hectare]) High-potential areas
Village/district-level factors						
Ln Distance to district town	0.113	0.323**	–0.019	0.080	0.105	0.139
Access to fertilizers	0.161	n.e.	–0.140	n.e.	–0.338	n.e.
Access to improved seeds	0.070	–0.482***	–0.125	–0.152	0.136	0.296
Access to purchased feed	–0.108	–0.107	–0.013	0.344***	–0.549***	–0.231
Access to credit	0.528***	–0.362**	0.141	0.165	–0.108	0.222
Presence of local association						
Input cooperative	0.053	0.844***	0.267	0.485**	–0.193	–0.266
Marketing cooperative	–0.647***	n.e.	–0.408	n.e.	–0.103	n.e.
Women's/youth	n.e.	–0.512*	n.e.	–0.384	n.e.	1.564***
Church	0.168	n.e.	–0.001	n.e.	0.352*	n.e.
Water users	–0.011	–0.292**	0.117	0.358**	0.410**	0.157
Constant	15.592***	6.473	12.127***	1.167	–6.041	3.259
F	11.680***	13.420***	26.320***	9.840***	7.300***	6.930***
R^2	0.636	0.696	0.710	0.554	0.454	0.460
Chow test[a]	2.169***		2.775***		2.391***	

Note: See Table 9.4 for detailed description of variables. Coefficients and standard errors are adjusted for stratification, weighting, and clustering of sample.

***, **, and *** mean coefficient is statistically significant at the 10 percent, 5 percent, and 1 percent level, respectively.**

Ln means variable is transformed by natural logarithm. n.e. means coefficient was not estimated as the associated variable was dropped to avoid dummy variable trap or because it perfectly predicted the outcome.

At the time of the survey, US$1 ≈ 8.50 Ethiopian birr.

[a]The Chow test is a test of equality of the coefficients in low- and high-potential areas.

Table 9.7 Least-squares regression results of value of crop yield by agricultural potential in the highlands of Amhara region, Ethiopia, 1999

	Ordinary least squares		Reduced form	
Factor	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas
Exogenous variables				
Plot-level factors				
Owner-cultivated	–0.067	–0.318*	–0.508**	–0.237
Expectation to operate	0.155	0.468***	0.873***	0.288
Ln Size	–0.111	–0.283***	–0.572***	–0.424***
Ln Slope	0.014**	0.008	0.018**	0.011
Soil depth (cf. deep)				
Medium	–0.132	0.107	–0.230	0.054
Shallow	–0.342***	–0.044	–0.468***	–0.202
Soil color (cf. black)				
Brown	0.124	0.080	–0.054	0.137
Gray	–0.257*	0.309*	–0.359	0.004
Red	–0.134	–0.072	–0.267*	–0.084
Presence of gullies	–0.039	–0.062	–0.053	0.213
Waterlogging problem	–0.051	–0.492***	–0.124	–0.740***
Investments on plot				
Irrigation	0.172	0.128	0.789***	0.352
Stone terraces	0.110	0.069	0.351***	0.197
Drainage ditch	–0.380***	0.134*	0.042	0.232**
Live fence	0.138	0.089	—0.085	0.303**
Fence	–0.050	–0.163	0.149	0.044
Household-level factors				
Gender of head	0.529	0.339*	0.771	0.475**
Ln Age of head	–0.020	–0.419***	0.276	–0.634***
Average education	0.027	0.000	0.020	0.033
Ln Size of farmland	–0.279***	–0.072	–0.314***	–0.020
Number of oxen	0.047	0.154**	0.146	0.188*
Tropical livestock units	–0.008	–0.053*	–0.008	–0.026
Village/district-level factors				
Land redistribution	0.278***	0.558***	0.184	0.467*
Ln Household density	–0.281***	–0.294***	0.031	–0.037
Ln Altitude	0.128	0.693*	0.198	1.291**
Ln Rainfall	0.323	0.158	–0.274	0.019
Subregional location				
Location (cf. Southern)				
Northern	0.521***	0.056	0.443*	–0.322
Western	0.567*	–0.152	1.256***	–0.517
Eastern	0.408***	0.857***	0.635**	1.122**

(*continued*)

Table 9.7 (continued)

Factor	Ordinary least squares		Reduced form	
	Low-potential areas	High-potential areas	Low-potential areas	High-potential areas
Endogenous variables				
Crops (cf. other crops)				
Barley only	0.196	0.108		
Maize only	0.152	0.254		
Wheat only	0.106	0.198		
Teff only	0.529	0.465***		
Other cereals	0.417	0.492***		
Cereal and other crops	1.038***	0.632***		
Legumes only	1.111***	0.302		
Extension (cf. 0 visits)				
1–5 visits	0.153	0.269***		
6–10 visits	0.108	0.305***		
More than 10 visits	–0.186	0.214*		
Use of reduced tillage	0.003	–0.236		
Use of contour plowing	–0.095	–0.029		
Use of crop rotation	0.025	–0.035		
Use of crop residues	–0.279***	–0.114		
Use of household refuse	–0.245*	–0.212*		
Use of manure	–0.101	0.148		
Use of chemical fertilizers	–0.010	0.442***		
Use of improved seeds	0.199	0.387***		
Ln Amount of labor	0.146***	0.163***		
Ln Amount of draft power	0.309***	0.011		
Ln Value of seed	0.279***	0.189***		
Instruments				
Plot level				
Homestead plot			–0.081	–0.248*
Ln Plot to residence			0.003	–0.002
Household level				
Ln Household size			–0.156	–0.079
Proportion male			–0.191	0.266
Dependency ratio			–0.132	–0.668*
Exogenous income			0.000	0.000
Access to markets or services				
Ln Drinking water			–0.033	–0.087
Ln Grain mill			0.122*	–0.077
Ln All-weather road			0.020	0.221**
Ln Development agent			0.066	–0.095
Ln Bus service station			0.054	–0.192*
Ln Fuelwood			–0.001	–0.001
Ln Input supply shop			–0.151*	0.001

Table 9.7 (continued)

	Ordinary least squares		Reduced form	
Factor	**Low-potential areas**	**High-potential areas**	**Low-potential areas**	**High-potential areas**
Village/district-level factors				
Ln Distance to district town			0.042	–0.045
Access to fertilizers			0.158	n.e.
Access to improved seeds			0.018	–0.165
Access to purchased feed			–0.390***	0.135
Access to credit			0.535**	–0.285
Presence of local association				
Input cooperative			–0.724***	0.581**
Marketing cooperative			–0.175	n.e.
Women's/youth			n.e.	–0.303
Church			0.436***	0.708**
Water users			0.303	–0.254
Constant	3.181	2.226	9.739***	2.157
F	17.580***	12.540***	7.600***	5.040***
R^2	0.661	0.604	0.479	0.474
Hausman test[a]	4.400	0.010		
Chow test[b]	3.174***		2.093***	

Note: Values are Ln (birr/hectare). See Table 9.4 for detailed description of explanatory variables. Coefficients and standard errors are adjusted for stratification, weighting, and clustering of sample.

***, **, and *** means coefficient is statistically significant at the 10 percent, 5 percent, and 1 percent level, respectively.**

Ln means variable is transformed by natural logarithm.

At the time of the survey, US$1 ≈ 8.50 Ethiopian birr.

[a]Hausman test of endogeneity when the instruments are used to predict the endogenous variables in an instrumental variables (IV) regression.

[b]The Chow test is a test of equality of the coefficients in low- and high-potential areas.

although the reduced-form estimates are occasionally discussed to distinguish indirect effects.

Consistent with the finding of Benin and Pender (2001), land redistribution was directly associated with higher value of crop yield, although the effect was about twice as large in the high-potential areas, where the incidence of land redistribution was also higher. This result is surprising, however, because land redistribution, although associated with greater plowing in of crop residues in high-potential areas, was associated with lower incidence of use of several of the land management practices as well as use of labor and animal draft power (see Tables 9.5 and 9.6).

Owner-cultivated plots, compared to rented plots, were weakly associated with lower value of crop yield by 27 percent in high-potential areas.[20] This result is also puzzling because it contradicts the tendency of yields to be lower on rented plots

(Otsuka and Hayami 1988). It also contradicts results from other parts of Ethiopia in the Oromiya region (Ahmed et al. 2002; Pender and Fafchamps 2006, forthcoming) and the Tigray region (Pender, Gebremedhin, and Haile 2002). Pender and Fafchamps found no difference in yields between owner-cultivated and sharecropped plots, and Ahmed et al. (2002) and Pender, Gebremedhin, and Haile (2002) found that crop yields were lower on sharecropped plots than on owner-cultivated plots. The result is puzzling also because the econometric results do not show many statistically significant differences in land management practices and inputs between owner-cultivated and rented plots in high-potential areas, except the case where likelihood of using manure or improved seeds was lower on owner-cultivated plots, whereas likelihood of using crop rotation, crop residues, and labor was higher (see Tables 9.5 and 9.6). Although the result is consistent with some of the findings of Holden, Shiferaw, and Pender (2001), who found that barley yield was about 51 percent higher on rented plots, the puzzle was addressed by reestimating the value of crop yield regression in high-potential areas using a household fixed-effects model and also by restricting the sample to households with both owner-cultivated and rented plots only.[21] In the household fixed-effects model, all variables that do not vary across plots (within the household) are dropped. The results of these estimations, presented in the appendix, show that the weak negative effect associated with owner-cultivated plots was not robust, suggesting that the land rental market may actually be operating efficiently. Note, however, that there is substantial loss of information (i.e., dropping several variables in the fixed-effects model and observations in the restricted sample) associated with these models. Thus, although their estimates compare fairly well with those in Table 9.7, they are not preferred for further discussion.

For the same total farm size, larger plots were associated with lower value of crop yield in high-potential areas only (value of crop yield elasticity with respect to plot size is –0.28), which is consistent with the lower use of inputs, especially labor, animal draft power, and seed. Larger farms also were associated with lower value of crop yield, but significantly so in low-potential areas only (yield elasticity of –0.28). This inverse farm size–productivity relationship is consistent with the findings of many studies, including Hayes, Roth, and Zepeda (1997) and Holden, Shiferaw, and Pender (2001). However, these findings should not be misinterpreted to mean that plots and farm sizes in the region should be reduced in order to increase farmland productivity, as farm holdings are already small: they average 1.3 hectares per household, and more than one-half of the households own less than 1 hectare.

Irrigation contributed to a higher value of crop yield in low-potential areas only via choice of high-value crops and greater use of some inputs. That is, irrigation by itself had no direct effect on value of crop yield, controlling for crop choice, input use, and other factors. This finding is consistent with results from the Tigray region (Chapter 5), where irrigation was also found to have no direct effect on crop yield, although it contributed significantly to increased use of inputs. Similarly, plots with stone terraces had no direct effect on value of crop yield. The indirect effect, however, was significant in low-potential areas (associated with 42 percent more value of crop yield). This result is consistent with other findings from Tigray region, which is typical of low moisture and generally of low agricultural potential (Gebremedhin, Swinton, and Tilahun 1999; Pender, Gebremedhin, and Haile 2002).

Male-headed households were weakly associated with higher value of crop yield (about 40 percent more) than their female-headed counterparts in high-potential areas. Because we control for factors that may be biased against female-headed households and contribute to lower value of crop yield (e.g., household size, composition, and education, access to credit, extension, and inputs), it is not clear why this is the case. Perhaps, as most women take over the management of the farm only when their husbands are not in a position to manage the farm, they may be less experienced in managing the farm than their male counterparts. This result suggests that poverty and food insecurity may be more problematic in female-headed households in high-potential areas. Ownership of an additional ox was associated with greater value of crop yield (about 15 percent) in high-potential areas, whereas ownership of additional livestock in general was weakly associated with lower value of crop yield (about 5 percent) among households in the same high-potential areas.

Extension had a significant positive effect on value of crop yield in high-potential areas only, and there seems to be an inverted-U-shaped relationship between value of crop yield and number of extension visits received by the household. Households that received between one and five visits were associated with 31 percent more value of crop yield than those that received none. However, those that received between 6 and 10 visits were associated with 36 percent more value of crop yield, and those that received more than 10 visits were associated with 24 percent more value of crop yield.[22] These data suggest that repeated extension visits are more effective, although the marginal effect declines as other aspects of livelihoods on which extension also focuses become more profitable, so that resources are shifted into those areas. The reason for extension not having a significant positive effect in low-potential areas is likely the emphasis on improved seeds and chemical fertilizers, as number of extension visits was similar in the two areas (see Table 9.4). Improved seeds and chemical fertilizers are more appropriate in high-potential areas or where ample and reliable moisture is available. This finding is consistent with the limited impact of these inputs and extension found in Tigray in Chapter 5. Value of crop yield was higher by 47 percent and 56 percent on plots that used improved seeds or chemical fertilizers, respectively, in high-potential areas. Plots in low-potential areas on which crop residues were used were associated with lower value of crop yield, whereas those in both low- and high-potential areas on which household refuse was used were associated with lower value of crop yield. These results may seem surprising, but organic materials take longer to break down and can actually reduce the availability of soil nitrogen to crops if their carbon to nitrogen content is high (Giller et al. 1997).

The value of crop yield elasticity with respect to labor, animal draft power, and seed in low-potential areas were 0.15, 0.31, and 0.28, respectively, and 0.16, 0.01, and 0.19 in high-potential areas, although the elasticity with respect to animal draft power was not significant in the latter. In low-potential areas, the elasticities translate into marginal returns of 4.75, 10.05, and 9.08 birr per hectare for 1 percent increase in labor (equal to 4.4 man-days), animal draft power (0.5 animal-day), and seed (2.5 birr) per hectare, respectively.[23] In high-potential areas, the marginal returns are 4.20 and 4.87 birr for labor and seed, respectively. At the time of the survey, the average farm wage rate for men was about 4 birr per day, whereas renting an ox cost 5 birr per day. With these unit values used, and all other factors controlled at the margin, oxen (except in high-potential areas) and seed returned significant profits, but farm labor was substantially overpaid.

Population density had a negative influence on the value of crop yield, with elasticities of –0.28 and –0.29 in low- and high-potential areas, respectively. These contradict the Boserupian (Boserup 1965) optimistic perspective about the responses of households to population pressure and suggest that, under current conditions, crop production in high-potential areas will not be able to support its growing population, and so the trickle-down effect to low-potential areas cannot be justified.

The effects of access to infrastructure and services on value of crop yield were mixed, and the estimates are obtainable from the results of the reduced-form regression model only. For example, households in the high-potential areas and closer to an all-weather road were associated with lower value of crop yield, whereas those closer to a bus service station were associated with greater value of crop yield. Presence of an input cooperative was associated with greater value of crop yield in high-potential areas but lower value in low-potential areas, but access to credit had a positive effect in low-potential areas only.

Conclusions and Implications

This chapter has presented a large amount of primary empirical evidence based on sound scientific methodology on the factors (biophysical, socioeconomic, policy, and program) that influence adoption of various land management practices and modern inputs (including reduced tillage, contour plowing, crop rotation, crop residues, household refuse, manure, improved seeds, and chemical fertilizers), amounts of inputs used (labor, draft animal power, and seed), and value of crop yield on farm plots in the highlands of Amhara region. Survey data from a total of 434 households and 1,434 plots were used in the analyses. The evidence was presented separately by agricultural production potential (low and high). In the discussion of the evidence, however, the chapter focused on the influences of land redistribution and tenure, plot and farm size, household endowments (gender, education, and ox and livestock ownership), population density, and access to infrastructure and services (access to roads, markets, and credit). The effects of irrigation, stone terraces, extension, land management practices, and use of conventional inputs (labor, draft animals, and seeds) and modern inputs (improved seeds and chemical fertilizers) on value of crop yield were also discussed.

Econometric results show that value of crop yield was significantly higher on household plots in villages affected by land redistribution since 1991, suggesting that land redistribution may have served well in the past to equalize farmland holding across households, especially in improving access to farmland of landless households. In conjunction with the finding that larger plots and farms were associated with lower value of crop yields, the result may seem to suggest that reallocation of resources among households is desirable, especially if the market transactions are artificially suppressed. However, such gains in the past should not be a guide for the future. The current farming situation is desperate: average farmland holding per household is only 1.3 hectares, and more than half of the households own less than 1 hectare. In addition, current conditions and farm technology barely support an average production of 1 ton per hectare. Thus, it is difficult to envisage how households can effectively meet their food needs with further smaller plots and farms. Other viable alternatives should be considered. For example, larger farms also tend to be more fragmented, requiring more resources per unit of area to manage them efficiently. Therefore, consolidation of farms may be a more desirable approach to improve land productivity.

The results also show that improving tenure security of farmers would be very beneficial, as we find that plots on which households felt more secure (i.e., expecting to operate for the next five years) were associated with greater value of crop yield, especially in high-potential areas (about 60 percent more). A major source of tenure insecurity is fear of loss of land during redistribution, which can have a negative effect on the land rental market, as land-abundant households may not be willing to rent out land. This is because renting out land is believed to increase tenure insecurity by increasing the likelihood of that plot being redistributed, as renting out signals inability to farm (Holden and Yohanner 2002). Fortunately, the

Amhara regional government stopped land redistribution in 2000. This would help to increase tenure security, which in turn would help to increase and sustain higher yields and also strengthen the efficiency of the current land rental market.

Several of the other policy and program variables considered, including irrigation, extension, and use of modern inputs, had differential significant effects on value of crop yield in low- and high-agricultural-potential areas. The results show that extension and use of improved seeds and chemical fertilizers had significant positive effects on value of crop yield in the high-potential areas only. Irrigation, on the other hand, had substantial total effect in low-potential areas only. These results suggest that different strategies are needed for the different environments. For example, in the low-potential areas, the extension strategy should focus more on promoting soil and water conservation structures such as stone terraces, which were associated with 42 percent more value of crop yield in those areas. Relying on external inputs (chemicals fertilizers and improved seeds) in low-potential areas, which has been the strategy in the past, is not likely to be beneficial unless moisture availability issues are addressed.

In the high-potential areas, improving input delivery and extension services would be very beneficial. In addition, adopting policies and programs that improve farm management abilities of women and promoting more education for children (especially girls) would have long-run beneficial effects, as the results show that female-headed households and households with more dependents were associated with lower value of crop yields, especially in high-potential areas.

Though the effects of access to infrastructure and services were mixed, promoting more nonfarm income-earning activities, especially in areas close to towns and roads, where the opportunity costs of farm labor and of other agricultural factor inputs are higher or where more exit options out of agriculture exist, would also be helpful. In addition, adopting policies and programs that reduce population pressure would be beneficial, as the results show that more densely populated villages were associated with lower farming intensity in several instances and lower value of crop yield in both low- and high-potential areas. Else, the notion of the trickle-down effect from high- to low-agricultural-potential areas will remain just that because crop production in high-potential areas will not be able to support its own growing population.

Appendix: Least-Squares Regression Results to Examine the Robustness of the Negative Impact of Land Tenure (Owner-Cultivated Plots) on Value of Crop Yield (Ln [birr/ha]) in 1999 in the High-Agricultural-Potential Areas of the Highlands of Amhara Region

	High-potential areas (ordinary least squares)	
	Household fixed-effects model, full sample[a]	Households operating owner-cultivated and rented plots only[b]
Exogenous variables		
Plot-level factors		
Owner-cultivated	–0.023	–0.184
Expectation to operate	0.152	0.326
Ln size	–0.129**	–0.280***
Ln slope	–0.002	0.028*
Soil depth (cf. deep)		
Medium	0.048	0.106
Shallow	–0.039	0.255*
Soil color (cf. black)		
Brown	0.124	0.226
Gray	0.016	0.250
Red	–0.008	–0.068
Presence of gullies	–0.055	0.365*
Waterlogging problem	–0.246**	–0.183
Investments on plot		
Irrigation	0.051	–0.110
Stone terraces	0.146	0.199
Drainage ditch	0.038	–0.221*
Live fence	0.104	0.165
Fence	–0.039	0.084
Household-level factors		
Gender of head		
Ln age of head		–1.155***
Average education		0.054***
Ln size of farmland		–0.339***
Number of oxen		0.198
Tropical livestock units		–0.018
Village/district-level factors		
Land redistribution		0.351
Ln household density		–0.303***
Ln altitude		–1.778***
Ln rainfall		0.369
Subregional location		
Location (cf. Southern)		
Northern		0.399
Western		0.563
Eastern		0.750

(*continued*)

Appendix (continued)

	High-potential areas (ordinary least squares)	
	Household fixed-effects model, full sample[a]	Households operating owner-cultivated and rented plots only[b]
Endogenous variables		
Crops (cf. other crops)		
Barley only	0.168	0.115
Maize only	0.122	0.042
Wheat only	0.244	0.565***
Teff only	0.385***	0.458**
Other cereals	0.431***	0.356**
Cereal and other crops	0.702***	0.851***
Legumes only	0.658***	0.501*
Extension (cf. 0 visits)		
1–5 visits		0.338*
6–10 visits		0.311*
More than 10 visits		–0.077
Use of reduced tillage	–0.066	–0.476***
Use of contour plowing	–0.103	–0.534***
Use of crop rotation	0.083	0.119
Use of crop residues	–0.123	–0.239*
Use of household refuse	–0.186*	–0.649***
Use of manure	0.019	0.230
Use of chemical fertilizers	0.230***	0.242
Use of improved seeds	0.198*	0.427***
Ln amount of labor	0.219***	0.239***
Ln amount of draft power	0.132***	–0.030
Ln value of seed	0.215***	0.113*
Constant	4.963***	24.348***
F	10.770***	37.390***
R^2	0.511	0.826
Fixed-effect test[c]	2.740***	

Note: See Table 9.4 for detailed description of explanatory variables. Coefficients and standard errors are adjusted for stratification, weighting, and clustering of sample. At the time of the survey, US$1 ≈ 8.50 birr.

***, **, and *** mean that coefficient is statistically significant at the 10, 5, and 1 percent level, respectively.**

Ln means variable is transformed by natural logarithm.

n.e. means coefficient was not estimated because the associated variable was dropped to avoid dummy variable trap or because it perfectly predicted the outcome.

[a] In the household fixed-effects regression model, all variables that do not vary within households are dropped and a dummy variable for each household is included.

[b] Only households that operate both owned and rented plots are included here. Number of observations is 163.

[c] Test that the coefficients on the dummy variables for each household are jointly zero.

Notes

1. Subscripts *v, h, p,* and *t* refer to village, household, plot, and time, respectively.

2. Following the same line of argument, restrictions on land sales, as exist in Ethiopia, need not be a source of inefficiency.

3. The peasant administration is the lowest unit of government.

4. The classification of drought-prone versus non-drought-prone districts used by the Ethiopian Disaster Prevention and Preparedness Commission was adapted for defining agricultural potential, referring to drought-prone districts as low-agricultural-potential districts (located in the eastern part of the region) and non-drought-prone districts as high-agricultural-potential districts (located mainly in the west and southern tip of the region).

5. Districts that have more than 50 percent of their total area below 1,500 meters above sea level were excluded from the sample frame.

6. Observations with missing data, mostly uncultivated plots, were dropped, leaving 1,187 observations for analysis.

7. Land redistribution was recently phased out in the region. However, there were significant differences across regions with respect to its implementation leading up to the time of data collection. For example, in the Tigray region, land redistribution was stopped in 1991, and the policy of no future redistribution was made official by a land use and tenure policy in 1997. In the Oromiya region too, there has not been a land redistribution since 1992, and the regional government is currently developing its land use policy.

8. At the time of the survey, US$1 ≈ 8.50 birr.

9. On rented plots, bequeath refers to the expectation of transferring the rental contract to an heir in the event that the current contract holder is unable to continue farming.

10. Because of the different crops produced on a plot, total output was aggregated using one set of unit prices of crops for all households.

11. Monthly rainfall data for 1999 were obtained from the Meteorological Services Agency for weather stations located in the districts where the surveys were carried out, and elevation data were obtained from the geo-referenced Country Almanac Ethiopia Database.

12. Wag Hamra and Oromia zones were excluded from the sample frame because they were predominantly lowland (see note 5).

13. The selection of land management practices for the econometric analysis was based on those practices occurring on 10 percent or more of all plots.

14. The regression results of these are available on request.

15. One tropical livestock unit (TLU) is equivalent to one cow weighing 250 kg. Conversion factors for other types of animals, based on weights, have been estimated by ILRI.

16. The Hausman test is given by the chi-square value, $\chi^2 = (\hat{\beta}_{IV} - \hat{\beta}_{OLS})(Var_{IV} - Var_{OLS})^{-1}(\hat{\beta}_{IV} - \hat{\beta}_{OLS})$, where $\hat{\beta}$ and *Var* are the estimated coefficient and variance, respectively. Detailed test results are reported in the relevant tables of results.

17. Note that only continuous explanatory variables without zero values were transformed by natural logarithm.

18. Detailed results of log-likelihood ratio tests for the probit models and Chow tests for the linear models are shown in the relevant tables of results.

19. With the large number of explanatory variables, there is the potential for a multicollinearity problem. This was tested using variance inflation factors, which were in the acceptable range of less than 10 (Kennedy 1985).

20. The predicted impact of these and other discrete variables on value of crop yield can be calculated by taking the exponential of the relevant coefficient in Table 9.7 because the dependent variable is the logarithm of total output per hectare.

21. Thanks to Kei Otsuka for suggesting these methods for addressing the puzzle.

22. Discrete variables (rather than a continuous one) for extension visits were used in the regression analysis because of two problems. First, there were many zero values, and the logarithm of zero is not defined. Second, there was insufficient variation in the nonzero values for reliable continuous-variable estimation. The same applies to other inputs such as manure, chemical fertilizers, and improved seeds.

23. The predicted returns in birr to a 1 percent increase in input can be calculated by multiplying the elasticity with respect to that input in Table 9.7 by 3,252.91 or 2,576.46 birr, which are the average values of output per hectare in low- and high-potential areas, respectively (see Table 9.4).

Chapter 10

Community Natural Resource Management in the Highlands of Ethiopia

Berhanu Gebremedhin, John Pender, and Girmay Tesfay

Common property resources[1] are important sources of timber, fuelwood, and grazing land in developing countries. When community members have unrestricted access to the resource, or when use regulations are ineffective, these resources are exploited on a first-come, first-served basis. Each individual user of the resource will tend to continue to use the resource until her average revenue is equal to the marginal cost of using the resource (Gordon 1954). In the presence of externalities, social marginal cost exceeds private marginal cost, and common property resources can still be degraded if an individual equates her marginal cost with her marginal benefit of utilizing the resource. These conditions lead to overexploitation of the resource and the dissipation of the scarcity rent.

Several alternative solutions have been proposed to solve this problem, including collective action,[2] privatization, and imposition and enforcement of use rules by external forces such as the government (Wade 1987). The transaction cost of enforcing use rules imposed on communities by an external force is likely to be prohibitively high because of the high incentives of individual users to shirk or of the community members to collude against the use rules. Privatization is not always superior to community resource management because poverty, dependence on the natural resources, and natural and environmental risks may make common property a more rational solution to problems of resource management (Runge 1992). McCarthy, Kamara, and Kirk (2001) argue that private property of communal rangelands will become optimal only when collective action is so poor that it becomes welfare-improving to appropriate land individually.

Collective action for natural resource management can also mitigate the negative influence of population pressure on natural resource management as predicted by the Malthusian perspective. In the presence of collective action, institutional and organizational development, and the development of infrastructure, population pressure is more likely to have a positive effect on natural resources than in the absence of these developments (Pender 2001). Moreover, the success of public policies to improve natural resource management depends to a large extent on the presence and effectiveness of local-level institutions and organizations to enforce them (Rasmussen and Meinzen-Dick 1995).

Hence, the solution to the problem of resource degradation in developing countries depends not only on appropriate technologies and efficient market prices but also on local-level institutions of resource management and the organizations to enforce them (Rasmussen and Meinzen-Dick 1995; Baland and Platteau 1996). Community resource management institutions and organizations are now receiving greater attention as a viable alternative to regulation by the state or privatization as a means of rectifying inefficiencies caused by attenuated property right systems, externalities, and other market failures.

However, devolving rights to local communities to help build institutions for common property management may not be a sufficient condition for sustainable use of such resources. Effectiveness in internal governance is needed for the effective application of community rules (Turner, Pearce, and Bateman 1994; Swallow and Bromley 1995). Hence, the need to identify factors that facilitate or hinder the development and effectiveness of local level institutions and organisations for natural resource management becomes important for developing policies to strengthen community resource management.

In Ethiopia, rural communities depend primarily on common property resources for irrigation water, construction material, fuelwood, and grazing land. Population pressure, market and government failures, and the absence or ineffectiveness of use regulations of common property resources have resulted in severe degradation of the resources (Stahl 1990; Gebremedhin 1998). Perhaps as a result, Ethiopia has been identified as the country with the most environmental problems in the Sahel belt (Hurni 1985).

After the 1974 revolution, increasing shortage of biomass for fuelwood and construction purposes resulted in emphasis given to rural afforestation and reforestation. Guided by Marxist ideology, the military government then favored state and social forestry, and individual tree planting efforts were undermined (Bruce, Hoben, and Rahmato 1994). Since 1991, the policies of the national and regional governments emphasized natural resource conservation as a key component of the agricultural development strategy. Unlike during the military government, decentralization of resource management has been encouraged. For example, in Tigray region, woodlot management has been devolved from community (*tabia,* which usually consists of four or five villages) level to village level to subvillage level and to individual farmers (Jagger, Pender, and Gebremedhin 2003). However, most of the woodlots in the region still remain under community management.

As part of the conservation-based agricultural development strategy pursued in the northern Ethiopian highlands of Tigray that is aimed at rehabilitating the degraded environment, several natural resource conservation and development efforts have been under way in the region, especially since 1991. These efforts include construction of soil and water conservation structures, area enclosures (areas closed from human and animal interference to allow natural regeneration with enrichment plantations), community woodlot development, community grazing land management, and the development of small-scale irrigation.

However, there is a scarcity of evidence regarding the factors that facilitate or hinder community resource management in the region. Empirical evidence on the determinants of collective action for natural resource management can provide useful guidance to policy makers in the region in their effort to enhance the effectiveness of community resource management efforts. The empirical results will also contribute to the growing literature and debate on collective action for natural resource management in developing countries.

This chapter provides evidence on the determinants of collective action for community woodlot and communal grazing land management in the highlands of Tigray. The chapter uses multivariate econometric methods to analyze the determinants of collective action and its effectiveness in managing woodlots and grazing lands.

Data

This study is based on a survey of 50 *tabias* (the lowest administrative unit in Tigray, comprising usually four or five villages) and 100 villages in the highlands[3] of Tigray in the 1998–99 cropping season, as part of the IFPRI/ILRI/Mekelle University research project on Policies for Sustainable Land Management in the Highlands of Tigray. Sample *tabias* were selected based on random sampling stratified by proximity to a market town and presence of an irrigation project. Within each *tabia,* two villages were selected randomly. A semistructured questionnaire was administered with representative individuals at both levels. Each interview involved 10 respondents chosen to represent different age groups (below 30 years of age, and older), villages (representation of each sample village), primary occupations (farming or off farm), and gender. The survey collected information about changes in agricultural and natural resource conditions between 1991 and 1998 and their causes and effects.

Community woodlots and grazing lands with use regulations are common in the highlands of Tigray. Almost 9 out of 10 *tabias* in the highlands of Tigray have woodlots (Table 10.1), and 90 percent of villages have restricted grazing areas[4] (Table 10.2). There are nine woodlots per *tabia* on average, and these average about 8 hectares in size; the average area of restricted grazing land per village was 38 hectares. Most of the woodlots were established since the fall of the military government in 1991. However, more than 58 percent of the restricted grazing areas were established before 1966, and only 17 percent were established after 1991. The establishment of most woodlots (95.5 percent) has been promoted by external organizations, usually the Tigray Regional Bureau of Agriculture and Natural Resources (TBoANR), while only 32 percent of the restricted grazing areas were promoted by external organizations and programs.

Whereas all restricted grazing lands were managed at the village level, woodlots were managed at both the village and *tabia* levels. *Tabia*-managed woodlots

Table 10.1 Characteristics of community woodlots: Means

Item	Village-managed	*Tabia*-managed	All woodlots
Percentage of *tabias* with a woodlot	57.7	29.9	87.6
	(8.1)	(7.2)	(5.8)
Number of woodlots per *tabia*	7.2	0.9	9.0
	(1.3)	(0.2)	(1.3)
Area of woodlots (hectares)	5.1	18.5	7.9
	(0.9)	(3.8)	(1.4)
Percentage of woodlots established since 1991	75.6	91.3	78.0
	(8.8)	(5.2)	(7.6)
Percentage of woodlots			
Promoted by a program or organization	94.6	98.7	95.5
	(3.8)	(1.4)	(3.0)
Promoted by BoANRD	76.5	91.4	79.5
	(8.7)	(7.4)	(7.2)
Promoted by REST	4.6	0.0	3.7
	(3.7)	(0.0)	(3.0)
Promoted by BoANRD and REST	4.8	7.3	5.3
	(4.6)	(7.2)	(3.9)
Promoted by World Vision	4.8	0.0	3.8
	(4.6)	(0.0)	(3.7)
Percentage of woodlots where users are:			
All *tabia* members	0.0	94.8	19.6
	(0.0)	(5.3)	(6.4)
Only village members	100.0	0.0	79.1
	(0.0)	(0.0)	(6.4)
Only the guard	0.0	5.2	1.1
	(0.0)	(5.3)	(1.1)

Note: Standard errors in parentheses. Means and standard errors are corrected for sampling stratification and weights.

Table 10.2 Characteristics and allowed uses of restricted grazing areas

Item	Village level	Grazing area level
Percentage of villages with restricted grazing lands	89 (0.0096)	
Number of restricted grazing lands per village	3.98 (0.16)	
Average area of restricted grazing lands (hectares)	38.2 (3.61)	10.45 (1.11)
Average age of restricted grazing land		23 (0.8)
Percentage of grazing lands promoted by external organizations		32 (3.5)
Value of community contribution for grazing land management (birr)		
Value per grazing land		1,580 (615)
Value per hectare		300 (60)
Value per household		3.66 (0.85)
Allowed uses of restricted grazing lands (percent)		
Cutting grass		22 (3.0)
Fuelwood collection		53 (3.4)
Collecting dung		90 (2.1)
Collecting fruits		66 (3.3)
Beekeeping		60 (3.2)
Cutting trees		0 (0.0)

Note: Standard errors in parentheses. Means and standard errors are corrected for sampling stratification and weights.

tend to be larger than village-managed woodlots, averaging more than 18 hectares in size compared to about 5 hectares for village woodlots (Table 10.1). The most common use allowed on woodlots is to cut and collect grass for animal feed, roof materials, or other purposes. Collecting fruits and beekeeping in woodlots are also commonly allowed. These uses are more common on village-managed than *tabia*-managed woodlots. In restricted grazing areas, in addition to grazing animals, fuelwood and dung collection and beekeeping are commonly allowed uses. Cutting and collecting grass was also practiced in 22 percent of the restricted grazing areas. Cutting trees, shrubs, branches, or roots and collecting fuelwood, barks, leaves, or dung are not allowed in woodlots. In a few cases animals are allowed to graze in the woodlot, but only during a drought.

Almost all woodlots and most grazing areas are protected by a guard paid in cash or in kind. In some cases, the guard is compensated by being allowed to collect grass from the woodlot or grazing area. It is more common for the local community to hire the guard for village-managed than for *tabia*-managed woodlots. In 77 percent of the restricted grazing lands, village residents contributed cash or in kind for guard payment.

The most common violations of restrictions of woodlots and grazing lands reported in 1998 were cutting grass and grazing animals when not allowed. Cutting of trees or branches were also frequently reported violations on woodlots. Violations are more common on *tabia*-managed than village-managed woodlots.

Given the limited allowed uses of the woodlots, the benefits received are, not surprisingly, small. Of 164 village-managed woodlots in our sample, benefits were reported being received in 1998 from only 57 woodlots, mainly from cutting grass. Fewer than half of the households in the villages benefited from grass cutting on average, and the average estimated value of benefit was 2,783 EB per woodlot in 1998, only about 2 EB per capita in the villages where benefits were received. The benefits from *tabia*-managed woodlots are even lower, averaging only 352 EB per woodlot, less than 0.10 EB per capita. In the case of restricted grazing areas, 42 percent of households were reported to have benefited from grazing animals in 1998. Other benefits of grazing lands to rural households include cutting grass for feed and other purposes, collecting dung, and collecting fuelwood from dead trees.

Villages are pursuing a more intensive strategy of woodlot management than *tabias.* Labor for tree planting, constructing soil and water conservation structures, weeding, and harrowing are the main collective input, averaging 0.18 person-days per capita for village-managed woodlots and 0.13 person-days per capita for *tabia*-managed woodlots. Village woodlots are also planted much more densely than *tabia* woodlots. The average survival rate is somewhat higher for *tabia* woodlots, but in view of the differences in planting densities, the number of surviving trees per hectare is still much higher on village woodlots. Considering the average returns per capita reported above, the average return per person-day invested in 1998 was about 10 EB for village-managed woodlots (comparable to the daily wage rate in rural Tigray) but less than 1 EB for *tabia*-managed woodlots.

The main benefit of a woodlot is not likely the value of grass collected but rather the value of the trees in the woodlot, a nonliquidated capital gain. The most commonly planted trees in community woodlots are eucalyptus trees (especially globulus and camaldulensis). The average price of eucalyptus poles in the highlands of Tigray was about 28 EB per pole in 1998 (Jagger and Pender 2003). On the basis of the average planting density (about 4,500 trees per hectare) and survival rate (64 percent), a woodlot of average-sized eucalyptus trees would be worth more than 80,000 EB per hectare on average, and much more in places where wood is very scarce. With an average of more than 70 hectares of woodlots per *tabia* (nine woodlots averaging almost 8 hectares each), this represents a substantial contribution to the wealth of communities in Tigray (averaging more than 5 million EB per community). Thus, despite the limited amount of current benefits that people are receiving from community woodlots in Tigray, community members are generally satisfied that they will benefit from them eventually. Only a small fraction of communities report uncertainty about future benefits as a problem, although the problem is more commonly reported for *tabia*-managed than village-managed woodlots. In almost all cases, community members reported that the condition of the area where the woodlot or the restricted grazing lands were established had improved substantially as a result of the protection and investment in developing the resources. Only a few communities reported a problem of increasing pressure on other lands as a result of the protection of woodlots or grazing lands.

Empirical Approach

When community resource users are able to negotiate among themselves to set rules of access, when cost of monitoring compliance or violations is not very high, and when noncooperation would lead to nonprovision, rational individuals will tend to voluntarily comply with rules of restrained access, thus paving the way to the development of collection action. Analysis of individual incentives to contribute to collective action for common property resource management has been the most dominant economic approach to the study of the determinants and effectiveness of collective action (Baland and Platteau 1999; Agrawal 2001; Varughese and Ostrom 2001). Underlying these incentives is the perceived distribution of benefits and costs, which may in turn be influenced by factors related to the nature of the resource, the characteristics of the community, the interrelationships between the community and the resource, the external environment such as the role of external programs and organizations, and access to markets (Agrawal 2001).

Hence, in this study, factors related to the number and characteristics of community members (by facilitating or hindering trust and cooperation), the external environment (through the effect of the involvement of external organizations and programs or access to markets on costs and benefits of collective action), importance of the resource for livelihood, and community experience in establishing and managing local organizations are considered important determinants of collective action and its effectiveness for woodlot and grazing land management.[5]

The indicators of collective action and effectiveness in managing woodlots used in the econometric analysis include the amount of uncompensated collective labor per hectare invested, whether the community pays for a guard to protect the woodlot, whether there were any violations of the restrictions on use of the woodlot, the number of trees planted per hectare on the woodlot since its establishment, and the survival rate of the trees planted. In the case of grazing lands, we used area of restricted[6] grazing land per household in the village, whether communities pay for a guard to protect the grazing land, the monetary value of contribution per household for grazing land management, whether communities established penalty systems for violations of use restrictions, and whether violations of use rules and regulations occurred in 1998, as indicators of collective action.

Community members may respond to noncooperation by cooperating to increase each other's incentive to cooperate or through exhortation and penalties. Thus, establishment of a penalty system is used as an indicator of collective action.

Violations of use restrictions and regulations are used as an indicator of failure of collective action.

The type of regression model used depends on the nature of the dependent variable. We use a Tobit model to explain collective labor investment and survival rate in the case of woodlots, and area of restricted grazing land per household and monetary household contribution per hectare in the case of grazing lands, because these variables are censored. We use binary probit models to explain whether the community pays for a guard, whether there were violations of restrictions in woodlots or grazing lands, and whether the community established a penalty system in the case of grazing lands, because these are binary variables. We use least-squares regressions for tree planting density because this variable is continuous.

The factors used to explain variations in collective action and its effectiveness in managing woodlots include population density, access to market, involvement of external organizations or programs in the establishment of woodlot, whether the woodlot is managed at the village or *tabia* level, and the area of the woodlot. The factors used to explain differences in collective action in managing grazing lands include the number of total households in a village,[7] heterogeneity in ox ownership by the community, community experience in running local organizations, distance to market, involvement of external organizations or programs in establishing the restricted grazing land, whether cattle production is the second most important source of livelihood in a community, and the total area of the community.

At low levels of population, the demand for collective action to manage community resources may be low, and the organizational costs of attaining it high, because of fixed costs. As population grows, increasing resource scarcity will increase the benefits of improved resource management, whether through collective action or development of private property. This may induce increased collective action, particularly if economies of scale or high exclusion costs favor collective over private management. However, as population grows to very high levels, the gains from collective action may be outweighed by the incentive problems associated with it, as rising scarcity increases the benefits from attempting to "free-ride" on the efforts of others or lowers the per capita benefits of cooperating. Thus, there may be an "inverse-U relation" between collective action and population, with higher levels and effectiveness of collective action at intermediate population than at very low or very high population (Pender and Scherr 2002).

The effect of market access on collective action for community resource management is ambiguous. On one hand, having better access to markets increases the value of resources and thus the value of managing resources well, which may favor collective action. On the other hand, better market access may tend to undermine individuals' incentives to cooperate by increasing the opportunity cost of labor or by offering more "exit" options, making it more difficult to punish those who fail to cooperate (Bardham 1993; Baland and Platteau 1996; Pender and Scherr 2002). The presence of external organizations or programs may favor collective action for community resource management when those organizations are seeking to provide complementary inputs to local collective inputs but may undermine collective action if external organizations are providing substitutes for collective action or otherwise undermining collective action (Pender and Scherr 2002).

We expect that collective action will be more prevalent and more effective for village-managed woodlots than for *tabia*-managed woodlots because villages are smaller, more cohesive, and a more stable unit than *tabias* (e.g., the *tabias* were reorganized in 1995 to include more villages). We were not able to test for the effect of level of management on collective action for grazing land management because all restricted grazing lands were managed at the village level. To the extent that economies of scale are important in favoring collective action (for example, in protecting the woodlot), we expect that collective action should be greater and more effective on larger woodlots.

The effect of heterogeneity on collective action is unresolved because communities may be heterogeneous in several aspects including sociocultural background, interests, and endowments, and each of these aspects may affect collective action differently (Baland and Platteau 1996; Baland and Platteau 1999). The conditions under which certain aspects of heterogeneity enhance or undermine collective action also remains unknown (Varughese and Ostrom 2001). In this study, we considered heterogeneity in terms of ox ownership in the community. We hypothesize that heterogeneity in ox ownership may undermine collective action for grazing land management because of possible divergence of interests in and perceived benefits from use of the grazing lands. We measured heterogeneity by the coefficient of variation of the distribution of the proportion of households with no oxen, one ox, two oxen, and more than two oxen.

Experience with local organizations should favor collective action because of possible learning effects, and the effect of social capital on the costs or community ability to enforce collective action (Rasmussen and Meinzen-Dick 1995; Baland and Platteau 1996; Pender and Scherr 2002). Up to ten different local organizations operate in the study area. Not all communities have all the local organizations. We measured differences in community experience with local organizations by the number of local organizations operating in a given community and expect that higher experience with local organizations will favor collective action for grazing land management.

Communities that depend on a common property resource for livelihood and are likely to use the resource over a long time horizon may be more likely to self-organize to manage the resource collectively (Varughese and Ostrom 2001). The primary source of livelihood for rural communities in the study area is cereal crops production. Communities showed differences in their second most important source of livelihood. We include a dummy variable representing whether the second most important livelihood source in a given community is cattle rearing. We expect that where cattle rearing is an important livelihood strategy, collective action for grazing land management will be more likely.

We include dummy variables for the different zones of Tigray to proxy for differences in agroclimatic potential, as well as other differences between these zones (e.g., differences in enforcement of restrictions on woodlots by zonal and *woreda* authorities), for both woodlots and grazing lands. The Southern and Western zones generally have higher potential as a result of better soils, higher rainfall, and irrigation. We include population density and population density squared for woodlots, and population and population squared for grazing lands to test for an inverted-U-shaped relationship between population density and collective action. Market access is represented by distance to the *woreda* (district) town, which is usually where farmers market their produce and purchase inputs. The effect of external organizational presence is investigated by including a dummy variable indicating whether the woodlot or restricted grazing land was promoted by an external organization. Another dummy variable reflects whether the woodlot is village-managed or *tabia*-managed. Finally, the size of the woodlot is included to investigate whether there are economies (or diseconomies) of scale in woodlot protection and management. In the case of grazing lands, we include area of village to test if collective action in grazing land management is higher in villages that have wider total area.

Results

Woodlots

The econometric results for the determinants of collective action for woodlot management are presented in Table 10.3. We find that the intensity of management of woodlots (labor input, community contribution to protection, and planting density) is lowest in the Central zone of Tigray, but survival rate is the highest in this zone (controlling for other differences between zones). This suggests that a less intensive approach to woodlots is being pursued in the Central zone but that this can be consistent with higher survival rates (though lower density of surviving trees), probably because of less competition among trees in the less densely planted woodlots for water, sunlight, and nutrients. Community labor input is also lower in the Eastern zone than in the Southern zone, but community contributions to protecting woodlots are greater, leading to fewer violations of restrictions and higher survival rates. Thus, the approach to community woodlots in the Eastern

Table 10.3 Determinants of collective action and its effectiveness on community woodlots, 1998

Explanatory variable	Collective labor input (person-days/hectare)	Whether community pays for guard	Whether any violations of restrictions occurred	Number of trees planted per hectare	Survival rate of planted trees (%)
Central zone (cf. Southern zone)	–1,541.292**	–1.258*	–0.437	–11,374**	18.03*
Eastern zone (cf. Southern zone)	–928.882**	1.060*	–1.509***	2,288	17.50*
Western zone (cf. Southern zone)	–1,442.685	0.363	–1.029	6,853	5.24
1994 population density (persons/km^2)	36.545**	0.0110	–0.0122	–249.3**	0.0085
1994 population density squared	–0.1023**	–0.0000601	0.0000387	0.693**	–0.000255
Distance to *woreda* town (kilometers)	16.0929**	–0.00462	–0.00623	241.5**	0.350***
Woodlot promoted by external organization	1,148.053	–1.286***	0.0870	5,505	–5.573***
Woodlot managed by village (cf. managed by *tabia*)	–615.094	0.668	–0.158	5,114	7.712
Area of woodlot (hectares)	–28.1209	–0.0122	0.00500	–278.3	0.426
Intercept	–3,639.085**	0.842	0.900	12,067	38.95**
Type of regression	Tobit	Probit	Probit	Least-squares	Tobit
R^2/pseudo-R^2	0.231[a]	0.273[b]	0.136[b]	0.525	0.436[a]
Number of positive observations/total observations	66/223	110/219	53/219	76/76	73/76[c]

Note: All regression results are corrected for sampling stratification and sampling weights, and standard errors are robust to heteroskedasticity and nonindependence within the primary sampling units (*tabias*).

*****, **, * indicate significance levels at 1 percent, 5 percent, and 10 percent, respectively.**

[a]R^2 for least-squares regression on the same data.

[b]Pseudo-R^2 values.

[c]Planting density and survival data were not collected for all woodlots in the sample.

zone appears to be oriented toward less labor intensity of management but greater effort to protect the trees, with a favorable effect on tree survival. We find no statistically significant differences in tree management, protection, or survival between the Western and Southern zones.

We find that the labor intensity of woodlot management is positively associated with population density but negatively associated with population density squared, consistent with the hypothesis of an inverse U-shaped relationship between population density and collective action. The turning point in this relationship (where maximum predicted collective labor input occurs) is at 179 persons per square kilometer, well within the range of population density observed in Tigray (the range in our sample is from 39 to 302 persons per square kilometer).[8] The magnitude of the effect is also substantial: an increase of population density from 40 to 50 persons per square kilometer would increase predicted labor input per hectare by 273 labor days (much more than the average labor input per hectare on woodlots, which is 164 labor days per hectare).

Other indicators of collective action and its effectiveness, including whether the community pays for a guard, violations of restrictions, and survival rate of trees, also show a relationship consistent with the inverted-U hypothesis (with the signs of the coefficients reversed for violations of restrictions), though these relationships are statistically insignificant. Unexpectedly, there is a statistically significant U-shaped relationship between planting density and population density, with planting density first falling and later rising as population density increases (the turning point is at 180 persons per square kilometer). It may be that lower planting density at moderate population density is a result of collective action; that is, a decision by communities to not overexploit the woodlot area by restricting the planting density. If this is the case, then this relationship also supports the hypothesis of an inverse-U relationship between collective action and population density. However, this is only an ex post hypothesis to explain a result that we did not expect, and further research would be needed to confirm or reject this hypothesis.

With regard to market access, we find that communities that are more remote provide greater collective labor input, plant trees more densely, and obtain higher survival rates. These results are both statistically and quantitatively significant: being 10 kilometers further from the *woreda* town increases predicted labor input by 16 labor days per hectare (10 percent of average labor input), predicted planting density by 2,400 trees per hectare, and tree survival by 3.5 percentage points. These findings are consistent with the argument that improved market access undermines collective action by increasing labor opportunity costs and/or giving people more "exit" options from the community.

The presence of external organizations, as indicated by whether the woodlot was promoted by an external organization (usually the TBoANRD), has a negative association with whether the community pays for a guard and with tree survival. The negative association with community payment for a guard is probably because external organizations often pay for the guard, reducing the need for this aspect of collective action. This is similar to results found by Pender and Scherr (2002) in Honduras, where external government organizations were found to displace local collective action. The negative association of external promotion with tree survival suggests that external programs may not be achieving full participation of local communities in promoting woodlots. Part of the problem may be that local communities often prefer to plant eucalyptus, which survive well and grow rapidly under the uncertain rainfall of Tigray, whereas external organizations sometimes promote other species that may be less hearty or less preferred by local households (Jagger and Pender 2003).

Contrary to our expectations, we did not find that collective action was significantly greater or more effective on village-managed woodlots than on *tabia*-managed woodlots, after controlling for other factors. This may be because the differences in benefits, community stability, or cohesiveness between the *tabia* level and the village level are relatively small, and other factors such as population density, market access, or external organizations may be more responsible for the differences in collective action found on different woodlots. The area of the woodlot also had a statistically insignificant effect on our measures of collective management of woodlots and its effectiveness. This suggests that economies or diseconomies of scale in woodlot management are weak.

Grazing Lands

The results of econometric analysis are presented in Table 10.4. We find that the Western zone has the least area of restricted grazing lands per household, consistent with the existence of a relatively more abundant grazing land in the zone compared to other zones of the region, thus perhaps reducing the need for restricted grazing areas. The Central and Eastern zones also have less area of restricted grazing lands per household compared with the Southern zone. However, communities in the Central zone are more likely to pay for guards and establish penalty systems for violations of use restrictions, and communities in the Eastern zone are less likely to violate use restrictions and are more likely to establish penalty systems than those in the Southern zone, suggesting that in areas where collective action for grazing land management is not easily established, it can nevertheless succeed once the hurdle of establishment is overcome.

Table 10.4 Determinants of collective action for grazing land management, 1998

Explanatory variable	Area of restricted grazing land per household	Whether community pays for guard	Average value of household contribution for grazing land management	If community established penalty system	If violations of use restrictions and regulations occurred in 1998
Central zone (cf. Southern zone)	–0.169***	1.017***	2.126	1.002*	–0.254
Eastern zone (cf. Southern zone)	–0.115**	0.073	–2.757	0.978*	–1.214***
Western zone (cf. Southern zone)	–0.259***	0.0173	2.000	0.053	0.153
Total number of households in village (average of 1991 and 1998)	–0.00038	0.033***	0.009	–0.0046	–0.00495*
Total number of households in village squared	0.000000065	–0.0000372***	–0.00001	0.000006*	0.0000067**
If restricted grazing area was promoted by external organization	–1.888***	3.380	0.249	0.076	
Distance to nearest market town (walking time in minutes)	–0.000034	0.0078***	0.006	0.005**	0.0016
If cattle rearing is second most important livelihood source	0.0237	–0.255	0.585	0.031	–0.231
Total number of local organizations operating in village	–0.0037	–5.375**	1.906**	1.591*	–1.502*
Heterogeneity of ox ownership in community	–0.029	–0.481	–25.708	2.816	3.713*
Total area of community	0.0015***	–0.0067	0.0639	0.0068	–0.0036
Intercept	0.218	–3.873*	–9.845	–0.3812	0.248
Type of regression	Tobit	Probit	Tobit	Probit	Probit
Number of positive observations/total observations	74/100	119/154	161/225	210/231	62/237

Note: All regression results were corrected for sampling stratification and weights, and standard errors are robust to heteroskedasticity and nonindependence within the primary sampling units (*tabias*).

*****, **, * indicate significance levels at 1 percent, 5 percent, and 10 percent, respectively.**

Communities are more likely to pay for guards at intermediate population than at low or very high total population. The turning point in this relationship (where maximum probability of communities paying for guards occurs) is 450 households per village, well within the range of total number of households per village and very close to the average number of households per village.[9] We also find that violations of use restrictions are least likely to occur at intermediate population (368 households per village). These results of the effect of population on collective action for grazing land management are consistent with the hypothesis of an inverse-U-shape relationship between population and collective action.

The involvement of external organizations in promoting restricted grazing areas reduced the likelihood of communities paying for guards, suggesting that the need for communities to pay for guards is eliminated by the payment made by the external organizations. Involvement of external organizations has a positive (but statistically insignificant) effect on household contributions for grazing land management.

Communities with greater presence of local organizations make higher contributions per household for grazing land management, are more likely to establish a penalty system, and are less likely to have violations of use restrictions and regulations. These results are consistent with the hypothesis that collective action for natural resource management may be higher and more effective in communities that have higher social capital. However, we also find a negative effect of experience with local organizations on the likelihood of communities paying for a guard. Perhaps a guard is less necessary in communities with greater investment in such local social capital.

Communities that are more distant from markets are more likely to pay for guards and establish a penalty system for grazing land management, suggesting that more distant communities have a higher need for restricted grazing lands and that collective action may be more likely because of lower opportunity cost of labor or limited exit options in such areas. These results suggest that in areas closer to markets, alternative management options such as private management of grazing lands may be a better option.

Whether or not cattle rearing is a second most important source of livelihood in a community failed to affect any of the indicators of collective action significantly. This may be because cereal crops production is the first most important source of livelihood in all communities, and cattle rearing is considered only as supplementary to crop production.

Heterogeneity in ox ownership tends to detract from collective action for grazing land management, perhaps because of divergence in interest or benefits received from restricted grazing lands. Heterogeneity increases the likelihood of violations of use restrictions and regulations (an indicator of failure of collective action). Heterogeneity was also associated with less household contribution for grazing land management, but that correlation was statistically insignificant. Communities with larger total area have higher area of restricted grazing land, as expected.

A possible explanation for the weak influence of some of the explanatory variables is that there may be multicollinearity among the explanatory variables. We tested for problems of multicollinearity in the regressions of woodlots and grazing lands and found potential problems only between population density and population density squared, and between the total number of households in village and its squared value. We have retained these variables because they were necessary to test the hypothesized inverted-U-shaped relationship. Moreover, omitting one of these variables could result in omitted variable bias, given their significance in several of the regressions.

Conclusions and Implications

Collective action in managing woodlots and grazing lands generally functions well in the highlands of Tigray. Despite the fact that community benefits from woodlots in 1998 were limited as a result of various restrictions on use, the woodlots contribute substantially to community wealth. Community members remain generally satisfied with the woodlots as a reserve of natural capital. Farmers perceive that developing and enforcing use rules and regulations for grazing land management results in significant regeneration of the grazing lands, and the conditions of the area under community woodlot management have improved significantly.

Benefits from woodlots were greater, and reported problems of management lower, on woodlots managed at the village level compared to the higher municipality level. Communities that manage woodlots at the village level applied greater labor inputs, planted much more densely, hired guards more often, and reported violations of restrictions less often. All restricted grazing lands are managed at the village level and remain enforced once established. Community members contribute to woodlot and grazing land management through cash, in kind, or through uncompensated labor contributions.

We found support for the hypothesis of an inverted-U-shape relationship between population density and collective action for woodlot management. We also found evidence for an inverse-U-shape relationship between population level and collective action for grazing land management. Collective action is higher and more effective at intermediate population density or level.

Market access detracted from collective action for woodlot and grazing land management, probably by increasing opportunity cost of labor and/or providing more exit options to rural communities. Involvement of external organization was associated with lower tree survival rate in woodlots and reduced the need for community contributions for protecting woodlots and grazing lands.

Experience in organizing and running local organizations encourages collective action for grazing land management, perhaps because learning effects of managing cooperative effort or social capital helps to reduce the cost of attaining and enforcing collective action. Heterogeneity in ox ownership appears to decrease collective action for grazing land management, perhaps because of divergence in interest or in benefits received from restricted grazing lands.

Our findings support the role of community resource management in redressing resource degradation. The results suggest that community resource management can be an effective means of redressing resource degradation and increasing community wealth. The results also imply that community resource management may be more effective and beneficial if conducted at the most local level and if involvement of external organizations is demand driven and complementary to local initiatives. Collective action for community resource management is likely to be more effective in areas with intermediate population that are far from market places and have higher social capital. In areas of greater market access and high population density, privately oriented approaches to resource management may be more effective.

Appendix 1: Summary Statistics of Variables Used in Regressions for Woodlot Management

Variable	Number of observations	Mean	Standard error	Minimum	Maximum
Labor days per hectare	223	164.76	65.90	0	10,800
Whether community hires a guard	223	0.490	0.092	0	1
Whether violations of restrictions occurred	223	0.228	0.054	0	1
Number of trees planted per hectare	80	4,453	1,837	333	51,750
Tree survival rate (percent)	80	63.7	5.1	0	97.5
Southern zone	233	0.141	0.049	0	1
Central zone	233	0.423	0.100	0	1
Eastern zone	233	0.397	0.100	0	1
Western zone	233	0.039	0.019	0	1
1994 population density (per square kilometer)	225	154.9	14.7	39.5	301.7
Distance to *woreda* town (kilometers)	229	27.6	5.0	0	87
Woodlot promoted by external organization	227	0.949	0.233	0	1
Woodlot managed by village (versus managed by *tabia*)	227	0.799	0.063	0	1
Area of woodlot (hectares)	227	7.76	1.34	0.13	100

Note: Means and standard errors are corrected for sampling stratification and weights.

Appendix 2: Summary Statistics of Variables Used in Regressions for Grazing Land Management

Variable	Number of observations	Mean	Standard error	Minimum	Maximum
Whether village has restricted grazing area	100	0.89	0.050	0	1
Area of restricted grazing area per household (hectares)	100	0.067	0.015	0	1.916
Whether community pays for guard	154	0.72	0.042	0	1
Average household contribution for grazing land management (Birr)	226	3.661	0.852	0	63.157
Whether village established penalties	231	0.97	0.008	0	1
Whether violations occurred	229	0.35	0.036	0	1
Eastern zone	231	0.23	0.047	0	1
Southern zone	231	0.30	0.050	0	1
Western zone	231	0.13	0.038	0	1
Central zone	231	0.32	0.053	0	1
Households per village	100	410	20.62	85	1,050
Walking distance from village to nearest *woreda* town (minutes)	231	200	8.04	10	720
If grazing land promoted by external organization	231	0.31	0.035	0	1
If cattle rearing is second most important livelihood source	231	0.68	0.053	0	1
Number of local organizations operating in village	231	4.1	0.124	1	6
Heterogeneity of ox ownership (coefficient of variation)	231	0.25	0.007	0.10	0.45
Area of community (square kilometers)	231	62.08	4.78	12.3	179

Note: Means and standard errors are corrected for sampling weights and stratification.

Notes

1. Common property resources are defined as those resources that are owned and possibly managed by a given community. They are contrasted with open access resources, which have no defined owner.

2. Collective action is defined as action taken by a group (either directly or on its behalf through an organization) to achieve a common objective, when the outcome depends on interdependence of members.

3. Highlands are defined as those areas above 1,500 meters above sea level.

4. All villages in the highlands have some type of communal grazing lands, including restricted and unrestricted.

5. The history of land tenure and redistributions is similar throughout the region. Hence, no variables of local histories of land allocation and tenure were included in the regressions.

6. Every village has communal grazing lands. Some communities organize rules and regulations to use and manage part of the community grazing lands. We used the area of the community grazing land used according to community rules and regulations as indicator of collection action.

7. Total number of households was used instead of population density because all restricted grazing lands were managed at the village level, for which we did not have area data.

8. Summary statistics of the variables used in the regressions are presented in Appendix 1.

9. Total number of households per village in the study area ranged from 85 to 1,050 with an average value of 410. Summary statistics of variables used in the regressions are presented in Appendix 2.

Chapter 11

Influences of Programs and Organizations on the Adoption of Sustainable Land Management Technologies in Uganda

Pamela Jagger and John Pender

Governments are devolving service and infrastructure provision, regulatory authority, and decisionmaking in many developing countries. Market reforms and structural adjustment policies devolve the provision of services and infrastructure to nongovernmental organizations (NGOs), community-based organizations (CBOs), and the private sector (Farrington and Bebbington 1993; Uphoff 1993; Pender and Scherr 2002). The transition from the provision of extension services, input supply, rural credit delivery, regulation, and other aspects of natural resource management from centralized governments to alternative institutions may have significant implications for the capacity of smallholders to sustainably manage their resources.

Uganda presents an interesting opportunity to analyze the challenges and opportunities for institutional change in the face of government devolution and increasing land degradation. The government of Uganda is presently decentralizing many of its services, including those that are directly related to agriculture and the environment. There is considerable evidence that land degradation in Uganda's rural areas has been increasing and will continue to do so. Average annual soil nutrient losses in Uganda of more than 70 kilograms of nitrogen, phosphorus, and potassium (NPK) are among the highest rates of depletion in Sub-Saharan Africa (Stoorvogel and Smaling 1990). Analysis of community perceptions about changes in natural resource conditions since 1990 indicates that the availability and quality of cropland, grazing land, forests, and woodland are perceived to be decreasing throughout the country (Pender et al. 2004a). Soil fertility is perceived to have significantly deteriorated, and soil moisture-holding capacity and erosion problems are worsening. Natural water sources and the biodiversity of plants and animals are also perceived to be deteriorating in availability and quality (Pender et al. 2004a).

Land management policy in Uganda is currently being shaped by the Plan for the Modernization of Agriculture (PMA), the Poverty Eradication Action Plan (PEAP), and the Decentralization of Public Service Reform Plan. One of the main goals of the PMA is that all activities related to agricultural production, agricultural processing, trading, the supply of inputs, and the import and export of agricultural produce will eventually be carried out by the private sector (MAAIF 1999). However, given lags in the time it takes for effective private sector intervention, nongovernmental organizations and community-based organizations are being asked to take the lead in providing these services in the medium term, with the goal of privatization of services by 2020.

The primary objective of this chapter is to characterize programs and organizations in Uganda and to determine whether or not community and/or household involvement in programs and organizations is influencing household-level adoption of land management technologies. If community and/or household involvement in programs and organizations have an observable influence on the adoption of sustainable land management technologies, then there is a case for providing incentives to encourage their development and sustainability. In particular, less-favored areas that have traditionally been serviced by few programs and organizations may be key areas for the promotion of organizations.

This chapter is organized as follows. The next section provides a brief historical review of the roles of programs and organizations in Uganda from the mid-1950s to the present. We then describe the study area and survey. Using survey data we characterize programs and organizations that operated in rural Uganda between 1990 and 1999. The next section provides a conceptual framework and econometric analysis of the determinants of programs and organizations and their effect on the adoption of land management technologies. We conclude with a discussion of policy implications emanating from the study.

NGOs and CBOs in Uganda: A Brief History

Organizations, including indigenous NGOs, urban associations, trade unions, and cooperative societies such as the Ugandan African Farmer's Association enjoyed relative independence under the colonial government (Mamdani 1993). However, the newly independent government of Milton Obote was quick to impose government regulation of cooperatives (Cooperative Societies Act of 1963), and the regulation of trade unions (1970 Trade Union Act), which resulted in the formulation of a single state-run cooperative and a single trade union in the early 1960s (Hyden 1983). Although a 1973 decree restored the autonomy of unions, organizations were unable to function effectively under Idi Amin's regime.

Government programs dealing with agriculture and/or sustainable land management also failed under Obote and Amin. Agricultural research and extension services collapsed in the late 1970s (ISNAR 1988). Smallholder cash crop production was seriously affected. Food crops that could be sold in local or regional markets replaced cotton production, and coffee survived through the smuggling of produce across borders by an evolving network of private traders (Brett 1991).

Throughout the 1970s and 1980s, only a few international NGOs functioned in the country, providing disaster and relief services, and indigenous NGOs had very limited reach (Dicklitch 1998). During this time the most outspoken rural voices were churches, which, in addition to acting as human rights watchdogs, provided assistance to meet basic social needs. Churches also became increasingly involved in the provision of basic health and education services as the economic collapse of state services worsened in the early 1980s (Nabuguzi 1995).

When Musuveni took over leadership of the country in the mid-1980s, rural infrastructure was in serious disrepair (Brett 1991, 1994; Howes 1997). However, economic, social, and political change was rapid under Musuveni's National Resistance Movement. The implementation of structural adjustment programs that emphasized market rather than state delivery of services was the focus of the new government. In addition, donors, self-help organizations, NGOs, and others arrived to assist with rebuilding the country (Dicklitch 1998). Uganda's relative success with structural adjustment led to growth in real agricultural GDP of 4 percent per annum between 1987 and 1997, while real manufacturing GDP averaged 16 percent growth (Belshaw, Lawrence, and Hubbard 1999).[1]

In the late 1980s, during the first structural adjustment phase, the National Agricultural Research Organization (NARO) was formed. In addition to a strong focus on agricultural research, NARO took on the responsibility of organizing and training extension personnel to service the rural areas (ISNAR 1988). Land distribution and tenure rights were also significant issues. Throughout the Amin years the elite appropriated large tracts of land and evicted occupants without recourse, resulting in common lands and forest reserves being invaded by squatters (Brett 1991). The new government assumed responsibility for monitoring and protecting common land and protected areas as foreign NGOs, indigenous NGOs, community organizations, and cooperatives reorganized.

The current framework of decentralization is providing an enabling enviroment for NGO activities. The National Agricultural Advisory Service (NAADS) is an example of one of the five central initiatives of the PMA that is relying on NGOs to provide demand-driven fee-for-service extension services to smallholders until the provision of services can be fully privatized. Proposed requirements to align government policy with NGO mandates will make the transition to fee-for-service extension smoother but may also limit the previously independent scope of NGOs focused on natural resource management.

Community-based organizations (CBOs) are much less formally organized in Uganda and generally grow out of an identified need within the community. CBOs are not registered unless their activities go beyond the needs and services of the immediate community. Because of the absence of a registration system or any formal requirements at the district level to document their presence, information on CBOs is scarce, and their numbers are difficult to estimate. CBOs have the potential to reach policy makers by communicating their message through the established local council (LC) system or by directly lobbying their member of parliament.

Research Method

We investigate the presence and roles of programs and organizations and their influence on the adoption of sustainable land management technologies using data collected from a series of surveys (community, village, and household level), conducted between 1999 and 2001. Community-level characterization of programs and organizations is based on a survey of 107 LC1s (local councils comprised of one or a few villages), and villages from throughout most of Uganda conducted in 1999–2000.[2] A random sample of LC1s was stratified by agricultural potential, market access, and population density.[3]

Agricultural potential classification was based on average length of growing period, average rainfall, maximum annual temperature, and altitude (Ruecker et al. 2003). Six zones were identified: the low- and medium-potential unimodal-rainfall areas at moderate elevations (much of northeastern Uganda and parts of northern and eastern Uganda), the low-potential bimodal-rainfall area at moderate elevations (lower-elevation parts of southwestern Uganda), the medium-potential bimodal-rainfall area at moderate elevation (most of central and parts of western Uganda), the high-potential bimodal-rainfall areas (Lake Victoria crescent), the high-potential bimodal-rainfall areas of the southwest highlands, and the high-potential eastern highlands (see Figure 7.1, in color insert). Market access was classified using the measure of potential market integration estimated by Wood et al. (1999), which is a measure of travel time from any location to the nearest five towns or cities, weighted by the population of the towns or cities. Areas with high market access include most of the Lake Victoria region, the southwest and eastern highlands, and parts of the north and west that are close to major roads or towns (Sserunkuuma, Pender, and Nkonya 2001) (see Figure 7.2). Population density was classified on the basis of parish-level rural population density in 1991, where more than 100 persons per square kilometer was classified as a high-population-density parish (Sserunkuuma, Pender, and Nkonya 2001). Both highland (elevation greater than 1,500 meters above sea level) and lowland sites are represented in the sample.

One village was randomly selected from within each LC1. Respondents were groups of approximately 8 to 15 LC1 or village members selected to represent different ages, occupations, and genders. Data on programs and organizations encompassed all programs and organizations present at the LC1 level and below.

Household surveys were conducted during 2000–01 with four or five randomly selected households from within each LC1. The household head as well as other members of the household actively engaged in household decisionmaking were interviewed. Data on household-level involvement with all types of programs and organizations were collected. Information on sustainable land management technologies used by the household was also collected in this survey. We have a sample size of 451 households.

Characterizing Programs and Organizations in Rural Uganda

Types of programs and organizations. Programs are characterized as institutions associated with the government of Uganda. Programs are unique in their ability to evoke the authority of the state to levy taxes and prohibit certain behaviors by implementing and enforcing laws (Uphoff 1993). We divided organizations into two categories. Community-based organizations are those that evolve and are administered, financed, and managed at the local level. Community-based organizations are not registered with the government. Nongovernmental organizations include both international and indigenous organizations established to provide services to communities or districts. They are autonomous and are required to conform to the government's regulatory requirements regarding registration and reporting.

We examined community-level presence of programs and organizations between 1990 and 1999, focusing on the number of each type of program or organization present in each community. We also considered household-level involvement in programs and organizations, where household involvement was defined as any member of the household participating in the program or organization between 1990 and 2000 (Table 11.1). At the community level, NGOs were the most common type of organization, with an average of almost one NGO per LC1. The bimodal high- and low-rainfall zones had the highest average number of NGOs present per LC1. These areas, including the Lake Victoria crescent and the southwest cattle

Table 11.1 Average number of programs and organizations per LC1, 1990–1999, and household involvement in programs and organizations, 1990–2000

		Agricultural potential						Market access		Population density	
Program or organization	Average	Unimodal	Bimodal low	Bimodal medium	Bimodal high	Southwest highlands	Eastern highlands	Low	High	Low	High
Community presence (*n* =107)											
Number of programs or organizations per community											
Government program	0.64	0.74	0.36	0.39	1.10	0.17	0.30	0.58	0.66	0.60	0.66
	(0.11)	(0.17)	(0.15)	(0.11)	(0.32)	(0.10)	(0.22)	(0.11)	(0.15)	(0.11)	(0.16)
NGO	0.99	1.10	1.41	0.50	1.44	0.79	0.55	0.64	1.13	0.78	1.10
	(0.11)	(0.40)	(0.37)	(0.14)	(0.22)	(0.29)	(0.25)	(0.14)	(0.14)	(0.13)	(0.15)
CBO	0.62	0.07	0.85	0.33	0.52	2.13	0	0.25	0.78	0.48	0.70
	(0.08)	(0.07)	(0.36)	(0.14)	(0.15)	(0.35)		(0.12)	(0.11)	(0.14)	(0.12)
Household involvement (*n* = 451)											
Percentage of households											
Government program	0.71	0	0	0	1.2	1.7	0	0	1.0	6.9	18.5
	(0.41)				(0.1)	(1.7)			(1.0)	(2.7)	(3.5)
NGO	14.9	20.3	3.4	6.2	21.1	3.1	17.0	8.8	17.0	76.9	84.0
	(2.6)	(9.5)	(3.4)	(2.4)	(4.6)	(1.9)	(9.7)	(2.9)	(3.3)	(3.1)	(2.9)
CBO	81.8	74.2	75.1	76.1	86.2	96.6	2.5	70.7	85.7	6.9	18.5
	(2.2)	(9.6)	(6.7)	(4.0)	(3.1)	(2.4)	(11.0)	(4.2)	(2.6)	(2.7)	(3.5)

Note: Means and errors are corrected for sampling stratification and sampling weights. Values in parentheses represent standard errors.

corridor, have good access to roads and markets, which may influence why NGOs operate in these regions. The lowest average numbers of NGOs per LC1 were found in the medium-potential bimodal-rainfall and eastern highland zones.

The average number of government programs and community-based organizations present in sample communities was approximately equal. The highest average number of government programs was found in the bimodal high-potential areas, which are close to the urban areas of Kampala and Jinja. The unimodal areas in the north and east had the second highest number of government organizations. Conversely, the southwest and eastern highlands had very few government programs. Community-based organizations were most common in the southwestern highlands, in sharp contrast to the eastern highlands and low-potential unimodal areas, where there were no or few CBOs.

We found higher numbers of NGOs in areas with good market access and in areas with high population density. The number of government programs did not vary significantly across low- and high-market-access areas or areas of low and high population density. Like NGOs, community-based organizations were more common in areas with good market access and high population densities. Households reported being primarily involved in NGOs and CBOs. Low reported levels of involvement in government programs might result from the fact that most government programs are infrastructure related. Though these programs may have required labor inputs from households, the households themselves were unlikely to perceive this as "involvement" in the program.

Approximately 15 percent of households reported having at least one member involved in a nongovernment organization at some time between 1990 and 2000. These organizations include both externally organized (for example, CARE, African Highlands Initiative, World Vision) and locally organized groups that were registered as NGOs. The unimodal and bimodal highland areas had the highest levels of household involvement in NGOs with approximately 20 percent of households reporting involvement by at least one household member. The eastern highlands also had a relatively high level of involvement in NGOs, which contrasts with very low levels of involvement in community-based organizations in this region. Over 80 percent of households in our sample were involved in CBOs between 1990 and 2000, with almost all households in the southwestern highlands being involved in a CBO. The proportion of households involved in NGOs and CBOs was higher in more densely populated areas and areas with good market access. These findings are consistent with community-level data on the presence of programs and organizations.

The general picture of organizational presence in the sample communities is that government programs, NGOs, and CBOs were well represented in the bimodal high-potential areas close to urban centers. Government programs, NGOs, and CBOS were poorly represented in the highland regions with the exception of CBOs in the southwestern highlands. The absence of significant differences in the presence of government programs between high- and low-market-access areas or areas of varying population density indicates that government programs were relatively unbiased with respect to investment in less-favored areas. Higher average numbers of NGOs in areas with good market access and high population densities may result from the lower transactions costs of operating in these areas and contacting potential participants, higher potential economic returns to organizational activities, and the potential for influencing a greater number of people. Our finding that CBOs were more common in areas with good market access may be explained by better access to information about how to organize and the potential benefits of organization, as well as ease of organizing when community members are located closer together.

Main focus of programs and organizations. Programs and organizations in rural Uganda operate in a wide variety of sectors. We consider both the proximate and underlying causes of land degradation to categorize programs and organizations and to identify their potential relationships to sustainable land management. The proximate causes of land degradation include natural factors such as soil type and climate fluctuation and unsustainable farming practices such as decreased fallow periods and the cultivation of fragile lands. We hypothesize that programs and organizations focused on agriculture or environment related topics such as tree planting or the distribution of agricultural inputs are likely to have a direct effect on the adoption of land management technologies (Table 11.2). Programs and organizations also focus on issues such as population pressure, poverty, lack of infrastructure and services, lack of access to credit, and the provision of social services. Though the goal of these types of programs and organizations is not to address the issue of land degradation, they may have an indirect effect on the adoption of land management technologies.

In approximately half of the LC1s in our survey at least one program or organization focused on agriculture- or environment-related issues during the 1990s (Table 11.3). Agriculture and environment programs and organizations were most common in the high-potential bimodal-rainfall areas. Surprisingly, there were very low numbers of these programs and organizations in the highland areas where land degradation is a particularly serious problem, and in the medium-potential bimodal-rainfall areas. Approximately 30 percent of the households in our survey reported involvement in an agriculture- or environment-focused organization. Above-average levels of involvement were found in the unimodal-rainfall areas (42 percent) and in

Table 11.2 Main focus of programs and organizations in relation to the proximate and underlying causes of land degradation

Cause of land degradation	Description of cause	Relationship to land management	Main focus of programs or organizations (activities)
Proximate causes of land degradation			
Natural factors	Soil type and climate variability	Direct	Agriculture and veterinary services/extension (training and sensitization, supply of inputs, stocking and restocking livestock, credit for input purchase, promoting adoption of new technologies, marketing of agroproducts)
Unsustainable farming practices	Decreased fallows and cultivation of fragile lands	Direct	Environment (afforestation, promoting soil and water conservation, energy conservation and research)
Underlying causes of land degradation			
Population pressure	Increased land pressure as a result of decreased fallows and partitioning of farmland, increased food demand	Indirect	Women's empowerment and emancipation (increase household decisionmaking power and community participation) Health (sex education and family planning)
Lack of infrastructure and services	Poor infrastructure can slow price signals and reduce access to agricultural inputs Lack of adequate education, health, water services, and so on can reduce labor productivity	Indirect	Education (construction and maintenance of schools, provision of scholastic materials) Health (construction and maintenance of health facilities, provision of medical supplies and pharmaceuticals) Water and sanitation (improved access to water for drinking and irrigation) General infrastructure (investment in roads)
Lack of credit	Providing credit may affect the use or adoption of inputs and sustainable land management technologies	Indirect	Credit
Poverty	May lead to short-term planning horizons that inhibit households from investing in land management	Indirect	Income generation (job training, entrepreneurial skills) Poverty eradication Social development Social assistance to the disadvantaged
Lack of community services	Generally meet short- to medium-term community needs for assistance	Very indirect	Mutual support Funeral arrangements Youth programs

Table 11.3 Average number of programs and organizations per LC1, 1990–1999, and household involvement in programs and organizations, 1990–2000, by sector

Main focus of program or organization	Average	Agricultural potential: Unimodal	Bimodal low	Bimodal medium	Bimodal high	Southwest highlands	Eastern highlands	Market access: Low	Market access: High	Population density: Low	Population density: High
Community presence (*n* =107)											
Number of programs or organizations per community											
Agriculture/environment	0.44	0.32	0.57	0.14	0.87	0.13	0.25	0.17	0.55	0.26	0.53
	(0.07)	(0.19)	0.23)	(0.06)	(0.19)	(0.10)	(0.21)	(0.10)	(0.10)	(0.10)	(0.10)
Population	0.09	0.15	0.08	0	0.17	0.09	0.25	0.02	0.13	0.05	0.12
	(0.03)	(0.08)	(0.08)	N/A	(0.08)	(0.09)	(0.21)	(0.02)	(0.05)	(0.03)	(0.05)
Infrastructure and services	0.74	0.74	0.76	0.76	0.58	0.52	0.61	0.77	0.71	0.67	0.75
	(0.10)	(0.10)	(0.33)	(0.25)	(0.17)	(0.22)	(0.29)	(0.18)	(0.11)	(0.16)	(0.12)
Credit	0.08	0.07	0.07	0	0.18	0.09	0	0.03	0.11	0.07	0.09
	(0.04)	(0.07)	(0.07)	N/A	(0.11)	(0.09)	N/A	(0.02)	(0.06)	(0.04)	(0.06)
Poverty	0.76	0.68	0.97	0.49	0.82	1.35	0.09	0.51	0.86	0.74	0.76
	(0.12)	(0.27)	(0.33)	(0.19)	(0.26)	(0.3)	(0.05)	(0.19)	(0.15)	(0.18)	(0.15)
Community service	0.18	0	0.17	0.04	0.12	0.91	0	0.04	0.25	0.08	0.24
	(0.03)	N/A	(0.13)	(0.04)	(0.07)	(0.14)	N/A	(0.03)	(0.05)	(0.04)	(0.05)

Household involvement (*n* = 451)											
Percentage of households											
Agriculture/environment	29.8	41.5	11.0	23.1	34.2	25.0	27.4	19.7	33.4	26.6	31.3
	(3.4)	(9.6)	(6.5)	(4.8)	(6.2)	(6.3)	(10.7)	(4.5)	(4.3)	(3.6)	(4.7)
Population	0	0	0	0	0	0	0	0	0	0	0
Infrastructure and services	14.9	28.9	8.9	12.1	12.0	23.9	13.6	12.2	15.9	11.3	16.6
	(2.3)	(10.1)	(4.4)	(3.8)	(3.4)	(5.8)	(9.0)	(3.9)	(2.8)	(3.7)	(2.9)
Credit	41.8	32.3	62.3	34.4	37.9	82.1	22.6	35.9	43.9	41.2	42.1
	(3.1)	(5.8)	(8.0)	(4.9)	(5.7)	(5.3)	(11.3)	(5.0)	(3.7)	(4.9)	(3.8)
Poverty	14.0	9.9	13.6	11.6	13.5	23.5	27.6	10.8	15.2	12.5	14.7
	(2.6)	(5.0)	(7.0)	(3.8)	(4.6)	(7.3)	(11.3)	(3.7)	(3.2)	(4.1)	(3.2)
Community service	48.6	27.7	49.1	34.4	56.2	83.4	23.4	42.5	50.8	38.1	53.4
	(2.8)	(9.6)	(9.1)	(5.0)	(4.3)	(6.1)	(9.9)	(5.3)	(3.2)	(4.8)	(3.4)
Labor exchange	12.8	8.2	15.8	14.7	11.2	25.9	1.3	14.4	4.0	17.8	10.5
	(2.1)	(4.8)	(7.1)	(4.5)	(3.4)	(6.8)	(1.3)	(12.2)	(2.4)	(4.3)	(2.3)
Miscellaneous	12.2	11.1	4.7	8.7	16.5	9.6	4.2	9.5	13.2	9.9	13.3
	(2.6)	(9.1)	(4.7)	(3.6)	(4.6)	(3.4)	(3.8)	(3.4)	(3.3)	(3.4)	(3.4)

Note: Means and errors are corrected for sampling stratification and sampling weights. Values in parentheses represent standard errors.

the bimodal high-rainfall areas (34 percent). Given the relatively limited community-level presence of such organizations in the unimodal zone, household participation in the unimodal areas was higher than expected.

Of the programs and organizations focused on topics other than agriculture and the environment, community respondents cited very few with a main focus on credit or reducing population pressure. A high proportion of programs and organizations deal with infrastructure and services (including those focused on education, health, water, and general infrastructure). The highest average number of such programs and organizations was in the southwestern highlands, which may explain general improvements in health and education in this region between 1990 and 1999 (Pender et al. 2004a).

Household involvement in organizations focused on credit or community service was most common. This finding contradicts community-level data, which show such organizations to be relatively rare in many areas. It is possible that community members did not perceive locally organized credit and savings groups as "organizations" when responding to the community level survey. Alternatively, it could be that the provision of credit is the function that many households identify NGOs and CBOs with, whereas community leaders may not have identified credit as the organization's primary focus. The highest proportion of household-level involvement in community service–focused organizations was in the southwestern highlands. The bimodal high-rainfall and bimodal low-rainfall areas also had above-average household involvement in community service–focused organizations. In general, our findings with respect to household-level involvement in infrastructure and service or poverty reduction–focused organizations were consistent with community-level data on the presence of programs and organizations.[4]

Higher average numbers of agriculture and environment programs were found in LC1s with good market access or high population density. Households in areas with good market access also had higher rates of participation in agriculture- and environment-focused programs and organizations. Both poverty alleviation and community service–focused programs and organizations were more common in high-market-access areas. Household involvement in credit programs and organizations did not differ significantly with market access or population density. Approximately 50 percent of households in areas with good market access and higher population densities were involved in community service–focused organizations.[5]

Consideration of how main focus varies by type of program or organization illustrates the differing agendas of government programs, nongovernmental organizations, and community-based organizations. Table 11.4 summarizes the main focus of the government programs, NGOs, and CBOs found among the LC1s that identified programs or organizations functioning within their communities between

Table 11.4 Main focus of programs and organizations by type

Main focus of program or organization	Total (n = 249)	Program or organization (%)		
		Government	NGO	CBO
Agriculture/environment	18.5	6.7	10.8	1.0
		(1.7)	(2.4)	(0.1)
Population	4.2	0	3.2	1.0
		N/A	(1.0)	(0.1)
Infrastructure and services	31.9	12.3	17.4	2.2
		(2.0)	(3.1)	(1.2)
Credit	3.6	0	2.6	1.0
		N/A	(1.6)	(0.1)
Poverty	33.8	8.9	10.1	14.8
		(2.7)	(2.2)	(2.7)
Community service	8.2	0	0	8.2
		N/A	N/A	(1.4)
Total	~100	27.9	44.1	28.2

Note: Means and errors are corrected for sampling stratification and sampling weights. Values in parentheses represent standard errors.

1990 and 1999. Approximately 19 percent of the total number of programs and organizations are focused on the proximate causes of land degradation. NGOs account for the largest percentage of agriculture- and environment-focused programs and organizations, whereas community-based organizations make up only 1 percent of agriculture- and environment-focused organizations. Programs and organizations focused on infrastructure and poverty alleviation are most common. The highest proportion of infrastructure programs is NGOs, though government programs are also well represented. CBOs are heavily focused on poverty alleviation–related activities, though NGOs and government programs are also well represented in this category. The proportion of total programs and organizations devoted to population (e.g., family planning) and credit is relatively small (4.2 and 3.6 percent, respectively). The majority of organizations that deal with these focus areas are NGOs.

To investigate the effects of programs and organizations on farmers' adoption of land management technologies, we consider household use of inorganic fertilizer, animal manure, incorporating crop residues, mulching, and pesticides (Table 11.5). A higher proportion of households adopted pesticides when there was an agriculture- or environment-focused program or organization in the LC1. Rates of adoption of inorganic fertilizer, animal manure, and applying crop residues were only slightly lower for these communities. Having other types of programs or organizations present in the LC1 appears to have little influence on whether or not

Table 11.5 Household-level adoption of selected land management technologies, all households, households in communities with programs or organizations present, and households with involvement in organizations, 2000

Technology	All households (*n* = 446)	Agricultural/environmental program/organization in LC1 (*n* = 147)	Organization focused on indirect causes of land degradation in LC1 (*n* = 323)	Involved in agriculturally/environmentally focused organization (*n* = 112)	Involved in organization focused on indirect causes of land degradation (*n* = 318)
Applying inorganic fertilizer	10.0	9.1	7.6	17.9	10.9
	(2.0)	(3.7)	(2.2)	(5.5)	(2.6)
Applying animal manure	23.0	22.1	22.6	25.5	24.3
	(2.8)	(4.8)	(3.3)	(6.0)	(3.5)
Applying crop residue	17.6	14.3	19.0	19.4	17.8
	(2.4)	(3.6)	(2.9)	(5.9)	(5.7)
Mulching and applying organic matter	20.4	21.2	20.7	28.1	21.6
	(2.6)	(4.9)	(3.1)	(6.6)	(3.2)
Applying pesticides	23.4	29.9	21.5	25.0	26.3
	(2.9)	(5.9)	(3.4)	(5.8)	(3.6)

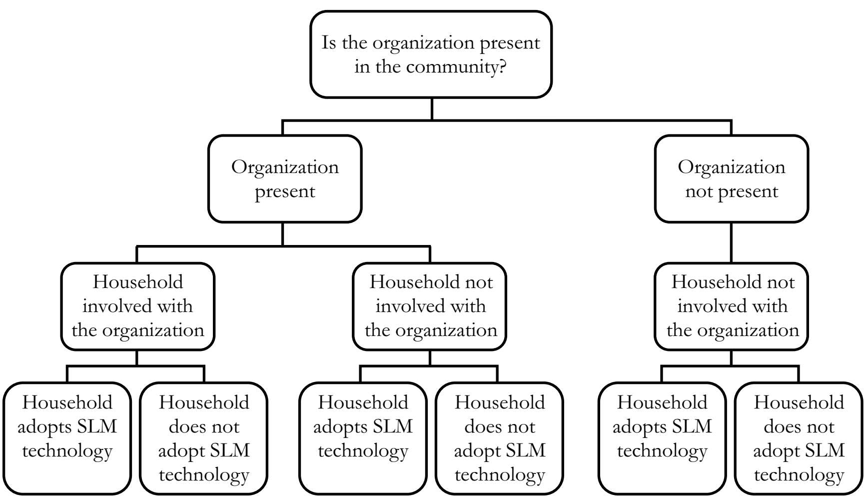
Note: Values are percentages. Means and errors are corrected for sampling stratification and sampling weights. Values in parentheses represent standard errors.

technologies are adopted. Rates of technology adoption were higher in all cases where households were involved in an agriculture- or environment-focused organization, most significantly the adoption of pesticides, mulching, and applying organic matter. Household involvement in other types of programs or organizations (i.e., infrastructure, credit, poverty alleviation, and community service) also had a positive association with the adoption of all land management technologies considered, though to a lesser extent than household involvement in agriculture- and environment-related programs and organizations. However, these associations may be related to other factors, such as differences in agricultural potential or market access, rather than to participation in these programs and organizations. The analysis in the following section further explores the potential effects of organizational presence or household-level involvement in an organization on the adoption of sustainable land management technologies, controlling for other factors.

Conceptual Framework for Econometric Analysis

We propose six possible outcomes related to the effect of a program or organization on the adoption of land management technologies (Figure 11.1). We first consider whether or not the program or organization is present in the community. Our hypothesis is that households located in communities with agriculture- or

Figure 11.1 Organizational presence and the potential for sustainable land management (SLM) technology adoption



environment-focused programs or organizations are more likely to adopt land management technologies, even if not directly involved in such organizations, as a result of knowledge spillover effects. We also expect that communities that have programs or organizations focused on credit provision, poverty reduction, and other areas that generally lead to improved incomes and welfare may be more likely to adopt land management technologies. However, this linkage will be indirect.

The second decision deals with whether or not the household participates in the program or organization. This decision is determined by the organization if they are targeting households that fit specific program criteria, as well as the household. We explore the determinants of household-level involvement in programs and organizations econometrically. As with the presence of a program or organization in a community, we hypothesize that households directly involved with an organization focused on agriculture- or environment-related issues are more likely to adopt land management technologies. We also expect that household-level involvement in organizations focused on poverty reduction, reducing population pressure, and so on may indirectly affect technology adoption. Involvement in these types of programs or organizations may lead to medium to long-run changes in the ability or willingness of smallholders to adopt land management technologies. However, these longer-term effects may be difficult to discern from the limited time period our data consider.

The third decision is whether or not the household will adopt the land management technology. We estimate a two-stage probit model to determine the effect of the presence of a program or organization in a community and household-level involvement in the program or organization on the adoption of land management technologies.

When there is no program or organization in the community, there are two possible outcomes in our model: the technology is adopted or not adopted by the household. Technology adoption could depend on interactions with government extension officers, farmer innovations, information diffusion through social networks, and so on. We control for these and other factors in our analysis. The framework we have proposed enables us to investigate the direct effects of programs and organizations on the adoption of land management technologies versus spillover or diffusion effects. Spillover or diffusion effects come into play when a program or organization has the ability to affect adoption even among households not directly working with the program or organization through diffusion of information. This is very important to investigate because the ability of technologies to be widely adopted depends largely on ease of diffusion. Some technologies are more likely to diffuse than others. For example, soil and water conservation measures such as Fanyu ju terraces that require substantial labor investments and offer limited returns in the short to medium term are less likely to diffuse easily than low-cost, high-return technologies such as improved seeds.

Explanators of Organizational Presence

The dependent variables used in our analysis of community-level program or organizational presence were whether or not there is an agriculture- or environment-focused program or organization functioning in the community and whether or not there is another type of program or organization functioning in the community. Our analysis includes only programs and organizations that started working in communities in 1990 or later.[6] The explanatory variables in our analysis include agroclimatic zone, market access, population density, community-level indicators of welfare and wealth estimated for 1990, estimated community-level indicators of average education, and access to basic infrastructure and services in 1990.[7] By using explanatory variables based on estimates of conditions in 1990, we get a sense of the factors that have motivated programs or organizations to locate or evolve in these communities since then (Table 11.6).[8]

We have only one significant variable in our model to explain the presence of agriculture- and environment-focused programs and organizations. The finding that the coefficient of distance to a tarmac road is negative and significant is consistent with our descriptive analysis and indicates that agricultural and environment programs and organizations are associated with good market access. Because we have few significant variables, our model may be failing to capture some key explanatory variables, or these programs may not be well targeted. The model better explains the presence of programs and organizations that may influence the indirect causes of land degradation, though most of our significant variables are only weakly significant. We find that such programs and organizations are less likely to occur in the bimodal medium-rainfall and eastern highland regions. We find that programs and organizations are more likely in more populous communities and also where housing quality (measured by the proportion of people with a metal roof) is lower. We also find that these programs and organizations are more likely in communities where the proportion of school-aged children enrolled in secondary school is higher, suggesting a linkage between education and organizational development. Finally, we find that programs and organizations are more likely where access to basic infrastructure is poorer (in the case of roads) but where access to resources is better (with respect to access to fuelwood). Such programs and organizations appear to focus on less-market-connected and more-resource-abundant communities.

Table 11.6 Determinants of program or organization presence by main focus between 1990 and 1999, probit estimation

Variable	Program or organization focused on agriculture and/or the environment present in LC1	Program or organization focused on other issues present in LC1
Agricultural potential (cf. unimodal)		
Bimodal low	0.1102	0.0422
Bimodal medium	–0.2148	–0.3234*
Bimodal high	0.3085	0.2269
Southwestern highlands	0.0223	0.1655
Eastern highlands	0.1903	–0.5319*
Market access (0/1 dummy where high = 1)	0.1941	0.1937
Population density (0/1 dummy where high = 1)	0.0313	–0.1767
(ln) Households in LC1 in 1990 (number)	0.0561	0.1290*
Households without adequate food in 1990 (proportion)	–0.0023	0.0346
Households with metal roof in 1990 (proportion)	–0.0041	–0.5448*
Households where adult can read and write, 1990 (proportion)	–0.0018	–0.5253
Households with children of secondary school age in school, 1990 (proportion)	–0.0041	0.5497*
(sqrt) Distance to tarmac road in 1990 (miles)	–0.0724**	0.0593*
(sqrt) Distance to primary school in 1990 (miles)	0.0612	–0.0153
(sqrt) Distance to nearest fuelwood source in 1990 (miles)	–0.0708	–0.1588**
(sqrt) Distance to drinking water source (dry season) in 1990 (miles)	–0.0296	0.0244
(sqrt) Distance to drinking water source (rainy season) in 1990 (miles)	0.0735	0.0152
Number of observations	98	98
Mean of dependent variable	31.6	73.8
Mean predicted probability of program or organization	23.9	80.0
Pseudo-R^2	0.2863	0.2773

Note: Reported coefficients represent the effect of a unit change in explanatory variable on probability of a program or organization being present at the mean of the data. Coefficients are adjusted for sampling weights and stratification and are robust to heteroskedasticity. Intercept is not reported.

*** and ** mean coefficient statistically significant at 10 percent and 5 percent levels, respectively.**

Explanators of Household Involvement in Organizations

Household-level characteristics determine whether or not households will be involved in organizations. The dependent variables for our probit regressions include whether or not any member of the household was involved in any type of organization, any agriculture- or environment-focused organization, or any organization with a focus on topics that might influence the indirect effects of land degradation, between 1990 and 2000 (Table 11.7). Our explanatory variables include the human, social, and physical capital of the household. Indicators of human capital include the education level of the household head, whether or not the household head is female, the number of male and female members in the household, and the age of the household head. We consider religion and ethnicity of the household head as well as whether or not the household head and spouse were born in the village they currently reside in, as indicators of social capital.[9] We use estimated acres of land owned or operated by the household in 1990,[10] the number of bulls and cows or heifers owned by the household in 1990, and whether or not the household owned a radio or bicycle in 1990 as our proxies for physical capital.

We also consider whether or not the primary or secondary source of income of the household is dependent on farming or some other natural resource–based enterprise (for example, fuelwood-intensive enterprises such as brickmaking and beer brewing). We expect households with a high degree of resource dependence (i.e., those households where both the primary and secondary sources of household income are related to agriculture or natural resources) to be more involved in agriculture- or environment-focused organizations than households less dependent on natural resources for income.[11,12]

In general, social capital is an important determinant in household involvement in organizations. Households where the head is from a dominant ethnic group (e.g., Banyankore and other southwestern highland peoples), or where the head's spouse was born in the village, are more likely to be involved in programs and organizations. Human capital and gender are also an important determinant in our regressions. Female-headed households and households with higher proportions of women are more likely to be involved in programs and organizations. We also find that higher levels of education of the household head are positively and strongly associated with involvement in agriculture- or environment-related organizations. Note also that all households with education beyond "O" level participated in some kind of organization. This is a significant result, although the variable had to be dropped since it predicts participation perfectly. We find that resource dependence is positively correlated with household-level involvement in programs and organizations. However, surprisingly, this is not the case for household involvement in programs focused on agriculture and the environment.

Table 11.7 Determinants of household involvement in programs and organizations between 1990 and 2000, all households, probit estimation

Variable	Household involved in any organization	Household involved in agriculturally/environmentally focused organization	Household involved in other organization
Education level of household head (cf. none)			
Some primary or completed primary	–0.0139	0.1204	0.0168
More than primary up to O-levels	0.0019	0.3571**	0.0058
Beyond O-levels	Variable dropped[a]	0.7286***	0.1397
Female household head	0.0856	0.1280	0.1378*
(sqrt) Number of men in household	–0.0573	–0.0515	0.0026
(sqrt) Number of women in household	0.0652*	0.0916	0.0099
(ln) Age of household head	0.0408	0.0925	–0.0236
Non-Christian household head	0.1068	0.0005	0.0950
Baganda	0.1100*	0.0136	0.1180
Banyankore and southwestern highland peoples	0.1388***	–0.0231	0.1895***
Northern people (e.g., Acholi, Langi)	0.1538**	0.4183	0.1037
Iteso and Kumam	0.0676*	0.0208	0.0565
Eastern peoples (e.g., Basoga, Bagisu)	0.1636*	–0.0061	0.1474
Eastern highland peoples	0.0307	–0.1550	0.0136

Household head born in village	−0.0019	−0.0967	0.0428
Spouse born in village	0.0342*	0.0792	0.0453
Estimated acreage in 1990	−0.0007	−0.0060	0.0002
(sqrt) Number of bulls in 1990	0.0188	0.0296	−0.0224
(sqrt) Number of cows/heifers in 1990	0.0057	0.0296	0.0027
Owned radio in 1990	0.0913	0.1040	0.0549
Owned bicycle in 1990	−0.0299	0.0062	−0.0013
Only secondary source of income resource dependent, 1990 (cf. income not resource dependent)	0.1184	−0.0599	0.1867*
Only primary source of income resource dependent, 1990	0.1246**	−0.0383	0.1390***
Both primary and secondary source of income resource dependent, 1990	0.2268***	0.0103	0.2474***
Number of observations	425	445	445
Mean of dependent variable	83.0	29.9	78.8
Mean predicted probability of program or organization	85.8	27.4	80.9
Pseudo-R^2	0.1211	0.1847	0.0916

Note: Reported coefficients represent the effect of a unit change in explanatory variable on probability of a program or organization being present at the mean of the data. Coefficients are adjusted for sampling weights and stratification and are robust to heteroskedasticity. Intercept is not reported.

[a]Variable dropped: predicts success perfectly.

***, **, *** mean coefficient statistically significant at 10 percent, 5 percent, and 1 percent levels, respectively.**

Explanators of Household Adoption of Sustainable Land Management Technologies: Do Programs and Organizations Matter?

Whether or not the presence of an organization in a community and/or a household's level of involvement in an organization contributes at least in part to the adoption of new technologies has important implications for the future role that organizations will have in providing an enabling environment for sustainable land management in Uganda. In our final set of regressions, we use the adoption of selected land management technologies in 2000 as our dependent variables. We focus on five technologies that have been adopted by at least 10 percent of the households in our sample: use of inorganic fertilizer, use of animal manure as fertilizer, incorporation of crop residues, mulching, and pesticides.

Our explanatory variables include those factors that we hypothesize will directly affect the adoption of land management technologies. We use the agro-ecological potential of the LC1s in which the households are located as well as market access and population density as described in the community-level regressions. We hypothesize that the costs and returns associated with technology adoption will be a function of agroclimatic factors as well as access to markets and population density (Pender, Scherr, and Durón 2001; Chapter 2). We also consider the population growth rate in the community, hypothesizing that high rates of population growth may prompt the adoption of land management technologies to compensate for land use pressure. To provide information about household-level access to infrastructure, we include average distance from all parcels of land the household owned or operated to the nearest all-weather road and nearest market. We also consider the average distance from the household to each parcel owned or operated by the household. Travel time to plots as well as the distance bulky inputs such as animal manure need to be carried will influence whether households adopt different technologies.

We include several household-level variables to describe human, social, and physical capital. We include whether or not the household is female headed, the age of the household head, the education level of the household head, and whether or not the household head was born in the village as indicators of household-level human and social capital. We are uncertain of the effect of gender of household head on technology adoption. Female-headed households are likely to have significant constraints on their time, possibly making them unlikely to undertake labor-intensive technologies such as manure collection. We also include information on the household labor force. We hypothesize that larger households will be more likely to adopt labor-intensive land management technologies. Asset access is indicated by the estimated total area of land the household owned or operated in 2000 as well as the number of bulls and cattle the household owned in 2000 and whether or not the household owned at least one radio or one bicycle. Households with greater wealth may be more likely to undertake land management technologies that offer medium- to long-run returns because of lower discount rates and less binding cash constraints (Pender 1996; Holden, Shiferaw, and Wik 1998; Pender and Kerr 1998). We expect households with low asset levels to undertake technologies, such as using animal manure as fertilizer, that are labor-intensive and may offer short-run returns.

Access to both informal and formal credit may be important indictors of whether or not households can obtain access to external inputs such as inorganic fertilizer, improved seed, and pesticides. We hypothesize that access to credit will have a positive effect on the adoption of technologies purchased with cash. Where access to credit is poor, the adoption of technologies that do not require the purchase of external inputs, such as use of manure or mulch, may be greater. We also consider the effect of contact with an extension worker in 2000. We hypothesize that contact with extension will be positively correlated with adoption of the various land management technologies we consider. With respect to land tenure, we expect that adoption of technologies such as tree planting that yield benefits over the medium to long term will be associated with more secure forms of land tenure such as freehold (Feder and Onchan 1987). Tenure security also may increase the value of land as collateral for credit, thus potentially increasing the adoption of technologies requiring cash inputs (Feder and Onchan 1987). As with the last set of regressions, we consider the level of dependence of the household on natural resource–related primary and secondary income sources. We hypothesize that households are more likely to undertake various sustainable land management technologies when their livelihoods are more dependent on natural resources.

Finally, we include the presence of agriculture- or environment-related programs in the community, and the presence of a program or organization focused on the indirect causes of land degradation in the LC1 as potential determinants of the adoption of various technologies.[13] We hypothesize that the presence of an agriculture- or environment-related program increases the likelihood of the household adopting various land management technologies. We also include household involvement in agriculture- or environment-focused organizations and group together those that are focused on the indirect causes of land degradation in our regressions. Similarly we expect that households involved in agriculture- or environment-related organizations are more likely to adopt sustainable land management technologies. However, household-level involvement in other types of organizations may also affect technology adoption.

Note that we do not include variables related to community-level infrastructure and poverty in 1990 from our first set of regressions. We also omit variables pertaining to ethnicity and religion that were used in our second set of regressions. The variables that have been excluded from our two-stage probit model but that were included in our earlier models are instrumental variables used to help identify the effects of programs and organizations using predicted values to control for endogeneity of program placement and participation. Consider, for example, ethnicity: we expect that stature in the community is likely to be directly related to household-level involvement in programs and organizations. As we have already pointed out, organizations may seek out community leaders to work with, or leaders themselves may organize groups within the community. However, we do not expect social capital to directly cause the adoption of land management technologies, controlling for household participation in programs and organizations. Regression results are presented in Table 11.8.[14]

Our findings with respect to the presence of agriculture- or environment-focused programs and organizations in a community provide limited evidence that they are directly affecting household adoption of land management technologies.[15] We found a strong positive association between the adoption of pesticides and the presence of an agriculture- or environment-focused program or organization in a community. One possible explanation for this is that the knowledge spillover effects of programs and organizations may be greater for purchased inputs, yielding higher short-term benefits than for labor-intensive on-farm organic alternatives such as mulching and manuring. When we consider the effects of direct household involvement in programs and organizations, we find significant results for two of the five technologies we consider. Household involvement in agriculture–environment organizations is associated with a higher likelihood of adopting inorganic fertilizer (a purchased input) and manuring (a labor-intensive organic technology). Thus, more direct involvement in programs and organizations may be required to promote the adoption of organic land management practices.[16]

We find a positive association between household involvement in other types of organizations and the adoption of pesticides and crop residues. Household adoption of pesticide use may be facilitated by involvement in credit and community service–oriented programs and organizations. Such organizations enable poorer households to purchase inputs such as pesticides.

In general, with the exception of organizations focused on agriculture and environment, we do not have strong results linking involvement in programs and organizations to the adoption of land management technologies. However, community survey respondents perceived strong positive effects of several types of organizations on crop production, land quality, and livestock production. Additional research is needed to consider the effect of involvement in programs and organizations on crop productivity, livestock productivity, and other livelihood strategies.[17]

Table 11.8 Determinants of investment in selected land management practices, probit estimation, 2000

	Inorganic fertilizer	Pesticides	Crop residues	Mulching	Animal manure
Presence of agriculturally/environmentally focused program or organization in LC1	0.0013−−−	0.1942***	−0.0042	−0.0186	−0.0633
Presence of program or organization focused on indirect causes of land degradation in LC1	−0.0056+++	−0.0282++	0.0954**	−0.0335	−0.0181
Household involvement in agriculturally/environmentally focused organization	0.0326**	0.0908+++	0.0273	0.0862	−0.0982**+++
Household involvement in organization focused on indirect causes of land degradation	0.0029	0.1314***	0.0695*	0.0742	0.0175
Agricultural potential (cf. unimodal)					
Bimodal low	−0.0144	−0.1848***−−	−0.1160**−−	0.3478**++	0.0347
Bimodal medium	−0.0051	−0.0055	−0.1152***−−−	−0.1334**−−−	−0.2011***−−−
Bimodal high	−0.0593***−−	−0.1693*−−	−0.2918***−−−	0.0952	−0.1311*−−
Southwestern highlands	−0.0203***−−−	−0.0973	−0.1264***−−−	0.2027	−0.0631
Eastern highlands	0.1093+++	0.1680	−0.1132**−−−	0.0149	0.3269*+
Market access (low/high)	−0.0011	−0.0749	−0.2256***−−−	−0.1566**−−−	0.0856
Population density (low/high)	0.0161+++	0.0945*+++	0.0703*	0.0603	0.0814
Altitude (meters above sea level)	0.0001**+++	0.0001	0.0001	0.0001	−0.0001
Population growth rate (percent)	−0.0008	0.0035	−0.0013	−0.0033	−0.0092−
(sqrt) Average distance from all parcels to all-weather road (kilometers)	−0.0050	−0.0329	0.0065	−0.0108	−0.0206
(sqrt) Average distance from all parcels to market (kilometers)	0.0079	0.0656**++	0.0272*+	−0.0136	0.0247
(sqrt) Average distance from all parcels to residence (kilometers)	0.0056	−0.0277	0.0198	0.0029	0.0253
Education level of household head (cf. none)					
Some primary or completed primary	0.0042	−0.3003***−−−	0.0266	−0.0347	−0.2702***−−−
More than primary up to O-levels	0.0414	−0.1617**−−−	0.0694	−0.0058	−0.0943
Beyond O-levels	0.0915	−0.1422−−−	0.3168**++	0.0819	−0.0374
Female household head	0.1686***++	−0.0806	−0.0391	−0.0881	0.0878
(ln) Age of household head	−0.0169	−0.1498−−	0.0378	0.0604	−0.2690***−−
Household head born in village	0.0000	0.1071**++	0.0120	−0.0541	−0.0997**−−

(*continued*)

Table 11.8 (continued)

	Inorganic fertilizer	Pesticides	Crop residues	Mulching	Animal manure
(sqrt) Number of men in household	0.0132+	0.0431	0.1336***+++	–0.0027	0.1259***+++
(sqrt) Number of women in household	0.0188**++	–0.0247	–0.0742**––	–0.0486	0.0351
Estimated acreage in 2000	–0.0018**–	0.0025	0.0007	0.0009**	–0.0059**
(sqrt) Number of bulls in 2000	0.0139*++	0.0179	–0.0126	0.0898	–0.0179
(sqrt) Number of cows/heifers in 2000	–0.0022	–0.0351	0.0083	–0.0266++	0.0343+
Owned radio in 2000	0.0083	0.0169	–0.0062	0.0529	0.0764*
Owned bicycle in 2000	–0.0100	0.0272	–0.0178	0.0920**++	–0.0337
Formal credit available in village in 2000	–0.0027	0.1738	–0.0872	–0.1522	–0.2258**––
Informal credit available in village in 2000	–0.0137	0.1362	–0.0115	–0.1049	–0.2848***–––
Contact with extension in 2000	0.0692***+++	0.1373**+++	–0.0493	0.0884**+++	0.1263**++
Tenure status of primary parcel (cf. freehold)					
Leasehold	–0.0142–	–0.1574	0.0721	0.1734	–0.0079
Mailo	–0.0007	0.0946	0.1992***++	0.2037**++	0.1058+
Customary	–0.0324**––	0.0006	0.0514	–0.0041	–0.0313
Only secondary source of income resource dependent, 1990 (cf. income not resource dependent)	–0.0138	–0.1245–	0.0724	0.0499	0.0288
Only primary source of income resource dependent, 1990	–0.0065	–0.0707	0.0722	0.0994+	0.0486
Both primary and secondary source of income resource dependent, 1990	–0.0314***––	–0.1265*	–0.0332	0.0622	0.0162
Number of observations	445	445	445	445	445
Mean of dependent variable	10.0	23.8	17.6	20.4	23.0
Mean predicted probability of adoption	1.3	17.5	11.5	11.4	14.2
Pseudo-R^2	0.4434	0.2357	0.2492	0.3009	0.2975

Note: Reported coefficients represent the effect of a unit change in explanatory variable on probability of a program or organization being present at the mean of the data. Coefficients are adjusted for sampling weights and stratification and are robust to heteroskedasticity. Intercept is not reported.

***, **, *** mean coefficient statistically significant at 10 percent, 5 percent, and 1 percent levels, respectively; +,++,+++ and –, ––, ––– denote level of positive or negative significance when predicted probabilities of programs and organizations are used in regressions.**

With respect to the other determinants of adoption of various land management technologies, we had somewhat mixed results among our five regressions. In general, we found that households with higher numbers of male members were more likely to adopt organic technologies such as manuring and crop residues. Female-headed households and households with more women were more likely to adopt inorganic fertilizer. Households with more cattle, bulls, and bicycles were more likely to adopt some technologies (inorganic fertilizer, manuring, and mulching), which supports our hypothesis that wealthier households will be more likely to invest in land management technologies characterized by medium- to long-term returns, such as manuring and mulching. We also find that households with extension contact are more likely to adopt inorganic fertilizer, manuring, mulching, and pesticides. Education of household head and age of household head have varying effects on technology adoption. Households with older heads were less likely to use animal manure. Access to both formal and informal credit was negatively associated with adoption of animal manure in 2000. Households with resource-dependent primary and secondary income sources were less likely to use inorganic fertilizer and pesticides.

Better market access is associated with less use of some organic practices such as incorporating crop residues and mulching, possibly because of higher labor opportunity costs or higher demand for such organic materials in places of better access. Higher population density is associated with greater likelihood of using crop residues and pesticides, and smaller land area owned is also associated with more fertilizer and manure use. These findings support the Boserupian hypothesis of population-induced intensification (Boserup 1965).[18]

Conclusions and Policy Implications

Government devolution of infrastructure and services is taking place in Uganda. Of particular relevance to the Plan for the Modernization of Agriculture is the role that NGOs and CBOs will play in fulfilling roles traditionally filled by government programs. Our analysis of programs and organizations functioning at the community level indicates that during the 1990s government programs were better distributed throughout Uganda than NGOs and CBOs and that, in general, government programs focused on poorer communities. As devolution takes place, it is worth considering how these roles will be fulfilled by NGOs and CBOs. Providing incentives for NGOs and CBOs to locate in less-favored areas may ensure that these communities do not experience negative effects as a result of devolution. This is particularly important to the delivery of land management technologies to smallholders as the Government of Uganda moves toward demand-driven fee-for-service extension. The ability of communities or individual households to identify extension needs and request services will be influenced by access to information on technologies and options available to smallholders.

With respect to household-level involvement in programs and organizations, we found relatively high levels of involvement in credit and community service–oriented NGOs and CBOs. Fewer households were involved in organizations focused on agriculture and the environment. We found that female-headed households and households with high numbers of women were more likely to be involved in organizations. Strong female involvement in organizations is encouraging news, and this may have implications for the adoption of land management technologies. If women are able to influence household-level decisionmaking regarding the adoption of land management technologies, then higher proportions of women involved in organizations may have positive implications for technology adoption. Recall that female-headed households and households with higher numbers of women were more likely to use inorganic fertilizer. However, it may be the case that women prioritize education, health, and/or basic needs ahead of land management. Our data indicate that high proportions of women are involved in community service–focused organizations that generally do not deal with land management issues. Further investigation into household-level decisionmaking regarding technology adoption is required.

With respect to social capital and household involvement in organizations, we found that households where the head belonged to a dominant ethnic group were in some cases more likely to be involved in organizations (for example, Acholi and Langi in the north and Banyankore and other dominant groups in the southwestern highlands). Also, having the spouse born in the village increased the likelihood of involvement in organizations focusing on the indirect cause of land degradation. These findings indicate the importance of social capital in organizational involvement and suggest that households with weak social capital may be excluded from participation. With respect to assets, we found that households with smaller landholdings were more likely to be involved in infrastructure- or credit-focused programs and organizations and more likely to use inorganic fertilizer and manure, indicating that they are farming more intensively. Households facing tighter land constraints may be participating in organizations as a way of learning about or becoming involved in both farm and off-farm opportunities.

The results of our econometric analysis of the determinants of adoption of land management technologies indicate that the presence of an agriculture- or environment-focused program or organization at the community level had a negative effect on the adoption of animal manuring and a positive affect on the adoption of pesticides. This suggests that spillover effects of programs and organizations may be greater for technologies that have short-term benefits and that require some degree of coordination to be most effective. For example, technologies such as pest management are most effective when a group of households with contiguous cropping fields use them (Knox, Meinzen-Dick, and Hazell 2002). Household-level involvement in an agriculture- or environment-focused organization had a positive effect on the adoption of inorganic fertilizer and manuring. Adoption of labor-intensive land management technologies such as manuring that yield longer-term benefits apparently do not spill over to nonparticipants in local programs and organizations. Thus, direct involvement of households in programs and organizations that promote such technologies may be necessary to ensure technology diffusion throughout communities.

This information may be taken as an indicator of the effectiveness or influence of agriculture- and environment-focused organizations in Uganda and should be considered in the broader context of the government devolution of services to NGOs and CBOs. Further analysis of additional technologies is required to determine whether or not agriculture- and environment-related programs are positively affecting land management in Uganda. One possible explanation for our weak results regarding the effect of these programs and organizations on the adoption of land management technologies is that smallholders may be receiving training on land management but not actually adopting the technologies. If this is the case, there is a need to evaluate the role and effectiveness of these organizations. There is evidence of limited profitability of many land management technologies in Uganda. Analysis of the productivity effects of land management technologies including the use of inorganic fertilizer, manuring, improved fallows, and others indicates limited benefits to adopting these technologies in the short run (Nkonya et al. 2004). This emphasizes the importance of identifying profitable technologies or applying technologies to more profitable crops.

Notes

1. Growth rates can be compared with real average annual rates of growth of 4 percent for agriculture and 8 percent for manufacturing in the late 1960s and early 1970s (Belshaw, Lawrence, and Hubbard 1999).

2. The original sampling frame excluded most of northern Uganda. Community-, village-, household-, and plot-level surveys have since been conducted in this region.

3. Because of security threats in the western part of the country during the time of the survey, some LC1s drawn in the random sample were dropped.

4. As with the community data, we encountered some households that reportedly had no involvement in organizations (20 percent).

5. In our sample of 107 LC1s, approximately 21 percent of communities did not report having any programs or organizations between 1990 and 1999. This finding might be a result of miscommunication during the administration of the questionnaire.

6. We use indicators of general welfare, access to infrastructure and services, and so on in 1990 as a benchmark. By examining the programs and organizations present in communities between 1990 and 1999, we are able to determine how factors in 1990 have contributed to the presence of programs and organizations.

7. We have estimated the proportion of households in the community with each of the welfare, wealth, and education indicators by adding or subtracting 10 percent for minor increases or decreases since 1990, and 25 percent for major increases or decreases since 1990 from 1999 proportions.

8. Regressions were checked for multicollinearity using variance inflation factor (VIF). The maximum VIF of any of our explanatory variables was 3.63, indicating that multicollinearity is not a serious problem in our models (Mukherjee, White, and Wuyts 1998). We take the natural log or square root of our explanatory variables when the variable is more normally distributed in this alternative functional form. Doing so generally improved the specification of our model (Mukherjee, White, and Wuyts 1998).

9. Social capital refers to features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit (Putnam 1995). In our model, religion and ethnicity of the household head are proxy indicators of social capital, whereas our indicators of physical and human capital are direct indicators.

10. Land owned or operated by the household in 1990 was estimated by calculating the total area of land acquired before 1990.

11. Our regressions were based on all households in our survey (not only those in communities reporting the presence of programs and organizations) because we found that households reported involvement in a wider range of organizations at the household level than was indicated in the community survey. We ran a second set of regressions including only those households with a program or organization present in their LC1 (in keeping with our conceptual framework as presented in Figure 11.1) and found similar results.

12. These regressions were also checked for multicollinearity using variance inflation factor (VIF). The maximum VIF of any of our explanatory variables was 8.83, indicating that multicollinearity is not a major problem in our models (Mukherjee, White, and Wuyts 1998).

13. To control for endogenous program and organization presence and participation, regressions were run with both actual and predicted probabilities of program or organization presence/involvement. The robustness of the results to use of predicted probabilities is reported in the results.

14. Regressions using actual and predicted values were checked for multicollinearity using variance inflation factor (VIF). The maximum VIF of any of our explanatory variables was 8.05, indicating that multicollinearity is not a major problem in our models.

15. We also considered a model that examined type of program or organization (i.e., government program, NGO, or CBO) rather than main focus of program. Of the five technologies considered, only NGO presence at the community level was found to positively influence the adoption of using animal manure on fields and was only weakly significant ($P < 0.10$).

16. We considered an alternate model specification that excluded variables indicating household involvement in various types of programs and organizations. The specification yielded similar results to those presented in Table 11.8, although the presence of an agriculture or environment program or organization at the community level was no longer significant for the regression examining explanators of household-level animal manure technology adoption. Because of the additional

information gained from including household level involvement in various types of organizations and the significance of these variables in several of our models, we have included both community presence of and household involvement in programs and organizations of various types.

17. Nkonya et al. investigate some of these impacts in Chapter 7 in this volume.

18. We considered the differential impact of programs and organizations by running a series of probit models for the lowland and highland subsamples. The presence of an agriculture- or environment-focused program or organization in the community was more likely to affect the adoption of pesticide use in lowland areas. In highland areas, the use of inorganic fertilizers and pesticides was negatively associated with the presence of other types of programs and organizations in the community. Household involvement in agriculture- or environment-focused programs and organizations was associated with adoption of pesticides in lowland areas and animal manuring in highland areas. Household involvement in other types of programs and organizations was positively associated with the adoption of pesticides and crop residues in lowland areas.

Chapter 12

Zero Tillage or Reduced Tillage: The Key to Intensification of the Crop–Livestock System in Ethiopia

Jens B. Aune, Rahel Asrat, Dereje Asefa Teklehaimanot, and Balesh Tulema Bune

Numerous methods are available for increasing crop and livestock production in the Ethiopian highlands. Both national and international research institutes have developed technologies that are technically appropriate for these conditions. Examples of such technologies are the broad-bed maker for vertisols and cow traction (Zerbini, Woldu, and Shapiro 1999) and use of a single ox to pull the plow (Ouwerkerk 1990). However, farmers' adoption of these technologies has been very limited, and farming is still characterized in most areas by low input use and limited use of improved technologies. Fertilizer application has increased in recent years because improved crop production packages have been introduced through the Ethiopian extension service. Fertilizer has been easy to introduce because it does not require fundamental changes in the farming system. These packages have been accompanied by supply of credit. However, introducing these packages to farmers has not been without problems, particularly in dryland areas where crop failures are common. Farmers are often forced to sell animals to repay their debt. Despite these problems, it must be recognized that fertilizers do have an important role to play if farming in Ethiopia is to progress.

We believe that increased emphasis should be given to integrated approaches for agricultural development. There is a need to develop technologies and management schemes that can simultaneously enhance production, preserve the natural resource base, and reduce poverty. Different technological options have different effects. A pure fertilizer-based approach cannot address the problems of the poorer households and solve the problem of soil erosion, and a focus only on indigenous knowledge and low input use cannot generate sufficient growth. The crop–livestock system in Ethiopia is highly complex, with strong interlinkages between the crop and livestock components. These interlinkages are related to manure production, traction power, fodder production, and income generation. This makes it impossible to change one component of the system without affecting the others. More fundamental changes toward more productive crop–livestock systems therefore require an integrated and holistic approach. This chapter discusses the problems of the current crop–livestock system and suggests an alternative pathway for the crop–livestock system to enhance productivity and safeguard the environment.

Composition of the Livestock System in Ethiopia and Productivity Effects

The livestock production system in Ethiopia has low productivity. A survey in Tigray showed that average daily milk production in 8 *woredas* (administrative unit) per cow was 1.2 liters, and the average calving interval 27 months (Berhane 1996). Average productivity per animal slaughtered in Ethiopia is estimated to be 110 kilograms of meat and 213 kilograms of milk, and annual per caput consumption of milk and meat is estimated at 16 and 10 kilograms, respectively (Suttie 2000). In Kenya, by contrast, per caput milk production is 85 kilograms per year. This classifies Ethiopia as having the lowest per capita consumption of meat and milk, even among neighboring countries, although it has Africa's largest national herd (Bebe, Udo, and Thorpe 2002). We believe that one of the fundamental causes for the low productivity of the livestock system is the composition of the livestock herd. Studies of the livestock composition in different parts of Ethiopia show that there are often more oxen than cows (Aune et al. 2001). The composition of the livestock is a reflection of the production objectives of the livestock system (Ketelaars 1991), and for Ethiopia the dominance of oxen in the livestock system indicates that the primary output from the livestock system is traction power. The trend across different regions of Ethiopia is that farmers tend to retain oxen instead of cows when reducing the number of livestock (Aune et al. 2001). A survey in the Amhara region showed that the number of households owning oxen declined by 19 percent from 1991 to 1999, whereas the number of households owning cows declined by 35 percent during the same period (Jabbar and Ayele 2002). This shows an "oxenification" of the livestock system in Ethiopia. Cows are mainly used for reproduction purposes and to get some milk production in part of the year.

Several studies indicate that the composition of the herd in Ethiopia negatively affects the productivity of the crop–livestock system. A large survey in Tigray showed that the return to investment in livestock was 16 percent on average, whereas for cows it was 36 percent (Pender, Gebremedhin, and Haile 2002). Results from a crop–livestock model based on data from northern Gonder indicate that replacing oxen with milk-producing goats increases the profitability of the crop–livestock system (Ayele and Aune 2001).

This dominance of oxen in the current livestock system makes it difficult to introduce improved fodder management schemes because of lack of economic returns from oxen. A change in the composition of the livestock population will not occur unless the tillage system is modified because without oxen the land cannot be cultivated. If zero tillage or reduced tillage were introduced, farmers would have much less need to keep oxen for traction purposes. Replacing oxen with animals for meat and milk production may increase the overall productivity of the system.

Alternatives to Ox Tillage

Ox plowing in Ethiopia dates back to before 1000 B.C. The reasons for its widespread use in Ethiopia are cereal cultivation and particularly the cultivation of *teff,* which requires up to six passes with the *maresha* (the Ethiopian plow) and absence of the tse tse fly (causing tripanosomiasis) in the highland areas (Aune et al. 2001). However, this ox-plowing system that was appropriate in the past may not be the ideal system in the current situation characterized by smaller farm size and shrinking fodder resources as a result of rangeland degradation. A survey in the Amhara region confirms that farmers think that fodder resources are becoming increasingly scarce (Benin, Ehui, and Pender 2002; Chapter 6). Ox rental and sharecropping have also become more costly and more favorable to the ox owner. In northern Ethiopia increased use of half share of crop production to landowner and half share to tenant/ox owner has increased over the previous arrangement characterized by two-thirds to landowner and one-third to tenant/ox owner (Benin et al. 2005). Particularly female-headed households are in a weak position because it is culturally unacceptable for female farmers to plow with oxen in the Ethiopian highlands. Zero tillage is therefore particularly appealing for female-headed households.

Despite these constraints with the ox-plowing system, it remains the dominant tillage system. The alternative tillage systems that are being tested are reduced tillage and zero tillage. Reduced tillage is characterized by one pass with the *maresha* rather than the three to six passes in the conventional system. Zero tillage is without any plowing, and mulch application, herbicides, or manual weeding is used to control weeds. Studies by Sasakawa Global 2000 (an NGO), the Combating

Table 12.1 Effect of tillage system on maize yields, 1999 and 2000

Tillage system	1999 (213)	2000 (210)	Average
Conventional	4,944	4,387	4,670
Reduced	5,706	4,876	5,290
Level of significance	$P < 0.05$	$P < 0.05$	$P < 0.05$

Note: Number of participating farmers in parentheses.

Nutrient Depletion (CND) project, and a survey in Tigray (Pender, Gebremedhin, and Haile 2002; Chapter 5) illustrate that crop productivity can be increased by developing alternatives to the ox-plowing system. Promising results have so far been achieved with both maize and *teff.* However, the primary reason for introducing zero tillage or reduced tillage is not increased crop productivity but rather the possibility of replacing oxen with meat- or milk-producing animals.

Results from reduced tillage demonstration plots of Sasakawa Global 2000 in farmers' fields in 1999 and 2000, using herbicides to control weeds, show that yields are higher under reduced than under conventional tillage (Table 12.1). Average maize yield for the two years, based on 423 demonstration plots in the Oromia and Amhara regions, was 620 kilograms/hectare (Table 12.1) higher under reduced than under conventional tillage (Asrat 2002). Labor demand per hectare was 78 days lower under reduced tillage because of the savings on plowing and weeding. Cash expenditures are 550 birr/hectare higher under reduced tillage because of herbicide costs. However, if farmers would have to pay the labor cost for weeding and ox rental, cash expenditures would be 235 birr/hectare higher under conventional tillage. These estimates are based on the average wage rate in the area and labor demands in the two cultivation methods according to farmers' assessments. Herbicides were given freely to farmers in 1999 and 2000, and only 10 percent of the farmers continued to use reduced tillage when they had to pay for the inputs in 2001. The reasons given for this discontinuation were the high price of herbicides and the low price of maize. Other reasons are that farmers in these areas normally have access to a pair of oxen and low opportunity cost of labor. The value of the additional yield under reduced tillage is estimated at 248 birr/hectare based on a maize price of 0.4 birr/kilogram. Hence, it is not economically attractive for farmers to use reduced tillage if the saved labor has a low opportunity cost. At a maize price of 1 birr/kilogram, as in 1998–99 (Asrat 2002), the increased yield could pay for the herbicide costs. This underscores that an important factor demotivating the farmers to use reduced tillage is the low maize price. It will become even more attractive for farmers to turn to reduced tillage if they replace the oxen by animals for meat and milk production. Results from a survey in Tigray showed that reduced tillage is associated with 57 percent higher crop productivity than conventional tillage, controlling for labor and other input use, confirming that benefits from reduced tillage are likely (Pender, Gebremedhin, and Haile 2002; see also Chapter 5).

Experiments in the CND project in Gare Arere close to Ginchi in the central highlands show that zero tillage is also possible in *teff* (unpublished results). In this crop, up to six passes with the *maresha* are practiced. Results from 2001 showed that the average yield on a vertisol was 1,486 kg/hectare under zero tillage, compared to 1,424 under conventional tillage. Corresponding figures for a nitisol were 561 and 470 kg/hectare. No herbicides were used in these experiments, and weeding was done manually. The weed infestation did not differ significantly between the tillage methods. This indicates that annual application of herbicides might not be needed under some conditions or every year, and this can reduce the cost and risks of practicing zero tillage considerably.

Experiments across 10 years in Kulumsa, Ethiopia, also showed that zero tillage or reduced tillage is feasible in wheat (Taa, Tanner, and Bennie 2004). Wheat yield in zero tillage and reduced tillage were respectively 94 and 96 percent of wheat yield in conventional tillage.

Another benefit for farmers without oxen is that they can retain the entire production. Currently, they may have to pay about 50 percent of the yield for plowing, and the ox owner will, in addition, take the straw. This leaves farmers without oxen with very limited benefits. Moreover, they are in a weak bargaining position, without alternatives to ox plowing. Experience has shown that where alternatives to ox plowing exist, the cost of ox rental is lower (Aune et al. 2001). Zero tillage or reduced tillage offers such alternatives.

Oxen receive the best quality fodder before and during the plowing season. In Tigray, 68 percent of crop residues are fed to oxen (UNECA 1997). Hence, considerable scope for increasing livestock production exists if the scarce fodder resources could be used for milk and meat production rather than for traction purposes. It has been shown in Kenya that development of an intensive milk production system is feasible, even among smallholder farmers, with considerable increases in farmers' income (Bebe, Udo, and Thorpe 2002).

Zero tillage or reduced tillage will, in addition, contribute to reducing environmental problems, both locally and globally. Zero tillage can be as efficient as other soil and water conservation methods in controlling erosion, as shown in Nigeria (Lal 1984). Erosion rates in Ethiopia are currently alarmingly high in many areas because of the hilly nature of the terrain, and measures are necessary to halt the degradation of Ethiopian soil resources. Agricultural practices that mimic "mother nature" are the best practices from an environmental point of view. Continuous soil cover and an undisturbed surface layer with a high degree of recycling of plant nutrients characterize such production systems. The zero tillage system is an example of such a production system, as the soil surface remains undisturbed. Zero tillage or reduced tillage will also have a positive environmental effect globally by sequestering carbon. Zero tillage sequesters carbon because there is a lower decomposition rate of soil organic matter under zero tillage (Young 1997) and because zero tillage is associated with more recycling of organic matter. Higher carbon content of the soil is also associated with higher crop productivity in the tropics (Aune and Lal 1996). Increased humus content of the soil improves the water-holding capacity of the soil and improves soil surface characteristics (Pieri 1989).

Fodder Availability

A change in the composition of the livestock population should be combined with improved access to fodder of good quality and improved veterinary services. Improved breeds may in addition improve productivity. Several options are available for increasing the quality of fodder in Ethiopia. These include improved pasture management, growing of fodder crops and trees, and upgrading straw quality. A well-documented method for quality improvement of straw is treatment with urea (Suttie 2000). This method, widely used in China, is practiced in Ethiopia to only a limited extent. An economic assessment of the urea treatment technology in Ethiopia, using a crop–livestock model, has shown that each birr invested in urea treatment of straw yields a return of 5 birr when straw is fed to milk-producing goats (Ayele and Aune 2001). This is a particularly interesting option for Ethiopia, as straw is one of the major fodder resources in the highland areas (Jabbar and Ayele 2002). The importance of straw will probably increase in the future, as cropland is expanding at the expense of pastureland. The limited use of urea-treated straw in Ethiopia could be related to the composition of the livestock population because feeding urea-treated straw to oxen is expected to give very limited returns. Studies from India show that the adoption of urea treatment of straw depends on such factors as animal response, the price ratio between milk and urea, labor costs, access to water, availability of straw, and access and price of other fodder resources (Singh et al. 1993). This indicates that urea treatment of straw is most likely to develop in the vicinity of major markets.

Another low-cost method to increase straw quality without compromising grain yield is to harvest the grain at physiological maturity (30 to 40 percent grain moisture content) instead of at 10 to 13 percent, as normally is the case. Early maize harvest was shown to be associated with higher crude protein content and digestibility of straw in a study from southern Ethiopia (Tolera and Sundstøl 1999). Hay harvesting, widely practiced in Europe in former times, is another low-cost method for producing quality fodder.

Common and private grazing lands have been substantially reduced in the Amhara and Oromia regions, mainly because the area under cultivation has increased (Jabbar and Ayele 2002). Moreover, farmers are of the opinion that the productivity of the pastures has declined.

Better management of common grazing land can greatly contribute to increasing the quantity and quality of fodder. Establishment of area enclosures is a management practice that has proven successful in Ethiopia and particularly in Tigray. An area enclosure can be defined as an area that, for a given time period, is protected from grazing and human activities to allow regeneration of the vegetation. A study in Tigray has shown considerable benefits from area enclosures (Asefa 2001). Estimates based on counting bundles of grass from three different area enclosures showed that 3,200 kilograms of high-quality grass can be harvested per hectare from an area enclosure. A cow of 250 kilograms will need about 2,200 kilograms of dry matter per year. The grass can also be sold at the local market. The value of grass harvested from an area enclosure is about 1,850 birr/hectare. Surprisingly, this is equal to the average value of crop production in Tigray (Pender et al. 2002; Chapter 5). The costs of establishing and surveillance of the area enclosures are moderate. Demarcation costs of the area enclosures are about 186 birr/hectare of land. Each household spends about 5 birr/year for guarding the land. Establishing stone terraces within the area enclosures is estimated at 1,018 birr/hectare, assuming a wage rate of 7 birr/day, 800 meter long terraces per hectare, and one man building on average 5.5 m of terrace per day (Asefa 2001). Additional benefits of the area enclosures are increased biodiversity, less soil erosion, more continuous water discharge from the land, and increased honey production as a result of increased vegetation cover and more flowers. A survey in three villages has shown that 73 percent of the farmers in the area are in favor of establishing new area enclosures on their farms, whereas the other 27 percent objected. Those who responded negatively particularly mentioned reduced grazing land when new area enclosures would be established. Establishment of area enclosures will increase the pressure on adjacent grazing land. This may increase degradation of this area, but experience from Ethiopia (Asefa et al. 2003) and Tanzania (Sianga 1995) has shown that grazing land normally has a high degree of resilience, implying that the vegetation will soon recover if the grazing pressure is removed. More long-term negative effects are therefore not expected. Establishment of area enclosures has been found to be most beneficial in areas with intermediate population pressure (Gebremedhin, Pender, and Tesfay 2004; Chapter 10).

The area enclosures can alternatively be used for tree plantations, albeit at the expense of grass production. The value of grass production in an area dominated by trees was calculated at about 700 birr per hectare. Wood production from an area enclosure is estimated at about 250 m^3/hectare. A cubic meter of wood is sold for about 50 birr, which is equivalent to a value of about 12,400 birr 10 years after the establishment of the area enclosure. A study in the Central Ethiopian highland confirms that households can increase their income substantially by planting eucalyptus on land not suitable for crop production (Holden and Shiferaw 2002). Grass production will be reduced as the tree canopy develops.

Policy Implications

Crop and livestock production are closely integrated in Ethiopia; hence, changes in one component directly affect the other components of the system. We believe that adoption of the zero tillage or reduced tillage system could trigger a change in the crop–livestock system in Ethiopia. Development of zero tillage or reduced tillage is most likely to take place in areas with good market access. Evidence of this is that improved forage production in Holetta area in central Ethiopia was more widespread by farmers with dairy crossbred cows (Gebremedhin, Ahmed, and Ehui 2003). It will be impossible for most farmers to provide good quality fodder both for dairy cows and for oxen used for plowing. Development of dairy production is therefore incompatible with the traditional ox-plowing system. The traditional subsistence agricultural system including use of ox plowing is likely to prevail in areas with limited market access.

Currently the number of oxen is increasing relative to that of cows, and in many regions the number of oxen exceeds that of cows. This composition of the livestock system cannot pay for improved management of fodder resources. Hence, in areas with good markets for milk and meat production, there is an option to change the composition of the livestock accordingly. Development of zero tillage or reduced tillage without accompanying technologies does not suffice. Intensification of crop production will also be of benefit to livestock production. Increased straw yield as a result of crop intensification can be used as a basis for improving livestock production. In order to intensify crop and livestock production, there is a need to develop more site-specific fertilizer recommendations, identify crop varieties and livestock breeds that can profit from increased use of inputs, better veterinary services, appropriate residue management and hay cutting, and improved management of grazing land. However, such fundamental changes in the Ethiopian agricultural production system can take place only when backed by favorable economic policies and an effective extension service. This implies a more market-oriented approach of the farming systems in the Ethiopian highlands.

The policies that can trigger such a change in the agricultural system are favorable price policies for outputs and inputs and strengthening local institutions, particularly in the field of management of natural resources and purchase and sale of agricultural produce. Furthermore, emphasis should be given to the development of an adequate infrastructure, development of local credit institutions, and strengthening research and extension programs. It is particularly important that the government ensure a favorable relationship between grain prices and prices of inputs. This can partly be achieved by regulating import of grain and by encouraging and facilitating donors and NGOs to purchase locally produced grains in disaster situations. Such developments may be encouraged through use of cross-compliance, meaning that access to vital inputs such as credit for fertilizer can be made contingent on installing erosion control measures on eroded land, as proposed by Shiferaw and Holden (2000). Even though results of a household model have suggested favorable returns from such an approach, we believe higher returns can be expected if access to credit for crop and livestock production is made contingent on practice of zero tillage or reduced tillage and change in livestock production objective toward milk and meat. Such a policy measure should be explored, as that might also strongly reduce soil erosion and lead to increases in both crop and livestock production. Zero tillage might also be a more lasting solution to soil erosion control because the maintenance requirements for erosion control measures, such as terraces and stone bunds, are considerable. This approach will also contribute to sequestering soil carbon.

The economic factors that can change the crop–livestock system toward the use of zero tillage or reduced tillage are higher prices of cereals, meat, and milk products and higher opportunity cost for labor. These prices are normally higher in areas with good infrastructure or in the vicinity of urban centers. Prices of agricultural inputs will also be lower in such areas, and access to credit more easily available. Hence, it will be easiest to introduce zero tillage or reduced tillage in areas with good access to markets, and in an early phase of development of a new crop–livestock system, emphasis should be given to such areas. Zero tillage is now rapidly expanding in Latin America, where it is used on more than 14 million hectares (Derpch 1998).

The research and extension system should particularly focus on the development of an appropriate zero tillage or reduced tillage system and on upgrading the quality of straw. These can mutually support each other, thus contributing to the development of more sustainable crop production systems in the highlands of Ethiopia.

The suggestions above for policy changes are very much in line with the five *I*s that IFPRI has identified as factors that promote agricultural growth (Hazell 1999): innovations, infrastructure, inputs, institutions, and incentives. The UN Task Force on Hunger also emphasized improved soil fertility management and diversification of agricultural production with high-value products as key components to increased agricultural productivity for food-insecure farmers (Sanchez et al. 2005).

There is now a possibility through the Clean Development Mechanism under the Kyoto agreement for transfer of funds from OECD countries to developing countries as payment for carbon credits. Governments and community organizations can finance environmental rehabilitation activities and poverty reduction programs through agreements with industries in the North that need to buy quotas for CO_2 emissions. Such arrangements may, in the future, increase farmers' interests in establishment of area enclosures, if parts of the payment for the carbon credits are transferred to the rural communities. It might be possible, therefore, that carbon sequestration projects could finance land rehabilitation in Ethiopia. This is an option to explore in the future. The World Bank launched in 2002 the Community Carbon Fund and the Biocarbon Fund to facilitate the establishment of carbon sequestration projects. The objectives of these funds are to promote small-scale projects that can sequester carbon and at the same time promote sustainable development.

There is an increase in number of oxen to number of cows in Ethiopia, and this development pathway is opposite to agricultural intensification. We have found evidence that an alternative pathway may give increased food production while safeguarding the environment. Such a pathway is characterized by zero tillage or reduced tillage, milk and meat production, improved management of pastures and stover, and improved soil fertility. Such a development can be favored by appropriate price policies, access to credit, and a focus on these technologies in the Ethiopian research and extension system.

Chapter 13

Land Management Options in Western Kenya and Eastern Uganda

Robert Delve and Joshua Ramisch

In the recent past, the image of agricultural and environmental crises in Sub-Saharan Africa (SSA) has become increasingly common. Soil erosion and soil fertility loss are considered to be negatively affecting the productive capacity of the agricultural systems (Giller et al. 1997; Sanchez et al. 1997; Smaling, Nandwa, and Janssen 1997). These problems have been ascribed to many different causes: social (e.g., marginalization of the poor and women), political (e.g., structural adjustment programs), economic (e.g., poor availability and/or high prices of inputs, limited market opportunities), biological (e.g., increasing population and reducing land sizes), and physical (e.g., climatic change).

Many authors also have expressed concern over the increasing land degradation in the highlands of East Africa (e.g., Getahun 1991; Farley 1995; Hilhorst and Muchena 2000). Increases in agricultural production in the last decades have been achieved through intensifying agricultural practices, such as increasing the frequency of cultivation at the expense of natural fallows and through expanding the cultivated areas, especially into fragile environments such as wetlands and steep hillslopes, with negative consequences, including soil degradation from soil erosion and loss of soil fertility.

Blaming smallholder farmers for this degradation is overly simplistic in the least. Tropical smallholder agricultural production systems are, in fact, markedly dynamic and resilient, and many examples exist of adaptations in production practices to cope with and adjust to changes (Brookfield and Padoch 1995; Farley 1995; Goldman 1995). Smallholder farmers use a wide range of agro-ecological management techniques, resource management practices, and production strategies specific to their ecological and social environment to minimize risk and to cope with changes and shocks. These techniques can include agricultural intensification, expanded market orientation, intensification of crop–livestock enterprises, or increased capital and labor investment. However, the natural resource base represents an important capital to small-scale farmers, which will be (over)exploited where production constraints are too high, purchased inputs or labor are scarce or absent, or environmental conditions are too erratically variable for secure investment. For example, if the returns to investments are too low (even negative, as when staple commodity prices plummet during bumper harvests), periodically or repeatedly mining the soil's nutrient capital resource to support minimal levels of production can appear to smallholders as good economics.

Within this context, this chapter uses evidence from research and extension efforts in eastern Uganda and western Kenya to investigate land management, land use changes, and the policy environment within which smallholders have to operate and to assess their influences on smallholder farmers' production strategies. It complements the discussion in Chapter 12 by Aune et al., which focused on land management options being tested in the Ethiopian highlands.

Kenya and Uganda

Uganda is one of the low-income economies in SSA and is among the poorest countries in the world (DANIDA 1996). Kenya is better off and has a higher gross national income (GNI) (Atlas method) of US$340 than Uganda (US$280), but in recent years, the GNI for Kenya has been decreasing at alarming rates (World Bank 2002b). Data for 1997, 2000, and 2001 show changes in GDP of 2.1, –0.2, and 1.1 percent for Kenya and a negative growth forecast for 2002. In contrast, for the same years, Uganda had GDP growth of 4.7, 3.5, and 4.6 percent, with projected growth of over 5 percent for 2002 (World Bank 2002b). In Kenya, agricultural productivity showed negative growth between 1990 and 1994, and throughout the 1990s growth in agricultural output was substantially lower than the population growth rate of 3.4 percent. In both countries, poverty is most pronounced in rural areas. The features of rural poverty are multidimensional and include food shortage, malnutrition of children, frequent illness with high rates of HIV/AIDS, and widespread illiteracy. The distribution of poverty is uneven, with areas in the east and north of both countries being the poorest. In Uganda the proportion of the population living below the poverty line has been declining in recent years, but households engaged in crop farming remain the largest group of the poverty-stricken population, accounting for about 80 percent of the households below the poverty line (Appleton 1998).

Agriculture is the primary source of income for most Ugandans and Kenyans, accounting for around 40–50 percent of GDP, up to 90 percent of exports, and employing approximately 80 percent of the labor force in both countries in 1996 (World Bank 2002b). On average, rural households derive nearly three-quarters of their income from crop farming. Smallholders dominate the agricultural sector with over 90 percent of crop production being produced on farms averaging less than 2 hectares. However, smallholders in Uganda have difficulties obtaining credit for investment and to improve farming techniques. Hence, improving credit access and farmer extension are key recent interventions for boosting agricultural development in Uganda (FAO 1998).

Both sides of the border have similar agro-ecosystems and cropping systems, with eastern Uganda through to western Kenya representing a gradient with changing soil types, from the lowland ferralsols to highland nitisols in Uganda to humic nitisols in western Kenya, with increasing agricultural production and increasing population densities from west to east. This has resulted in a range of land use systems that respond to this gradient.

Eastern Uganda

The eastern Lake Victoria crescent, the southern-eastern Lake Kyoga basin, and Jinja-Mbale Farmlands agro-ecological zones of Uganda comprise Tororo, Busia, Bugiri, Pallisa, Kumi, Soroti, and Mbale Districts, with a population density averaging 129–456 persons per square kilometer (Wortmann and Eledu 1999). They are poorly endowed with natural resources: the soils are sandy, with low soil organic matter levels, highly susceptible to leaching, and consequently low in base saturation and rather acidic. Agriculture in this region shows productivity decline, as the rapidly growing population overexploits its land resources, resulting in recurrent food shortages and occasional famines. The most serious problems faced by smallholder farmers are related to the low land productivity that results in household food deficiencies and to low selling prices for crop products in good seasons (i.e., seasons of bumper harvests).

Western Kenya

The densely populated Western Kenyan districts of Siaya, Vihiga, Kakamega, and Busia share a similar agro-ecology to the Ugandan districts across their common border. Population densities average around 400 people per square kilometer but exceed 1,200 in Vihiga district. Political and economic marginalization of the region has led to widespread rural poverty, resulting in massive outmigration of (especially male) labor on a seasonal or permanent basis. (See Chapter 8 for more information on economic conditions and farming systems in western Kenya). The soils of the region include nitisols and ferralsols that are much more P-deficient than those in Uganda.

Soil Fertility Status

In the 1950s and 1960s soil surveys revealed that about half the land surface in Uganda was rated as medium productive, that is, soils giving good yields under good management (Harrop 1970; Foster 1976, 1981). However, the export of nutrients through runoff and soil erosion and as components of harvested crop products is increasing for most of the farming systems, contributing to the negative nutrient balances reported for Sub-Saharan Africa countries (Smaling, Nandwa, and Janssen 1997) and for the farming systems of eastern and central Uganda (Bekunda and Woomer 1996; Wortmann and Kaizzi 1998; Kaizzi et al. 2002).

It is not possible to accurately assess the economic cost of this nutrient loss, but from work in Ethiopia a conservative estimate of the annual costs of soil nutrient depletion alone is $100 million (Böjo and Cassells 1995). There is less information for the highlands of Uganda and Kenya, but from soil nutrient losses reported elsewhere, the magnitude of the problem is comparable (Stoorvogel and Smaling 1990; Braun et al. 1997).

A recent survey across Uganda showed that between 1960 and 2000, soil organic matter (SOM) content did not decline significantly, and there were no significant decreases in soil N levels. In contrast, levels of P, K, and Ca and soil pH had declined significantly over the 40 years (Ssali 2003). This is a slightly unexpected result, as typically SOM contents decline under cultivation with inappropriate management, and as a result, the C:N ratio widens, indicating lower SOM quality and lower nutrient-supplying capacity (Tiessen, Samprio, and Salcedo 2001). However SOM is never fully exhausted under overcultivation; instead, it is reduced to a lower equilibrium steady state (Buyanovsky and Wagner 1998; Belay, Claasens, and Wehner 2002). To reach that steady state may take many years: starting from virgin land, 10 years of cultivation may lead to a reduction of between 30 and 60 percent in the original SOM content. The level at which the steady state is attained and its trend depend on the measures taken during the cultivation phase and the effectiveness of fallow periods. It is likely that these soils already had reached a low equilibrium level after many years of cultivation before the 1960s.

In traditional tropical farming systems, SOM lost from the topsoil under cultivation was restored during extended fallows. The length of the fallow period would depend on the degree of land degradation and fallow management. However, in most tropical areas, poor land management and increasing pressure on the land rarely allow fallows to restore soil productivity. There is evidence that the rate of SOM loss and hence land degradation during the cultivation phase can be reduced through various management practices, including erosion prevention and minimum tillage (Machado and Silva 2001; Nandwa 2001; Roose and Barthes 2001), strategic use of organic and mineral inputs (Bationo and Buerkert 2001; Katyal, Rao, and Reddy 2001; Nandwa 2001; Belay, Claasens, and Wehner 2002), and other improved systems that exploit the benefits of fallows, biological nitrogen fixation (BNF), rotations, intercropping, and agroforestry (Katyal, Rao, and Reddy 2001; Nandwa 2001; Palm et al. 2001).

Replenishing soil N, P, and K is essential for sustaining productivity and rehabilitating eroded and nutrient-depleted soils. Soil fertility replenishment will result in positive benefits, such as increased vegetative soil cover and increased soil biological activity associated with enhanced crop production (Sanchez et al. 1997). Replenishment of N can be achieved through the use of either inorganic or organic fertilizers and/or BNF. Organic and inorganic fertilizers can mitigate the losses of P and K, and biological options may also improve the efficiency with which crops use these nutrients.

Land Management Technologies

National agricultural research institutions in Uganda and Kenya, in collaboration with international agricultural research centers, have developed an array of management practices and technologies that might effectively address local production problems. These include fertilizer use recommendations, use of legume cover crops, and biomass transfer options (from within or outside the farm) that improve soil fertility and provide fodder.

Fertilizer Recommendations and Limiting Nutrients

Soil fertility characterization studies through limiting nutrient trials have been conducted over many years in the region. Studies in the 1960s indicated profitable responses to applied N and P fertilizers for much of eastern Uganda for cotton, maize, groundnuts, and finger millet (Foster 1976). A recent study in Tororo (Uganda), using maize as a test crop, found large responses to N alone and higher responses to N and P combined (Waata, Jama, and Delve 2002). There was no response to K. These results, confirming those of previous trials (Foster 1976), indicate that N is the main limiting nutrient, followed by P, and that K should be addressed after the N and P problems have been solved.

In Kenya, the Fertilizer Use Recommendation Project (FURP 1995) conducted multisite fertilizer experiments from 1985 to the early 1990s and formulated recommendations for different regions and crops. Unfortunately, these recommendations are not detailed enough to assist smallholder farmers in optimizing their fertilizer use. Even if such recommendations were available, the profitability of fertilizer use is highly variable and dependent on agro-climatic and economic conditions at the local and regional levels (Vlek 1990). Access to fertilizers remains inconsistent and problematic: high unit costs, irregular supply, low cost of commodity crops, and the unpredictable fertilizer quality contribute to the low use of fertilizers by most socioeconomic groups (Heisey and Mwangi 1995; Swinkels et al. 1997).

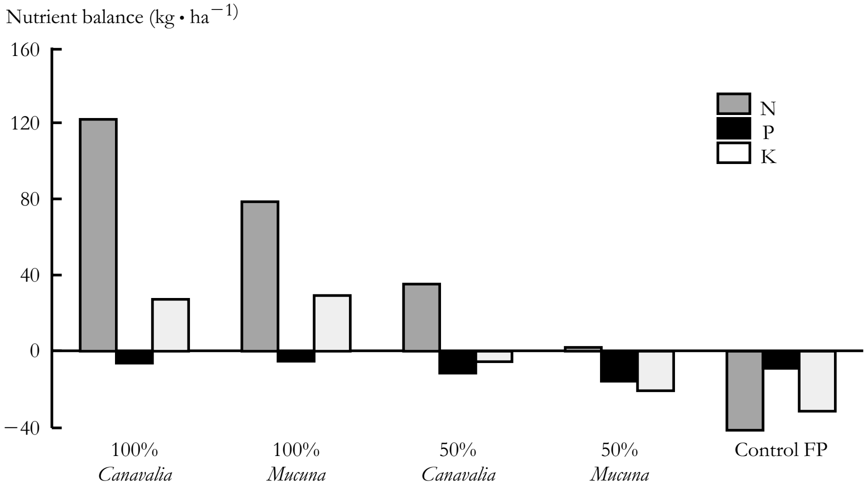
Legume Cover Crops

Legume cover crops (LCC) have been evaluated as a technology for improved land and resource management, appropriate to smallholder farmers with restricted access to inorganic fertilizers. *Crotalaria* species (*Crotalaria ochroleuca* and *Crotalaria grahamiana*) have proven very successful in western Kenya in improved fallow practices. Delve and Jama (2002) reported large increases in maize grain yield following sole crop *Mucuna pruriens* and *Canavalia ensiformis.* In contrasting soils and in contrasting agro-ecological zones of eastern Uganda, Kaizzi, Ssali, and Vlek (2002) also reported similar increases in maize yield following *Mucuna* fallows. However, where *Mucuna* was grown in relay with a maize crop, reduced maize yields as a result of competition for resources between the two crops have been reported (Fischler 1997; Kaizzi, Ssali, and Vlek 2002; Kuule 2002).

At average accumulation rates, green manure or LCC could entirely substitute for inorganic fertilizer N at the current average application rate in low-input agriculture systems (Becker, Ladha, and Ali 1995). Kaizzi (2002) showed that, in eastern Uganda, because approximately 43 percent of the plant N in *Mucuna* is derived from BNF, that BNF could contribute to the N requirements at moderate levels of output under favorable conditions (Giller et al. 1997). However, the N fixed by LCCs during the fallow period may not be a net addition to the system if increases in the yield of subsequent crops remove more N than was added by the legume. The excess applications of N in the LCC biomass above crop demand will be subject to losses (such as leaching or denitrification) during decomposition, especially during the early stages of crop growth, when N demand is not synchronized with release from decomposing LCC residues.

In eastern Uganda, results show that incorporation of legume cover crops in situ implies excess supply of N and K that is not matched by plant demand (Fig. 13.1). For example, incorporation of 100 percent of the above-ground biomass

Figure 13.1 Macronutrient balance for maize, grain, and stover production following incorporation of 50 or 100 percent of the above-ground biomass of a one-season sole crop fallow of *Mucuna* and *Canavalia*



Source: Delve and Jama (2002).

after a single season of improved fallow planted with *Canavalia* leads to a positive nutrient balance of more than 120 kg/ha of N and 30 kg/ha of K. An improved fallow using *Mucuna* also leads to positive nutrient balances of N and K if all of the biomass is incorporated. This is confirmed in another study carried out within the same agro-ecological zone, where dry matter and N loss by *Mucuna* was over 90 percent within 175 days (Kaizzi 2002). Management of the fallow rotation then becomes critical to maximize utilization of the resources, prevent nutrient losses, and provide enough nutrients, especially N, to maintain crop yields. This can be achieved, for example, through the use of deep-rooting species that can recover nitrate leached deeper into the soil profile.

Alternatively, Delve and Jama (2002) found that incorporation of either 50 percent or 100 percent of the LCC biomass produced in situ resulted in yields of maize grain and stover that were not significantly different from each other. This finding offers farmers alternative options for managing this technology, such as producing the biomass in one place, where half could be incorporated and the other half applied on an equivalent area for maize production. Alternatively, farmers might want to use 50 percent for incorporation and the remaining 50 percent for livestock feed, sale to other farmers, or to produce hay. Increasing the resource management options, and therefore the production options of the farming enterprise, is critical where the land area for nonfood crop production is limited and where cash is not readily available to buy inputs for crop and livestock production.

P Replenishment

Phosphorus availability is a major limiting factor for crop production on many soils of western Kenya because of both a low P content in the soils and their high P-fixing capacity (Mutuo 1999). Options available to farmers include the use of locally available rock P, inorganic fertilizers, and organic sources, such as *Tithonia diversifolia,* as P sources for crops (e.g., Buresh, Smithson, and Hellums 1997; Smithson et al. 2001; Mutuo et al. 1999). In addition to increasing P supply, farmers can improve the nutrient use efficiency of phosphorus fertilizers by crops, such as combining P fertilizers with organic residues.

Results of research on a P-fixing nitisol in western Kenya to study possibilities of replenishing soil P through addition of P fertilizers show that large, single applications of 150 kilograms P per hectare resulted in low nutrient use efficiency of applied fertilizers. More modest seasonal applications of 25 kilograms P per hectare increased maize yield and gradually increased available soil P, whereas the smaller rate of 10 kilograms P per hectare resulted in soil P depletion. These results show potential promise for seasonal application of small amounts of P fertilizers, which would be suitable for the small-scale farming systems of western Kenya (Nziguheba, Merckx, and Palm 2002). In another study, annual application of 1.8 tons DM per hectare of Tithonia applied to a P-deficient soil for three seasons at two sites resulted in maize yields consistently comparable and sometimes better than the maize yield following application of an equivalent amount of N in the form of mineral fertilizers (Jama et al. 2000).

Biomass Transfer with *Tithonia diversifolia*

A further option for land management to increase productivity is biomass transfer. For example, *Tithonia diversifolia,* common in hedgerows and along roads in western Kenya and eastern Uganda, is able to accumulate P and K in higher concentrations in its plant parts compared to other plant species and has shown good potential as a nutrient source for soil amendment. In western Kenya, *Tithonia* leaves (a high-quality resource) and maize stover (a low-quality resource) were applied alone or in combination with triple-super-phosphate (TSP) at a rate of 15 kilograms P per hectare. All treatments increased maize yields relative to the control, and yields increased in proportion to the amount of *Tithonia* in the residue–fertilizer mix where at least 36 percent of the total P applied in the mixture was supplied by *Tithonia* (Nziguheba, Merckx, and Palm 2002). Although the collection of *Tithonia* is highly labor intensive (roughly four minutes work per kilogram fresh matter), the economic returns were higher from the application of *Tithonia* alone than from sole fertilizers. Profitability was higher if *Tithonia* was collected from existing niches (to reduce labor costs) than when produced off site. Because the *Tithonia* gave higher net economic returns than equivalent rates of P in inorganic forms, it would appear that a high-quality organic input is as economically efficient (or more so) than inorganic fertilizers as a means of increasing maize yield and of supplying P to crops. The combination of *Tithonia* with fertilizers can be a beneficial use of scarce resources, with the greatest benefits in terms of yields and net benefits obtained by maximizing the proportion of *Tithonia* in the mixture.

One disadvantage of this management practice is that biomass transfer of *Tithonia* represents redistribution of nutrients within the landscape. At farm level, this practice is beneficial if the biomass originates from off-farm sources, but where the biomass is produced on-farm, it will lead to nutrient mining in one area and enrichment in another.

This technology is now being adapted on-farm. Because *Tithonia* decomposes quickly, many farmers in western Kenya now consider it more like a fertilizer (i.e., immediate effect, with little residual) and therefore less attractive than "farmyard" manure (compost of animal, household, and crop wastes), which "builds the soil fertility" for the long term. Increasingly, *Tithonia* is being taken directly to compost piles to "speed the rate of cooking" (i.e., decomposition) in the compost heap.

Soil Fertility Maintenance in Crop–Livestock Farming Systems

As discussed, maintenance of soil fertility is a key issue in agricultural intensification in Africa. When a mixed farming system is considered, the constraints to soil fertility replenishment become more severe because of competition between the allocation of land for crop production and livestock feed production. Farmers therefore must make choices in terms of resource allocation on their farms. Should the limited organic resource (available on-farm or purchased) be added directly to the soil, for example, through biomass transfer from farm boundaries and contour strips or additions of crop residues, or should the organic material be fed to livestock and then the manure added to the soil?

Intensification under the influence of increased pressure on the land restricts availability of manure from pastoralists and forces arable farmers to keep their own livestock for manure production, but many farmers do not possess suitable feed resources. Low digestibility, low protein content, and hence low intake, limit the utilization of many feed sources by ruminants. The option of treating the fodder with, for example, urea or alternatively supplementation with protein-rich concentrates is not available to all farmers, and where concentrates are used, they are fed mostly to lactating animals. The limited availability of high-quality feed resources will also encourage supplementation of livestock feeds, and as a result, there is increasing interest in the use of legumes as supplements to improve diet quality, provide additional dietary nitrogen, and provide better-quality manure (Savadogo 2000).

Within extensive livestock systems there is no direct return of manure to food cropping areas, as all manure is left on the grazing lands. However, manure deposited where the animals are housed overnight can be more readily collected and used. Animal production systems are inefficient converters of feed into animal products. A large fraction of the nutrients ingested in the feed is not retained in animal products but is excreted in feces and urine. This is particularly true of nitrogen, phosphorus, and potassium. In many mixed farming systems of the tropics, these excreta, when collected, represent the sole source of nutrients. The issue then is to capture these excreted nutrients by returning the maximum amount of manure to the cropland and through optimal management of the manure.

Closing the Nutrient Cycle

Integration and intensification that reduces the spatial separation of crop and livestock production systems offer the possibility of increased nutrient capture and recycling, such as converting crop residues into animal products and manure. As a result, a proportion of the nutrients that would otherwise be exported off farm, if that part of the crop were sold, can be returned to the soil in the form of manure, thus reducing nutrient losses. Losses in the crop-livestock-soil nitrogen cycle occur through leaching and denitrification, but most N is lost through volatilization of ammonia from feces and urine. The rapid loss of N from excreted urine means that it should preferably be applied to crop land immediately; unfortunately, very few farmers own facilities to collect and efficiently utilize this N, and hence, it is lost from the farming system. As more livestock are confined on-farm and are increasingly housed within limited- or zero-grazing units, manure collection should become more feasible (Ayantunde 1998). Manure management then becomes of paramount importance in these systems to optimize its use as a source of nutrients. However, in many areas, manure availability is insufficient to replace removed or lost nutrients, and inorganic fertilizers will be needed to maintain soil fertility.

Cycling of biomass through animals into manure that is used to fertilize the soil provides an important link between livestock and soil productivity in many farming systems of SSA. Many crop residues are characterized by high carbon and lignin contents, decompose slowly when added to the soil, and can immobilize available soil N during decomposition. Feeding of such residues to livestock can increase the rate of nutrient turnover through reduction in the immobilization of soil N and hence increasing its availability (Delve et al. 2001). Much of the feed offered to livestock is imported from off-farm sources, for example, roadside grasses and purchased concentrates, which form net imports of nutrients into the farm. Night housing and zero-grazing systems are examples of how improved livestock management practices can increase the amounts of manure and hence nutrients available to the farming system, provided the manure can be collected and utilized efficiently.

Economics of Land Management

Technologies for soil fertility replenishment often increase labor requirements and require more careful management (Kanté 2001), and options such as LCC or biomass transfer may withdraw land from agricultural production for varying periods of time, all of which represent economic costs to the smallholder farmer. Combinations of these technologies with inorganic fertilizers also increase the required capital investments. The returns to investment in these technologies vary enormously and are very sensitive to variations in the farm-gate prices of crop products.

For example, although LCC have given significant yield increases in the following maize crop, often these increases do not compensate for the loss of the one season of maize production or are insufficient to warrant the additional management and labor costs. As a result, technologies such as LCC will be appropriate only under specific conditions. In areas of high population density and consequently a high demand for cropping land every season, such as Vihiga in western Kenya, adoption of LCC is unlikely, even if the associated yield increases would compensate for the loss of maize production during the fallow. Alternatively, where population density is lower and natural fallowing still exists, such as the southern and eastern Lake Kyoga basin of eastern Uganda, the potentials for increased yields following improved fallows have been demonstrated and may be sufficient to promote adoption. The advantages of LCC are best utilized where land is out of production because of low fertility or high pest or disease pressures or where it would be left idle in a natural fallow system. In addition, the significant increases in maize stover production provide additional options for farmers, as stover can be used in livestock feed or bedding, soil erosion control, compost making, or mulching in perennial crops.

Agro-ecology also will influence the acceptability of alternative technologies. Positive economic benefits were recorded for most N replenishment strategies on highly productive soils in high-potential agro-ecological zones of eastern Uganda, but only *Mucuna* relay was profitable on low-productive soils (Kaizzi, Ssali, and Vlek 2002). In low-potential agro-ecological zones, none of the fertilizer-based strategies were economically viable at the current fertilizer and commodity prices on the less-productive soils, nor were the current farmers' practices. For the more-productive soils in low-potential zones, farmers' current practice is as profitable as alternative cropping strategies, but at lower production levels. Thus, there is no incentive for farmers on poor soils to adopt the alternative strategies under current conditions, even though current practice is itself not sustainable.

Opportunities and Constraints for Land Management Technologies

Improving soil fertility management options also means improving the access of farmers to new options by increasing their access to information from multiple sources. This greater access to a wider range of species and products gives farmers more flexibility in selecting management options and in decisionmaking as well as more opportunities to diversify their livelihoods or to pursue market-oriented activities. These technologies and the underlying knowledge have not been disseminated adequately to farmers and, therefore, still have had little effect at the farm level. Consequently, agricultural productivity is still declining in most of the smallholder farming systems. Although many studies have identified the need for improved dissemination of knowledge (e.g., Semalulu, Akwang, and Nakileza 1999), it is increasingly recognized that the best approach is active participation by farmers, local administrators, and the communities in general (Defoer 2000).

However, an assumption in developing new technologies is that providing farmers with "better information" leads them to make "better choices." It is also implicit that farmers' current choices are suboptimal. Nevertheless, the current strategies often appear optimal to land managers, given their current knowledge and resources. Hence, to be successful, interventions should increase soil productivity and potentially be profitable but also address the production objectives of the households and respond to the farmers' own understanding of the risks and opportunities of different options. Alternative technologies must address farmers' priorities of food security without creating additional risks and must also acknowledge constraints on the availability of land, labor, and inputs such as fertilizers and seed.

Because most resource-poor farmers need to produce a food crop every season, they are understandably reluctant to invest present resources for only the possibility of future increased production. As a research farmer in Emuhaya, Kenya, commented, "It's better to have even one *gorogoro* [tin] of maize [from a depleted field planted with maize] than to be guaranteed no maize at all this season by planting a cover crop we can't eat."

Farmers also often cite the increased labor requirements for incorporating LCC or collecting biomass as major constraints. In western Kenya schoolteachers have been found to use the "free" labor of children to harvest *Tithonia* to apply to school plots. Without access to this labor, it is unlikely that most farms could manage to apply *Tithonia* at the recommended rate, because each hectare demands up to 370 days of labor, compared to 1–7 days per hectare to apply an equivalent amount of nutrients in the form of manure or inorganic fertilizer (Mango 2002). Finally, new technologies must contend with problems of supply: the irregular availability and quality of seeds for LCC species is often mentioned by farmers, and in communities where the use of *Tithonia* in biomass transfer systems has become popular, its availability also becomes problematic.

In general, replenishing soil fertility remains problematic without understanding farmers' problems. Addressing these problems requires research at the farm level, including natural and man-made heterogeneity at plot and subplot levels (Braun et al., 1997; Kanté 2001). By working through progressively reduced scales, from region to district and then to farm, and through focusing on successively finer detail, understanding of production conditions and constraints can be increased (Carter et al. 1994). Similarly, gender and other intrahousehold differences play a role in resource control, resource use, and decisionmaking that will not necessarily become apparent if the only consultations are with the "household head." Technologies are not neutral in their impacts, and some individuals or groups will benefit more than others. The use of *Tithonia* on kales in western Kenya, for example, has led to increased productivity, but at the same time it has been observed that although women continue to grow kale for home consumption, men are beginning to commercialize plots of kale to increase their own personal incomes.

Chapter 14

Policies for Poverty Reduction, Sustainable Land Management, and Food Security: A Bioeconomic Model with Market Imperfections

Stein Holden, Bekele Shiferaw, and John Pender

Ethiopia is one of the poorest countries in the world, and its population of more than 70 million people lives mostly in the highlands. The food security of these people is threatened by land degradation and droughts that cause declining and highly variable land productivity. Changes in the global climate may also have caused an increase in the incidence of drought that has occurred recently in areas that were not affected by the earlier droughts. Along with a history of social conflict and unrest in the country, poor governance and misplaced government policies have contributed to the vicious spiral of poverty, land degradation, and food insecurity. There is a strong need for peace, better governance, and improved policies that can help break the Malthusian development path and put communities onto more sustainable development pathways where poverty is reduced and food security is improved. Especially, there is an urgent need for pro-poor alternative development strategies that address land degradation and food insecurity in less-favored areas where drought risk is higher and/or market access is poorer.

Market imperfections tend to be severe in rain-fed tropical agriculture because of the basic material and behavioral conditions, including spatial dispersion, seasonality, covariate risk, poor infrastructure, and moral hazard (Binswanger and Rosenzweig 1986) as well as because of policy distortions and social unrest. Policy reforms aiming at improving the functioning of markets may therefore be one important element in a new policy for sustainable development. Still, there is no guarantee that piecemeal improvements of some markets will lead to economic growth and more sustainable land use. It is even possible that improved access to some markets can lead to more land degradation. This is also consistent with the theory of second best (Lipsey and Lancaster 1956).[1] Both the mixture and sequencing of policies may matter for the outcomes.

Policymakers and technology development institutions have for a long period of time neglected less-favored areas. The International Food Policy Research Institute (IFPRI) has challenged the conventional wisdom that public investments in developing countries should emphasize investment in favored areas because of diminishing returns to investments in these areas and high concentration of poverty and natural resource degradation problems in less-favored areas (Fan and Hazell 2000; Pender and Hazell 2000; Hazell et al. 2002). Based on a comparative advantage argument, Pender, Place, and Ehui (1999) argue that certain types of agricultural and nonagricultural activities can give high returns and contribute significantly to poverty reduction and improved natural resource management in less-favored areas. More research is, however, necessary to investigate how big this potential is.

Stimulation of crop production through provision of credit for adoption of fertilizer has not been very successful in less-favored areas of Ethiopia, however (e.g., see Chapters 5 and 9). This has led to increased interest in alternative activities, including development of livestock production, tree crops, forestry, small-scale irrigation, and nonfarm activities.

We have in this chapter developed a bioeconomic model for a less-favored, severely degraded, densely populated area with fairly good market access in the Ethiopian highlands. The study area was chosen because of the unusual availability of biophysical empirical data on land degradation and the effect of alternative conservation technologies from the research carried out by the Soil Conservation Research Project, beginning in the early 1980s. Combined with our own household panel data from three survey rounds in 1994, 1998, and 2000, including very detailed farm plot-level data, we had a very good basis for developing bioeconomic models for the area. We use the models to assess the effects of alternative policies to reduce poverty, increase food security, and promote more sustainable land use in the study area. Specifically, we assess the (1) effect of improved access to off-farm income and credit for fertilizer, (2) effect of access to food-for-work (FFW), and (3) effect of promoting planting of eucalyptus on land unsuitable for crop production on household welfare, agricultural production, conservation investments, and soil erosion.

In the second part of the chapter we give a brief description of the case study area. The structure of the bioeconomic model is briefly described in the next part, and the results of the model simulations are presented and discussed in the fourth part, followed by the conclusions.

Description of the Case Study Area and Data

Andit Tid is located approximately 60 kilometers east of Debre Berhan, along the main road between Addis Ababa and the Tigray Region, in East Shewa in the Central Ethiopian Highlands. This implies that the market access is fairly good. The area is classified as belonging to the low-potential cereal–livestock zone and is severely degraded. It is a high-altitude area (> 3,000 meters above sea level). The land is located in two altitude zones: *dega* zone (< 3,200 meters above sea level) and *wurch* zone (> 3,200 meters above sea level). The average rainfall is 1,336 millimeters per year distributed over two growing seasons, the *meher* season from June to November and the *belg* season from January to May. Droughts have not been common in the area until very lately when the *belg* rains have failed in two consecutive years (1999 and 2000). Hailstorms and frost have, however, commonly damaged crops.

Yohannes (1989) estimated 75 percent of the land to be on steep slopes (>25 percent slope). Soil erosion rates in the area are very high, and a large share of the land has shallow soils, causing reduction of soil depth to affect crop rooting depth and thus yields (Shiferaw and Holden 2001). Holden and Shiferaw (2000) estimated 21 percent of the land to be shallow (<30 centimeters soil depth) and 48 percent to be of medium depth (30–60 centimeters).

Various forms of conservation technologies are common in the area. They have partly been introduced through external FFW programs. Some of the exogenously introduced conservation structures have later been removed by the farm households. Shiferaw and Holden (1998) found that human population pressure (land scarcity) increased the probability that conservation structures were partly or fully removed. The reasons for this were thought to be that the conservation structures did not contribute to increased yields in the short run, they occupied some land and therefore reduced the effective planting area, and they collected fertile soils that could be used to increase short-run production by dismantling the structures and spreading out the soil collected there. The structures could also harbor rats that may damage the crops.

The main crop in the area is barley, followed by wheat, horse bean, and field pea. Lentils and linseeds are also commonly grown. Most of the crop production takes place in the *dega* zone, but barley is also grown in the *wurch* zone in the *belg* season.

Cattle and sheep are the dominant types of livestock, but goats, equines, and chickens are also common. The animal population density is very high in the area: Yohannes (1989) estimated it to be 1.48 TLU (tropical livestock units) per hectare against 0.36 as the average for the Ethiopian highlands. We found this density to have increased to 2.03 TLU per hectare in 1998, but it declined to 1.71 by the end of 1999 as a result of the drought (Holden and Shiferaw 2000).

The human population density was estimated to be 145.5 persons per square kilometer in 1986 against the average of 61 persons per square kilometer for the Ethiopian highlands (Yohannes 1989). The population density was 230 persons per square kilometer of cultivable land. The population growth rate was estimated to be 3.0 percent per year, indicating high and increasing population pressure in the area.

Production of crops and livestock are well integrated in the area. Oxen are the dominant source of traction power. Hand cultivation is used only on very steep slopes inaccessible by oxen. Animal manure is used for fuel or as fertilizer on crops. Sale of animals is an important source of cash income. Crop residues are used as animal fodder. Fodder is otherwise obtained from fallow land and grazing land, but only a small share of this (5 percent) is from communal land. Fodder shortage is an important constraint, and purchase of fodder and use of a cut-and-carry system are the main strategies to overcome this problem besides limiting the number of animals kept (Holden and Shiferaw 2000).

The land resources are fairly evenly distributed in the area because of land reform and frequent land redistributions in Ethiopia, where land was allocated to households based on household size. Livestock wealth is therefore a better indicator of household wealth and wealth differentiation than land ownership. Particularly, ox ownership signifies the farming capacity of households because the rental market for oxen for plowing is highly imperfect (Holden and Shiferaw 2000; Holden, Shiferaw, and Pender 2001). It also leads to the typical pattern in which households without oxen rent out land to households with two oxen or more, whereas households with one ox exchange oxen among themselves. Land renting typically takes place in the form of share tenancy, where the share to the owner varies between 0.5 and 0.25, depending on land quality. Households may have access to credit in kind for purchase of fertilizers but are reluctant to take this kind of credit even though it appears profitable to do so. Risk and high aversion to this type of risk cause households to be reluctant to buy fertilizer on credit.

Households have limited access to off-farm income sources; crop production is highly subsistence oriented, but the trend during the last 20 years has been from households being net sellers of food grains to now being net buyers. The recent droughts have even made the area dependent on food aid (Holden and Shiferaw 2000).

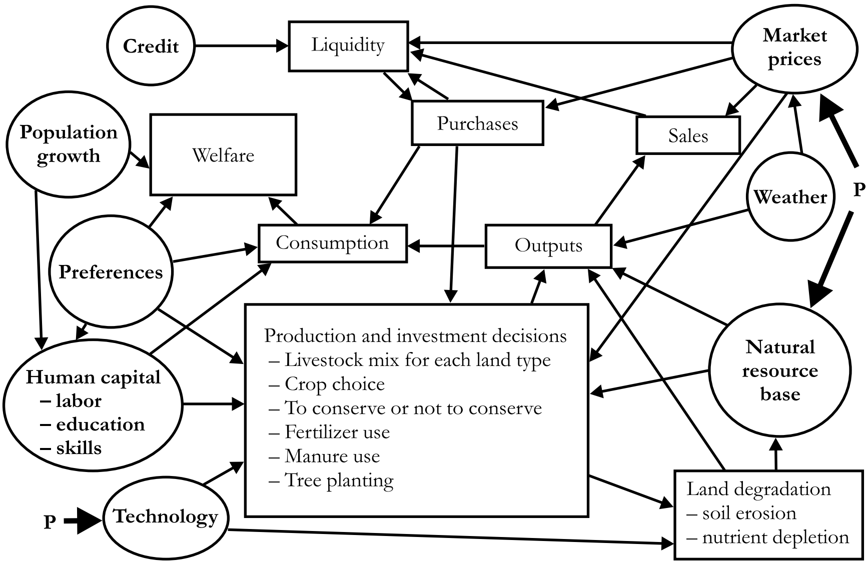
The development trend in the study area appears to be similar to that in other parts of the less-favored Ethiopian highlands, although it was less severe in the past than in South Wollo, for example (which has lower elevation and lower and more erratic rainfall than our study area) (Ege and Aspen 2003). Ege and Aspen find that households with oxen are generally poor, and even if they manage to sharecrop in land, this does not lead to wealth accumulation. Ege (2003a) finds that ox owners are usually poor and likely to grow poorer. Ege (2003b) finds that ox owners can be able to obtain extra land through sharecropping, but the costs of keeping oxen and the costs of renting land are so high that these “rich” households remain poor by any normal standard. Aspen (2003) also finds that informal sources of credit exist among close relatives and friends and semiprofessional money lenders, but he finds no evidence of money lending leading to accumulation of wealth by richer farmers. Devereux and Sharp (2003) have also found that the incidence and severity of poverty are increasing over time in Wollo, indicating a deepening livelihood crisis in this part of Ethiopia. Various studies in Wollo confirm the similarity in terms of limited off-farm employment opportunities and low income-generating potential (Holt and Dessalegn 1999; Devereux 2000; RESAL Ethiopia 2000; Yared et al. 2000). According to Devereux and Sharp (2003), there are some improvements in off-farm opportunities as a result of greater freedom of trade and population movement, improved roads, and new construction work on government offices, schools, and clinics. However, they find that the supply of labor far exceeds the demand.

The Bioeconomic Model

This model is an extension of the model developed by Holden and Shiferaw (2004) that was used to analyze the effects of land degradation, drought, and price risk and the suitability of the standard fertilizer-credit extension approach in the study area. The main expansion of the model presented here is that it looks at alternatives to the traditional fertilizer-credit development strategy in the form of off-farm income, FFW, and tree planting. Whereas the previous models were run for a simulation period of 5 years, these new models were run for a 10-year period. A detailed technical description of the model can be found in Holden, Shiferaw, and Pender (2005). Other published papers based on the model include Holden, Shiferaw, and Pender (2004) and Holden, Barrett, and Hagos (2006). Holden et al. (2003) provide a more detailed analysis of policies and poverty effects of investments in on-farm tree planting.

A simple conceptual representation of the model is presented in Figure 14.1. Households are maximizing their welfare (measured as utility of certainty equivalent full income) subject to many constraints. The model is a dynamic, nonlinear optimization model. For example, land degradation in the form of soil erosion and soil nutrient depletion is endogenous in the model, as it is affected by household production and investment decisions. Furthermore, soil erosion affects soil depth that affects yields and output in succeeding years, which affects income and welfare

Figure 14.1 Main components of bioeconomic household group model



in future years.[2] Weather risk affects production as well as prices, and this may again affect production decisions. Households make production decisions based on expectations about prices and output and the risk involved. Imperfections in markets[3] affect production decisions and cause nonseparability of production decisions from consumption decisions. Households in the study area were divided into groups based on ox ownership because oxen are used for land cultivation and represent a very important wealth indicator.[4] Population growth affects both the labor force and household welfare as more people have to share the outcome of a constant land area that also is affected by land degradation. This leads to a Malthusian development path when technology, prices, and other exogenous factors are constant. This poverty-environment trap can be broken only through availability of new technologies, improved access to markets, and better investment opportunities.

Results and Discussion

Effect of Improved Access to Off-Farm Income

Ten-year models were developed to explore the effect of better access to off-farm employment on household welfare, agricultural production, conservation incentives, and soil erosion. The results are presented in a set of graphs in Figure 14.2. The risk of drought in these models was low (10 percent), and so was the level of risk aversion. Higher risk and risk aversion caused infeasibilities when the time horizon was expanded much beyond five years.[5] Because of population growth, the land constraint, and land degradation, income per capita would fall by 8 percent over a five-year period when there is access to credit and by 16 percent when there is no access to credit. We did not manage to get the bioeconomic model to solve for a period of 10 years when access to both wage employment and credit are restricted at very low levels. This is indicative of the precarious situation faced by households in the study area. The income per capita would be lower and decline much faster than for the scenario with access to credit, given in Figure 14.2. This illustrates the severity of the combined effects of land degradation, increasing population pressure, stagnant technology, and drought risk in the study area. Households are becoming increasingly dependent on better market access for off-farm employment, selling of crop–livestock products, or assistance from the outside in case of adverse conditions.

We see furthermore that the hypothetical case of unconstrained access to wage employment at the going wage rates in Andit Tid would have substantially improved household income in the area. The fact that households have low levels of off-farm income (Table 14.1) demonstrates that there are insufficient local employment opportunities and entry barriers[6] in relation to getting wage employment in distant areas. Otherwise, households in the study area would have worked much more outside the farm given their small farms and the risks of agricultural production. Provision of better employment opportunities for unskilled labor (at low wages) may substantially improve household income.

We now look at how different market access conditions affect the agricultural production over time. Households without access to off-farm wage employment cultivate more of their land because they have a lower opportunity cost for family labor. Unconstrained access to credit but not to off-farm employment creates more incentives for land cultivation than both having access to credit and off-farm employment. Agricultural production is continued on a larger area for a longer period of time when households have access to credit only. The effect on livestock capital of households under the different market access conditions is such that households with access to credit only build up and hold more livestock than households with access to off-farm employment (with or without credit constraint). There is a downward trend in livestock capital over the 10-year period, however, and this may partly be explained by a decline in fodder production.

Households with unconstrained access to credit (but not to off-farm employment) remain net sellers of crops in years with good rains for most of the 10-year time period. The surplus declines over time, however, and turns into a net deficit in

Figure 14.2 Effects of improved access to credit, off-farm employment, and both credit and off-farm employment

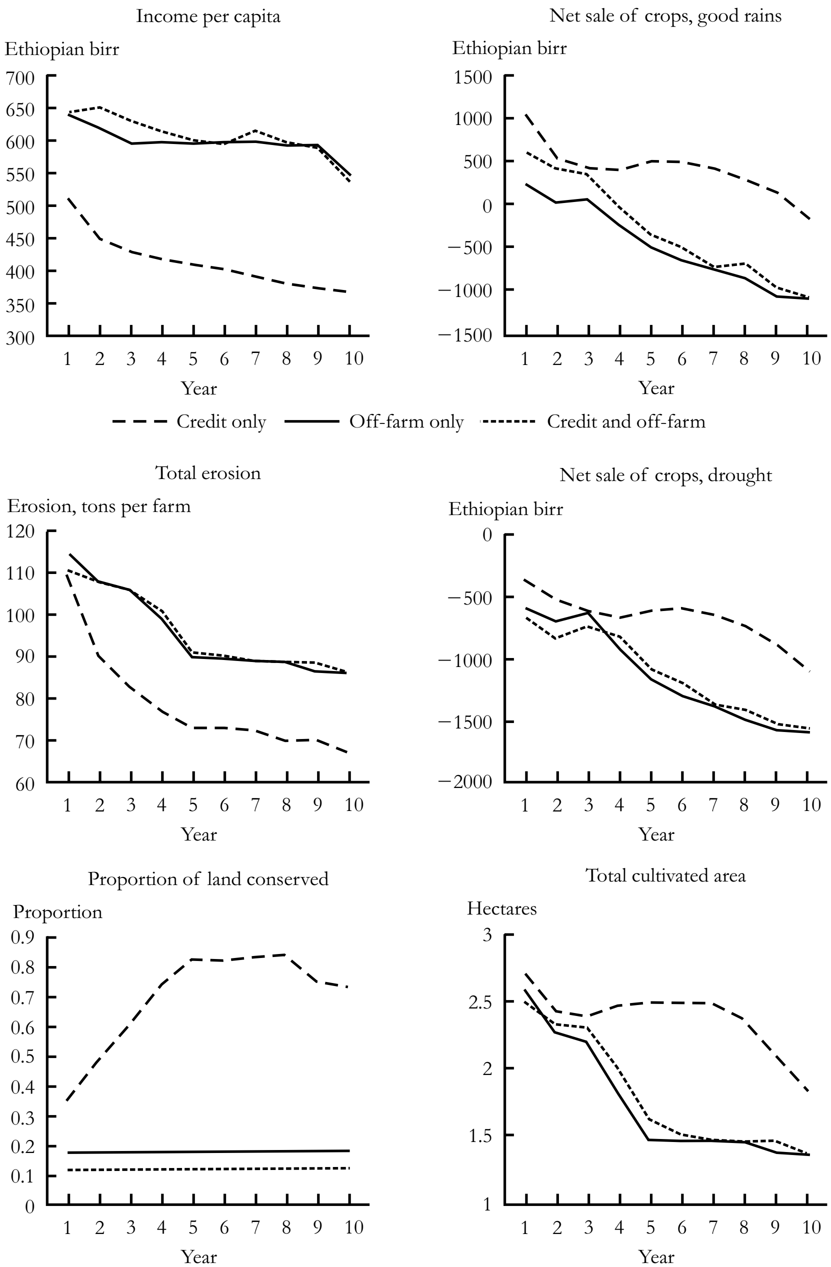
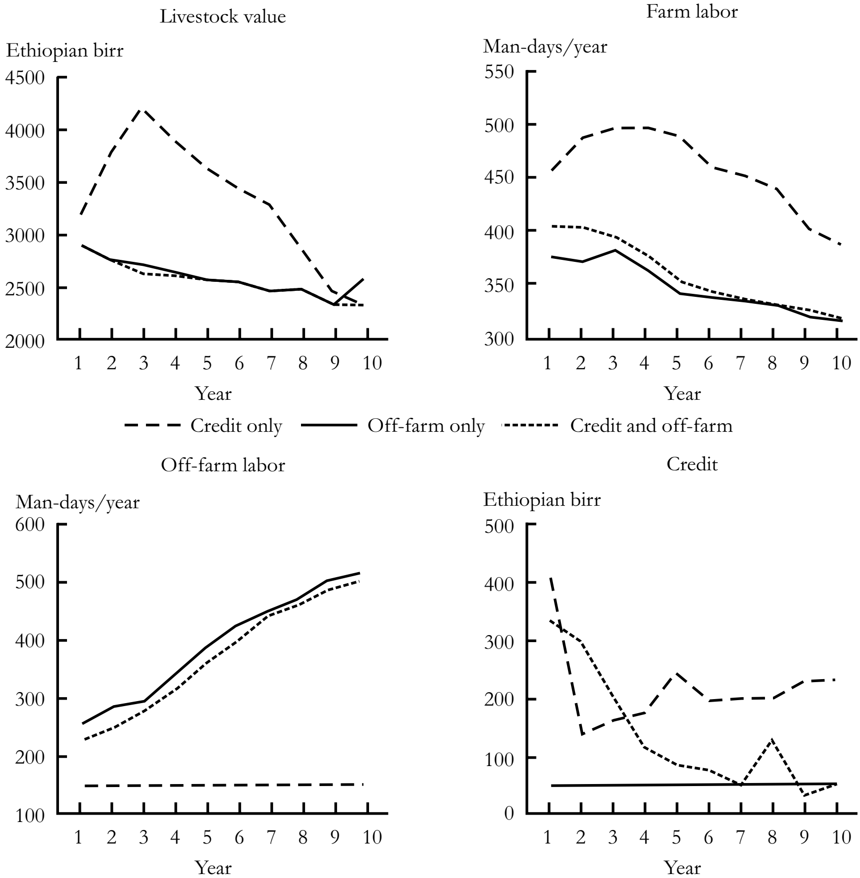


Figure 14.2 (continued)



the last year. Households with access to off-farm income gradually become deficit producers of food crops even in years with good rainfall, and the deficit grows to more than 1,000 kilograms of grain per household by the 10th year. Unconstrained access to off-farm income also reduces the demand for credit for purchase of farm inputs over time.

Households with unconstrained access to both credit and off-farm wage employment also gradually become deficit producers of food crops. They produce more food grain in the initial years than households with unconstrained access to off-farm wage employment only, but they have a more rapid decline in food grain production and have after 10 years a deficit as large as those with unconstrained

Table 14.1 Average income by source and household group in Andit Tid, 1999

	Number of oxen in household		
Income source	**0**	**1**	**2 or more**
Wage income	152	15	85
Remittance income	38	38	37
Common property resource income	44	25	35
Business income	80	60	44
Food aid	463	586	547
Farm income[a]	458	402	509
Total income	1,236	1,125	1,244

Note: Values in Ethiopian birr.

[a]Cash income only. It does not include the value of crops or livestock products that were produced and consumed by the household during the year. The year 1999 was a drought year, causing total failure of crop production during the *belg* season.

access to off-farm income only. Better access to off-farm income therefore reduces incentives to produce crops and produce a surplus or be self-sufficient in food grains. The pattern is very similar in drought years (net sale with drought), but then all households are deficit producers. The deficit increases from about 400 to above 1,000 kilograms of grains for households with unconstrained access to credit over the 10-year period, whereas it increases from 600 to above 1,500 kilograms for households with access to off-farm wage employment (with or without access to credit).

Households with unconstrained access to credit put much more labor into farming than households with unconstrained access to off-farm income. Access to credit does not help much for the incentives to work on the farm when there is unconstrained access to off-farm wage employment, showing the higher relative returns to family labor off-farm. The demand for off-farm employment increases steadily with the growth in the family labor force and the fall in agricultural productivity and thus labor input into agriculture.

Households with unconstrained access to credit had more incentives to conserve their land and conserved proportionally much more of it than households with unconstrained access to off-farm wage employment. Households with unconstrained access to credit and off-farm wage employment conserved even a smaller share of their land than households with unconstrained access to off-farm wage employment but not credit.

The consequences of this for land degradation on the typical farm was that even though households with off-farm employment cultivate small land areas (have less intensive agricultural production), their activity causes more erosion than that of households with access to credit because they conserve a much smaller proportion of their farmland. It appears, therefore, that provision of better off-farm employment opportunities does not necessarily provide win-win benefits, as the natural resource base may degrade as a result of neglect.

Effect of Introducing FFW Programs

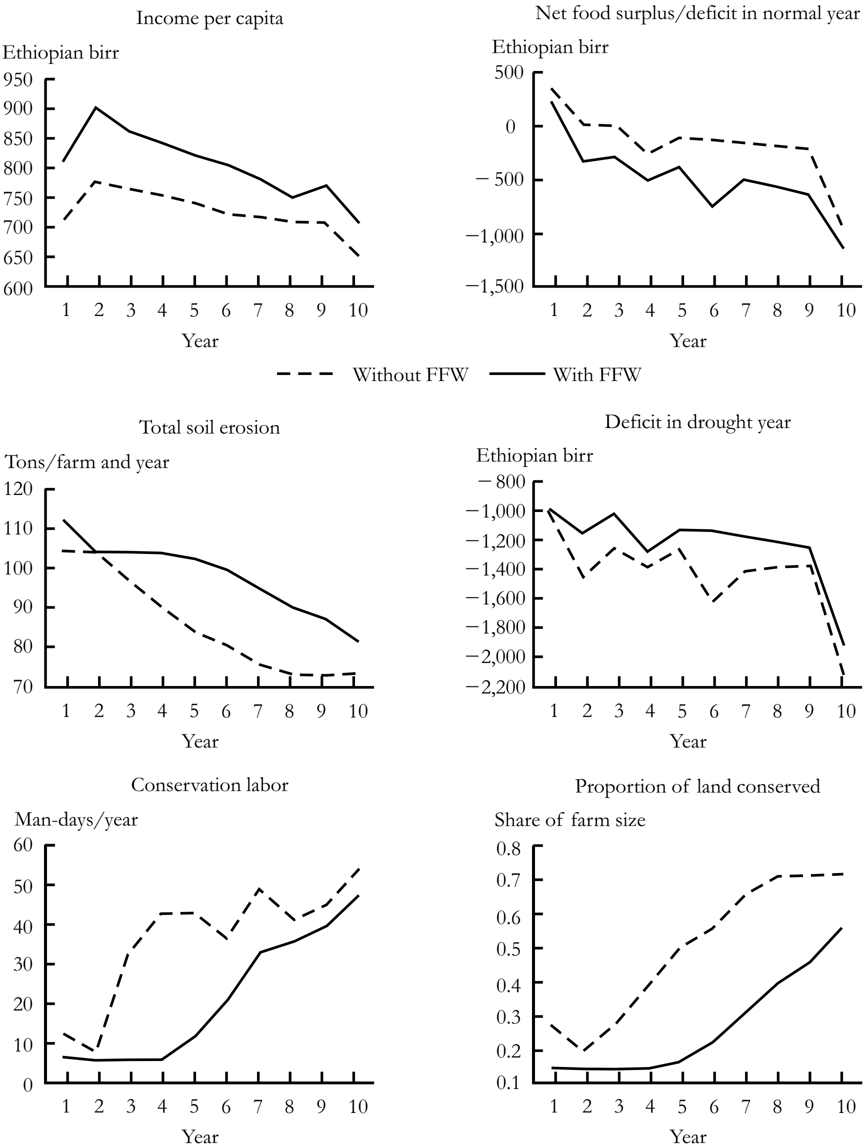
Food-for-work (FFW) programs have been widely used to target food insecure people and to promote development in various parts of Ethiopia. FFW was also used to establish conservation structures in Andit Tid in the early 1980s. This was done through a top-down approach that did not involve local people in planning or organization. The farm households themselves therefore had no say with respect to choice of conservation technology or how it was fit into the landscape on their farms. This caused many to reject the technologies, and many were found to have partly or fully removed these technologies on their farms (Shiferaw and Holden 1998). This may also have been caused by choice of inappropriate or nonprofitable conservation technologies (Shiferaw and Holden 2001).

The effect of new FFW programs in Andit Tid aimed at providing food security through provision of seasonal employment at a low wage rate (in food) was assessed using the model. The effect of three alternative scenarios was evaluated (1) when FFW employment is provided outside agriculture and (2) when FFW employment is provided for conservation investment on-farm. In both these cases we assume that access to off-farm employment is constrained and that conservation investment does not reduce initial yields. The third case (3) is like case (2) but with unconstrained access to off-farm employment and with conservation investment reducing initial yields (both these changes reduce incentives for farm production and conservation investment). In cases (2) and (3) we assume that the investment is taking place on-farm. In all cases, the "wage rate" is defined as 3 kilograms of wheat per day of work, the standard rate mostly used in FFW programs in Ethiopia.

One of the criticisms of FFW programs is that they undermine farmers' incentives to produce their own food and to take care of their own farms, partly because FFW activities compete with farming activities of households. Arguments against this are that if FFW is provided outside the main agricultural season, such competition may be reduced, thereby enhancing the synergies with agricultural production. In Andit Tid there are two growing seasons. It is most relevant to provide FFW after the short rains, that is, in the period March to May.[7] However, FFW may compete with households' own conservation activities in this period, as these are typically carried out in the slack season.

In our first simulation, case (1), presented in Figure 14.3, we look at the effects of provision of FFW when FFW is not used for conservation on-farm, when

Figure 14.3 Effect of introducing food-for-work (FFW) when FFW is not used for conservation, because of constrained access to the labor market or for land conservation, and FFW does not reduce initial yields



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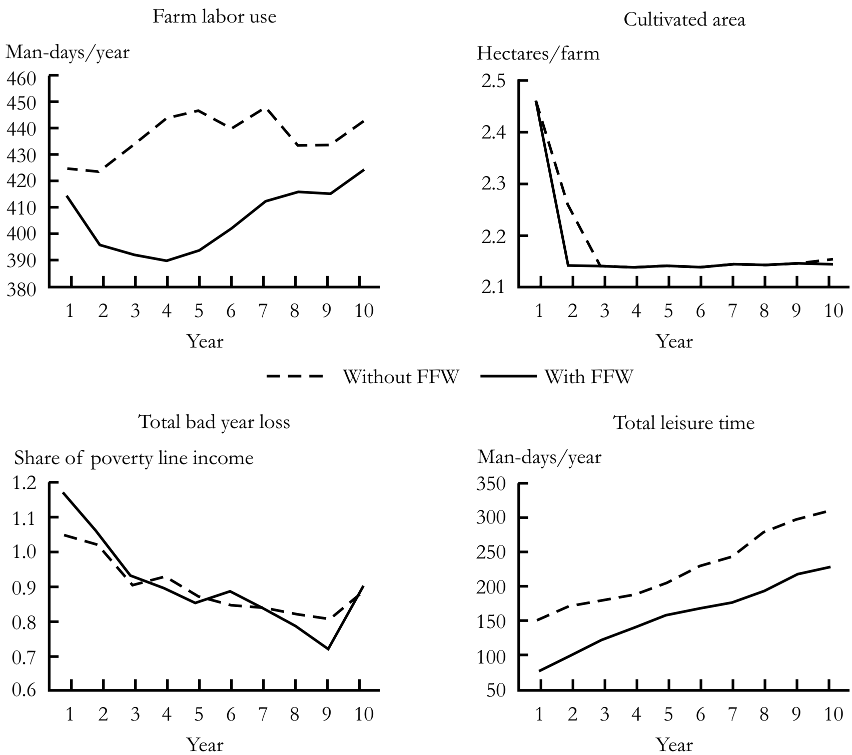


households have constrained access to the labor market, and conservation technologies do not reduce initial yields. We see from Figure 14.3 (containing 10 graphs) that FFW increases income per capita compared to the baseline condition without access to FFW. We also see that own food production is reduced in normal as well as in drought years for households with access to FFW (excluding the food obtained through the FFW activity). We see that farm labor use, including conservation labor use, is reduced when opportunities for off-farm employment through FFW are provided. This causes a smaller proportion of the farm to be conserved and total soil erosion to be larger compared to cases where such employment opportunities do not exist. Total leisure time is reduced, indicating that FFW has substituted not only for farm labor but also for leisure time. This indicates clear costs of providing FFW for poverty reduction and food security, as it reduces incentives for own food production and conservation and increases the dependency on assistance from outside.

Figure 14.4 Effect of food-for-work (FFW) when FFW is used for land conservation, because of constrained access to the labor market, or for conservation, and FFW does not reduce initial yields

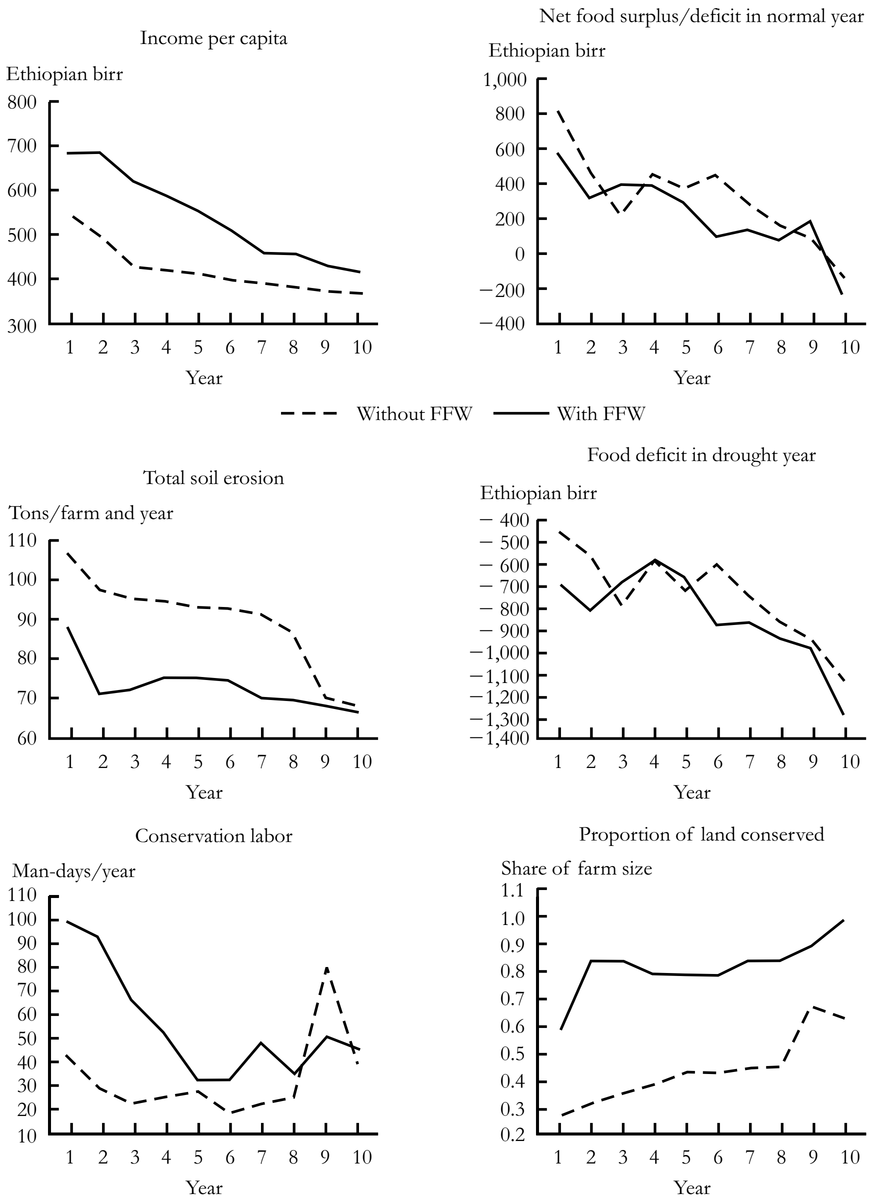
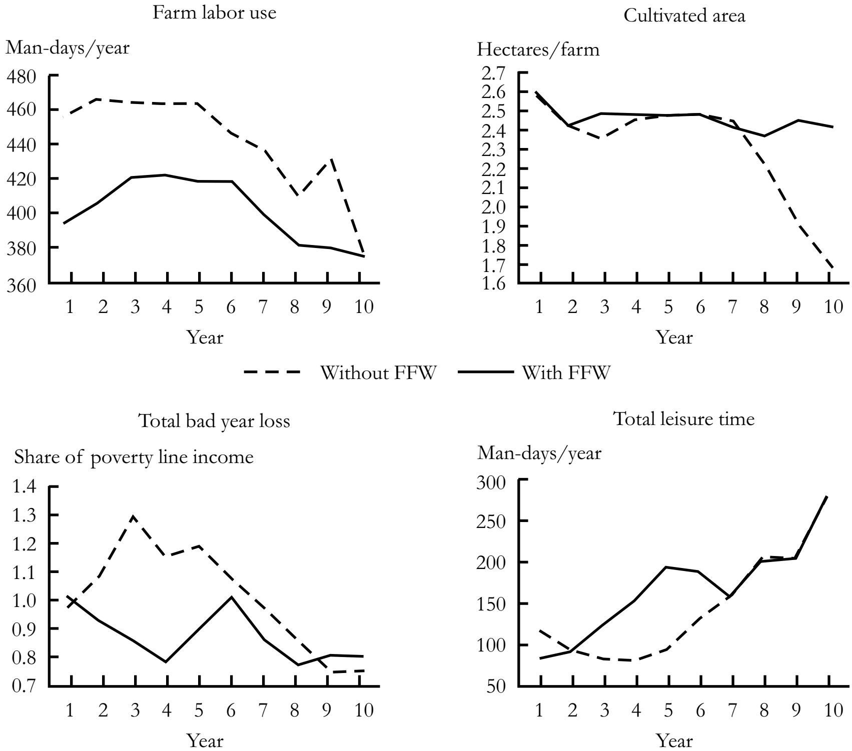


Figure 14.4 (continued)



In our second simulation, case (2), we look at the effects of FFW when it is used for conservation on-farm, when farmers have constrained access to the labor market, and conservation does not reduce initial yields. The results are presented in Figure 14.4.

We see from Figure 14.4 that household income per capita is increased when opportunities for on-farm employment are available through local FFW interventions. We also see that, as expected, conservation-linked FFW stimulates land conservation, and this leads to less soil erosion. The effect on household surplus food production is small (i.e., the food surplus is relatively lower with FFW than without it).

In the third simulation, case (3), we have altered two of the initial assumptions and look at the effect of FFW when FFW is used for conservation, when households have unconstrained access to the labor market (better nonfarm employment opportunities), and conservation technologies reduce initial yields (lower incentives to conserve land). The results of the model simulations are included in Figure 14.6. Household income per capita is increased for households with access to FFW in this case also, but less so than when access to the labor market was constrained. This implies that the payment from FFW (3 kilograms of wheat per day) is higher than that in the labor market. We also see that FFW substitutes for other off-farm work in this case. On the other hand, FFW stimulates own food production and reduces food deficits in normal as well as drought years, and particularly so toward the end of the 10-year period for which the models have been run. This is largely because FFW is used for land conservation, and this makes farm production more sustainable. Without FFW, households do not invest in conservation in this case because conservation reduces initial yields and because they have alternative off-farm employment opportunities.

We see that the effects of FFW on food production and conservation of land can be highly different depending on how and for what activities FFW is used, the wage rate, the level of access to off-farm cash employment, and the effect of conservation technologies on short-term yields. When FFW competes with labor used for conservation, FFW may reduce incentives to conserve land where such incentives exist without intervention. On the other hand, FFW may be used to stimulate conservation when there are insufficient incentives to conserve land. This illustrates that care has to be taken when such programs are designed to avoid unwanted disincentive effects and to achieve the social, economic, and/or environmental objectives of the programs. Good knowledge about the local farming systems, about the local market characteristics and prices, and about the distribution of resources and welfare are needed to avoid design failures. Those who have designed such programs in the past may not have had such knowledge, and this may also explain the mixed experiences with such programs (Barrett, Holden, and Clay 2004).

Effect of Stimulating Tree Planting

Planting of trees, especially eucalyptus, may be a promising option for farm households in marginal areas of Ethiopia where rainfall is adequate (Jagger and Pender 2003). In the past, most tree planting took place on government land and community woodlots. However, some tree planting also took place on privately controlled land. Jagger and Pender (2003) suggest that tree planting is most likely to be profitable in areas with low population density, low agricultural potential, good market access, market outlet for tree products, access to long-term credit, and secure access to the benefits from the investments. Holden and Yohannes (2002) found that resource poverty in land, livestock, and basic education may undermine planting of perennials in southern Ethiopia, whereas Gebremedhin and Swinton (2003a) found that tenure insecurity may undermine tree planting in the Tigray Region. If farm households adopt short planning horizons because of poverty and tenure insecurity, they may not adopt tree planting, as it may take 8–15 years before they can harvest the benefits of their investments. It may, under such conditions, be socially optimal to intervene to stimulate private tree planting because the benefits from intervention may be higher than the costs.

Interventions may take alternative forms depending on local circumstances, and various approaches should be tested. Direct regulation is one alternative, as has been recently done in Tigray, where planting of eucalyptus on land suitable for crop production was prohibited in 1997 (Jagger and Pender 2003). More recently, the regional government allowed private planting of eucalyptus on community wasteland and steep hillsides. In the Amhara Region distribution of state-owned communal lands on long-term lease contracts for private tree planting has started.

Our case study area has high population density, no access to long-term credit, and farmers may not feel secure that they will be getting the benefits from their tree-planting efforts (Holden and Shiferaw 2000). The land redistribution in 1997 may have undermined the feeling of tenure security and reduced the incentives to plant trees. Poverty, credit constraints, and lack of access to tree seedlings may be other reasons for underinvestment in tree planting compared to what would be socially optimal. Our survey showed that farm households in the area are not willing to plant trees on land suitable for crop production but are positive toward tree planting on land unsuitable for cropping. The potential of this option to improve household welfare is, therefore, what we explore with our bioeconomic model. We also want to explore the indirect effects on agricultural production and incentives for conservation, considering the income effect and possible competition between alternative uses of family time for agricultural production, including conservation, tree production, nonfarm employment, and leisure. We do not here explore alternative ways of promoting tree planting but rather assume that the constraints to tree planting have been removed and that a stable tree rotation has been established, given that it is profitable. We therefore try to assess the potential contribution of trees to household income and the influence such production may have on other production and conservation activities.

The model allows tree planting only on steep slopes and shallow soils unsuitable for crop production. Almost all land in densely populated Andit Tid has been distributed to individual households. The average area of steep lands with shallow soils is 0.45 hectare per household. The average area planted with trees on the farms was only 0.09 hectare per household. If trees are relatively more profitable, it should therefore be possible in principle to increase the area planted with trees from 3.3 percent to 18.2 percent of the average farm size without using land that is suitable for crop production.

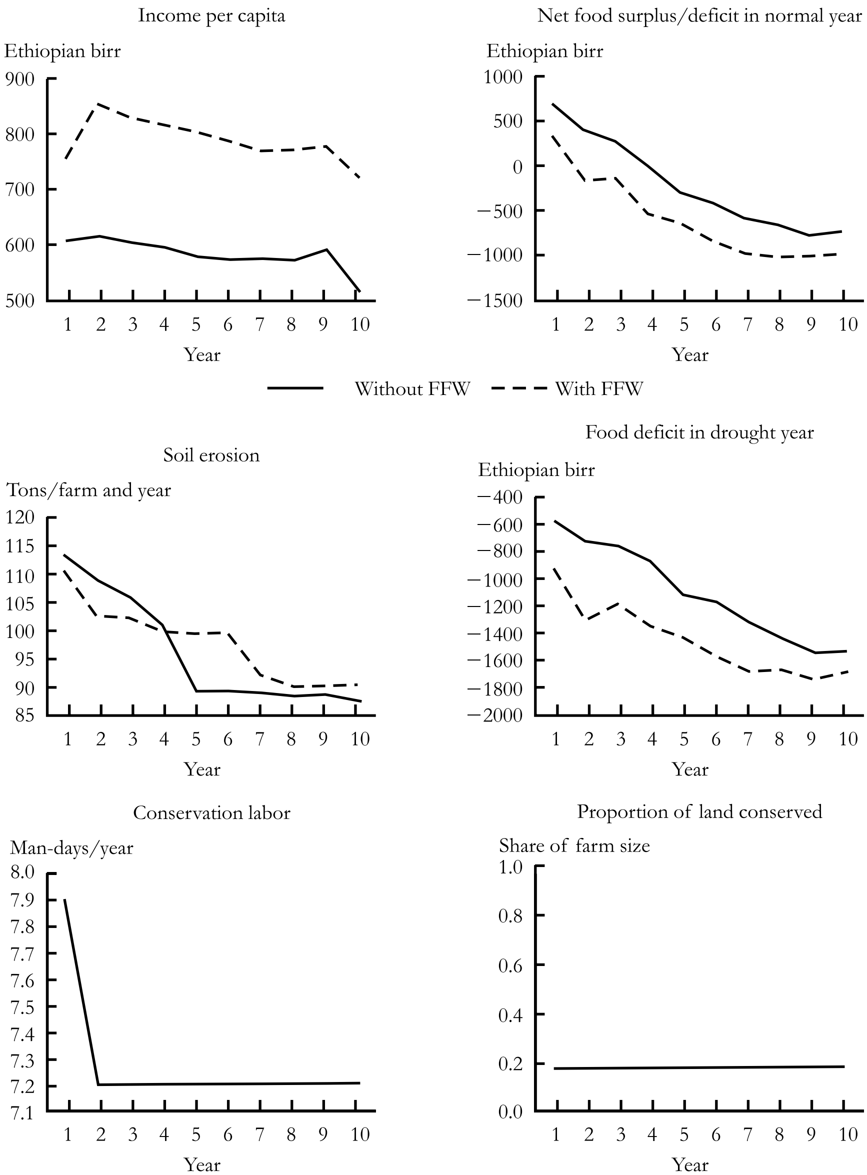
The high elevation in Andit Tid causes the time from planting to harvesting of eucalyptus to be as long as 12 years. The average price of harvested trees was 12 birr in 1998. This is substantially below the lowest price of 17 birr used by Jagger and Pender in their study in Tigray, suggesting higher scarcity of trees in Tigray compared to North Shewa, even though Andit Tid is located along the main road between Addis Ababa and the Tigray Region. We also assume away marketing constraints in our analysis and assume that farm households may sell all the trees they produce at the 1998 price. However, we included a small transportation cost for trees of 0.5 birr per tree. We used a planting density of 5,000 trees/hectare and a survival rate of 60 percent. We have not included additional ecological benefits and costs of eucalyptus planting in the model because these are highly uncertain and complex, and it is not clear whether the net effects are positive or negative (Jagger and Pender 2003).

Figure 14.5 illustrates the potential effects of planting of a stable rotation of eucalyptus trees on land unsuitable for crop production in Andit Tid. We have in this case assumed that households have unconstrained access to off-farm employment and that conservation investment reduces initial yields. We see that planting of eucalyptus on land unsuitable for crop production can increase household income substantially. This is in line with what has also been found in other studies (Okumu et al. 2002; Jagger and Pender 2003). We see that although land for crop production is not used for tree planting, food deficits are increased after tree planting has been stimulated. This is primarily because of higher demand for food when income is higher but to some extent also because of less food production. Planting of trees had little effect on incentives for conservation of land used for crop production and therefore also had little effect on total soil erosion on farms. Growing of trees reduced the demand for off-farm employment, indicating that the relative return to family labor in on-farm tree plantations was higher than the return to available cash employment for unskilled labor off-farm.

It appears that stimulation of on-farm trees may be a promising policy option for degraded drought-prone areas in the Ethiopian highlands provided that market outlets can be identified or developed. Interventions may be necessary to promote this through stimulation of seedling production, mobilization of labor, and identification of suitable areas.

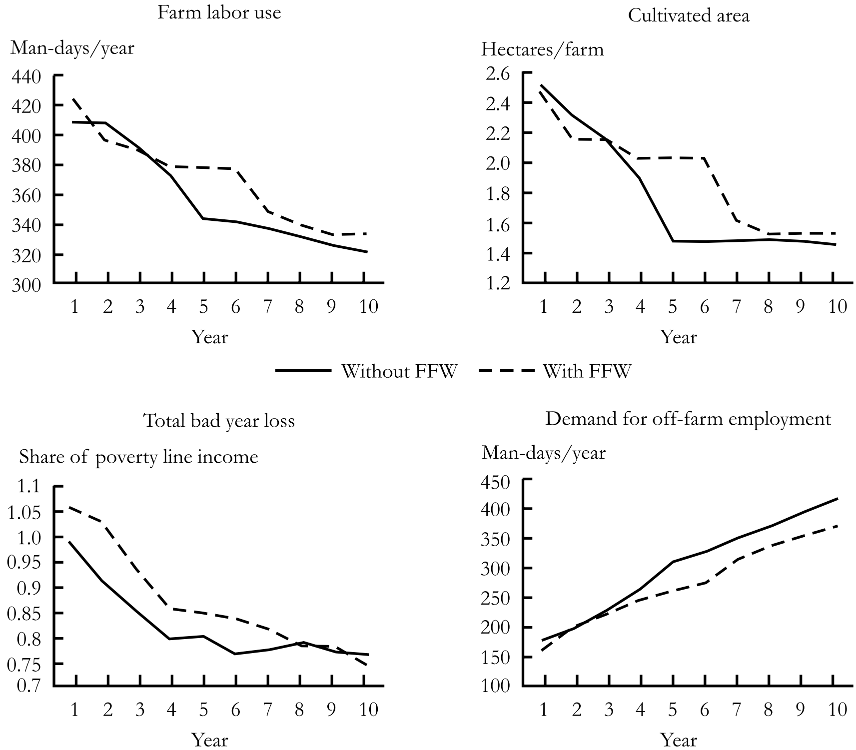
Finally, we looked at the combined effects of planting of eucalyptus and FFW employment to promote land conservation, in the case with unconstrained access

Figure 14.5 Effect of planting of eucalyptus when off-farm employment is unconstrained and conservation investment reduces initial yields



(*continued*)

Figure 14.5 (continued)



to off-farm employment, and when conservation investment reduces initial yields. The results are presented in Figure 14.6.

The influence of FFW on income is small compared to the planting of trees (when access to off-farm income is unconstrained). However, FFW stimulates land conservation and reduces soil erosion even when tree planting on shallow soils and steep slopes is included as an alternative livelihood strategy. The combination of tree planting and FFW for conservation therefore appears to produce superior outcomes, and substantial increases in household income are achieved while the erodible cropped lands are also conserved. We have, however, not taken into account the external costs of stimulating tree planting and using FFW. That has to be done to make a social cost-benefit analysis of the alternative policies.

We refer to Holden et al. (2003) for a more comprehensive analysis of the potential of tree planting for poverty reduction in less-favored areas of the Amhara Region.

Figure 14.6 Impact of tree planting and food-for-work for land conservation when off-farm employment is unconstrained and conservation investment reduces initial yields

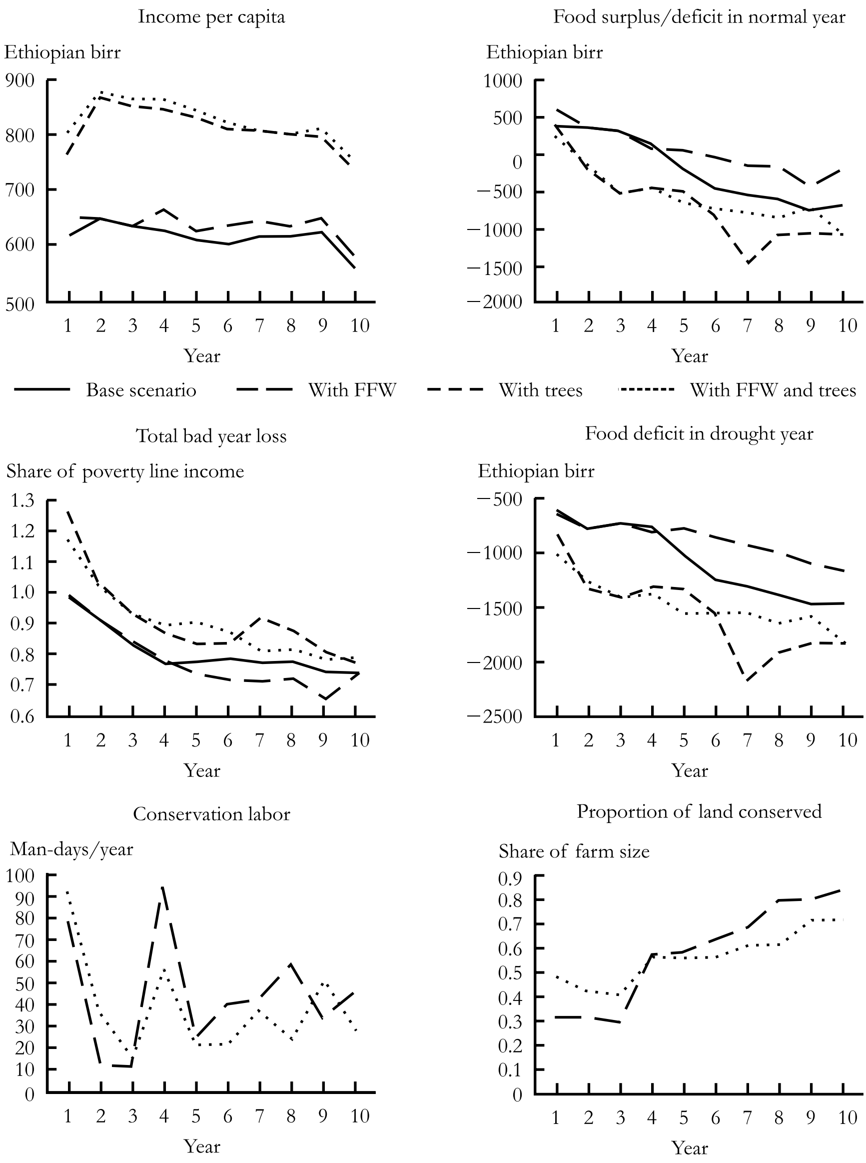


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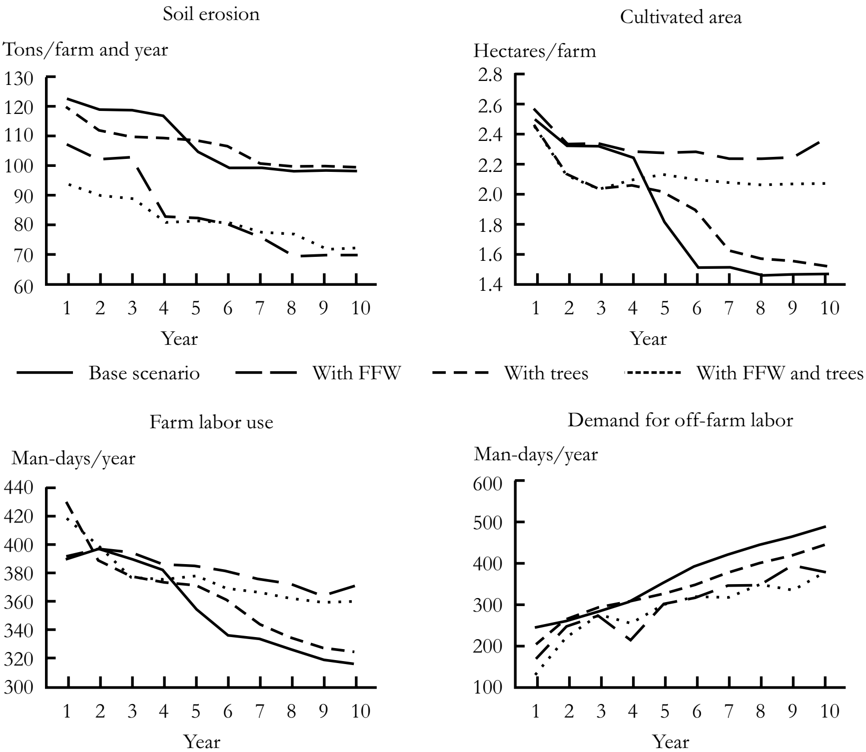
Figure 14.6 (continued)



Conclusions

We have developed bioeconomic models for a severely degraded area with high population density and fairly good market access in the Ethiopian highlands (building on the model by Holden and Shiferaw 2004).

The simulations indicate that there are limited off-farm employment opportunities in the local economy and entry barriers against wage employment in other areas. Better (unlimited) access to off-farm income at the low seasonal wage rates that are typical in the study area had a considerable positive effect on household income but also increased the need to import basic food grains to the area. We find that better access to off-farm income reduces farm households' incentives to invest in conservation and that this leads to more overall soil erosion and more rapid land degradation. Conservation investments require only labor inputs and are not limited by financial constraints. This is the case even though total agricultural production (crop and livestock production) and farm input use are reduced when access to off-farm employment is improved. There is therefore a need to complement a policy focusing on the development of the non-farm sector with a policy that ensures conservation of the natural resource base.

We find that FFW programs may be used to improve household food security and to promote more sustainable land management. There is a danger that such programs may undermine private incentives for food production and land conservation. By linking FFW to conservation investments, negative side effects may be minimized. However, local participation and commitment are important to ensure lasting effects of the investments.

Stimulation of planting of trees is a promising policy alternative. If land unsuitable for crop production is planted with trees and market outlets for the trees can be found, this can provide substantial increases in household incomes. This may not have large effects on incentives to conserve cropland.

FFW may be used to stimulate tree planting as well as cropland conservation. Policies combining promotion of tree planting and conservation through FFW may have the potential to achieve win-win benefits in terms of poverty reduction and more sustainable land use. Careful design and implementation are required to maximize such benefits.

Notes

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1. Starting from a point with many market imperfections and removing one of them does not guarantee that the new solution is closer to the social optimum.

2. Shiferaw and Holden (2001) provide a production function analysis based on experimental data that is used as basic input for the bioeconomic model. Households may decide to conserve their land by introducing conservation structures (graded soil or stone bunds). Only labor is needed as an input for this. The conservation technologies maintain yields better in the long run by reducing erosion and maintaining soil depth.

3. These market imperfections include limited access to off-farm employment, price bands for outputs and labor, a constrained rental market for land through share tenancy, ox rental market through exchange with labor only, and constrained access to formal credit in kind (for fertilizer) or to informal credit at a high interest rate. There is also no insurance market.

4. The model results presented are for the household group with two oxen (a pair of oxen is required for cultivation). This group cultivates 70 percent of the land in the case study area.

5. The households were operating close to their minimum subsistence level. Continued land degradation, population growth, stagnant technology, drought, and poor market access contribute to the infeasibilities.

6. Entry barriers are defined to include lack of information, uncertainty, risk aversion, and costs of obtaining information and moving to areas where wage employment could be obtained.

7. This is to minimize the crowding-out effects of FFW. In this period opportunity cost of family labor is at its lowest.

Chapter 15

Sustainable Land Management and Technology Adoption in Eastern Uganda

Johannes Woelcke,* Thomas Berger, and Soojin Park

Under the regimes of Idi Amin (1971–79) and Milton Obote (1980–85), Uganda's economy plunged into a prolonged crisis with negative real growth rates of GDP (Baffoe 2000). In 1987, under Yoweri Musevini, the Ugandan government introduced an economic recovery program in cooperation with the IMF and the World Bank, aiming at market liberalization, privatization, and decentralization. Although these reforms have had positive effects on the Ugandan economy (the GDP real growth has averaged 6 percent per annum), productivity in the agricultural sector has either stagnated or declined (APSEC 2000). Land degradation is generally seen as a major factor contributing to declining agricultural productivity as well as to poverty and food insecurity. Recent studies in eastern and central Uganda have revealed high negative nutrient balances for most cropping systems (Wortmann and Kaizzi 1998).

To address the issue of sustainable intensification of agriculture, the Ugandan government has published a Plan for Modernization of Agriculture (PMA) as part of the Poverty Eradication Action Plan with the vision of "poverty eradication through a profitable, competitive, sustainable and dynamic agricultural and agro-industrial sector" (Government of the Republic of Uganda 2000). The priority areas for action are improving access to rural finance, improving access to markets, increasing research and technology development, promoting sustainable natural

*The views included in this chapter are those of the author and do not necessarily represent those of the World Bank.

resource utilization, and providing opportunities for management and educational training in agriculture. This chapter analyzes the constraints that eastern Ugandan farm households face in the adoption of new technologies. It employs a bio-economic model to test which policy instruments may induce farm households to adopt ecologically sustainable farming practices.[1] Some policy conclusions are drawn on how to implement specific policy programs so as to overcome the household-level obstacles.

The causes of land degradation, including very low use of inorganic and organic fertilizers, declining fallow periods, deforestation, and crop production on steep slopes with limited investments in terraces or other conservation measures, are relatively well known, but the core of the land degradation problem is of an economic nature. Poor rural households in Uganda have to cope with stagnant or declining land productivity and farm incomes. Financial constraints and imperfect market conditions compel many farm households to adopt livelihood strategies that contribute to nutrient depletion. Ecologically sustainable intensification of agriculture is not pursued. Additionally, labor and land constraints limit the households' ability to invest in land improvements. It is therefore a difficult but important task to design agricultural policies that make these technologies affordable and adoptable, especially to poor farmers.

In their review of empirical studies, Feder, Just, and Zilberman (1985) analyzed the determinants that influence the adoption of technologies in general, including farm size, land tenure, risk, and farmers' age and level of education. However, what specific constraints the farm households face to the adoption of ecologically sustainable farming practices, what the optimal levels of adoption of these practices are, and what their effects on household income and natural resource conditions are remain unclear. This study was carried out to improve the understanding of key economic factors affecting land management decisions at the farm household level in the context of soil nutrient depletion, resource constraints, and fertilizer application.

The empirical research objectives were to

- assess, from the farm households' point of view, the feasibility of land management practices leading to nonnegative nutrient balances,
- identify the most binding factors affecting land use practices and adoption of new technologies (e.g., labor shortages, capital constraints, imperfect capital markets, distorted input and output prices, transaction and information costs),
- investigate the main reasons for the contrast between the current level of agricultural development and development opportunities in the study region, and

- explore the potential effects of policy and institutional interventions mentioned as priority areas in the PMA (e.g., development of local credit markets and promotion of improved technologies) on economic and ecological indicators.

Problem Setting in the Study Region

The agricultural market environment in Iganga District, as in most parts of eastern Uganda, is highly distorted. A market study by the International Fertilizer Development Center (IFDC 1999) reported inefficiency in procurement, high transportation costs, and absence of competitive pressure leading to unreasonably high input prices, especially for fertilizers. Since the initiation of market liberalization in Uganda, the government policy has been to leave the import of fertilizers entirely to the private sector. The fertilizer market, however, is still in a very early stage of development. There are only four fertilizer importers and wholesalers and surprisingly few business relationships with Kenyan traders, the potential suppliers of imported fertilizers for Uganda.

Fertilizer prices could be substantially reduced by improving the market environment and marketing chain. The "Soil Fertility Initiative Concept Paper" (FAO 1999) reports that by the end of 1998, the average price of fertilizer in Mombassa (Kenya) was US$250 per ton, freight to Kampala (Uganda) was about US$100 per ton, to which US$50 was added for clearance at the border, transloading, storage, and import charges. Therefore, the total CIF price in Kampala was about US$400, which is very high compared to prices in Kenya and other neighboring countries. It is estimated that fertilizer CIF prices in Kampala would fall by a quarter if the import quantities increased to a level that would justify imports by shiploads and/or trainloads. Most fertilizer is delivered to dealers in 50-kilogram bags. The fertilizers are repacked into smaller units of 5 kilograms and 1 kilogram, leading to a 100 percent price increase. According to the FAO (1999), exploiting economies of scale in transportation and avoiding the costs of repacking fertilizers would result in a fertilizer price amounting to 37.5 percent of the current price. A further reduction in input prices could be attained through market regulation policies aimed at fostering competition on the fertilizer market.

The marketing chain in Iganga District involves middlemen in villages, local buyers in trading centers and in Iganga town, and traders from Kenya and Mbale, Busia, and Kampala. The prices offered to the farmers for their produce by middlemen depend on the prices set by local buyers in towns or in trading centers, which in turn are determined by the prices offered by foreign buyers. A study carried out by Vredeseilanden-Coopibo-Uganda (1998) indicated a 60 percent price markup from farm gate to retail in Iganga District. Survey data from Woelcke

(2003) revealed even higher price differences among farmers, wholesalers, and retailers. In 2001, the average price markup of maize between farmer and wholesaler was 62 percent, and between farmer and retailer 212 percent. Farmers often face information asymmetries when selling their produce at the farm gate because they are often unaware of the prices offered at higher levels of the market chain. These examples are indicative of the influence that reduced transaction costs could have on farm-gate prices in the study region.

The model scenarios, to be presented in the next section, focus on how and to what extent the market environment in eastern Uganda could be improved so as to provide sufficient incentives to simultaneously reach the policy goals of growth and sustainability. The main question put to the model is: Is it realistic to expect farm households to attain these goals without direct market intervention in output price policies (e.g., taxes, subsidies, fixed prices), input policies (e.g., subsidies, input delivery systems), and marketing policies (e.g., monopoly parastatals, trader licensing)?

The identification of research objectives and the discussion of the specific problem setting in the study region led to the selection of the following policy scenarios:

- Binding constraints and feasibility of nonnegative nutrient balances under current market conditions.

- Economic and ecological effects of promoted technologies under market improvements such as decreasing fertilizer prices, increasing agricultural output prices, introduction of credit, or improvement of price relations and promotion of labor exchange.

Integrated Approach to Bioeconomic Modeling

Sampling Procedure

The International Food Policy Research Institute (IFPRI) identified the predominant development domains in Uganda. Three factors were used for the stratification: agricultural potential, market access, and population density.[2] Development domains can be used to identify potential profitable pathways of development, based on the comparative advantages that exist in a particular region.[3] For our study, we selected two villages in Iganga District, characterized by a program-induced development pathway with relatively high market access, high agricultural potential, and high population density. The district is located in the Lake Victoria Basin in eastern Uganda, about 120 kilometers northeast from Uganda's capital Kampala.

Table 15.1 Selected output prices and input prices for Iganga District, 2001

Output prices (at farm gate) (USh/kg)		Input prices (Iganga market) (USh/kg)	
Maize	200	Urea	800
Beans	300	TSP (triple-super-phosphate)	800
Sweet potatoes	120	NPK fertilizer	850
Millet	250	Rock phosphate	100
Sorghum	200	CAN (calcium-ammonium-nitrate)	660
Coffee	400	Ambush (insecticide) (USh/liter)	12,000
Cassava	100	Round-Up (herbicide) (USh/liter)	12,500
Bananas	100	Ripcord (insecticide) (USh/liter)	11,000

Source: Authors' survey.

Note: USh, Uganda shilling. Average exchange rate in 2001: US$1 = USh 1,788.

The traditional food crops are maize, bananas, sweet potatoes, cassava, beans, millet, and sorghum, and the traditional cash crops are coffee and cotton (Table 15.1 indicates output and input prices for Iganga District in 2001). The primary goal of the low-input and -output farm production is home consumption for the majority of farm households (Esilaba et al. 2001). Obviously, these low-intensity production systems are at variance with the development opportunities that exist in eastern Uganda. Another important characteristic of the region is the presence of numerous nongovernmental organizations (NGOs) and International Agricultural Research Centers (IARC), which focus on fostering agricultural and rural development. The International Center for Tropical Agriculture (CIAT) and Africa 2000 Network (A2N) are promoting different technologies aimed at sustainable intensification of agricultural production based on a participatory research approach in selected communities of the study region.

A listing of households in both villages indicated that approximately 7 percent of the households conducted agricultural technology trials in cooperation with the CIAT and A2N.[4] For the first round of the household survey, stratified random sampling was performed in order to capture the correct proportion of farm households participating in trials within the sampled population. Principal component analysis and subsequent cluster analysis were used to identify the following four representative household types: subsistence farm households (30 percent of all households), semisubsistence farm households (52 percent), trial farm households (7 percent), and commercial farm households (10 percent).[5]

Table 15.2 provides information about the characteristics of these household groups. Trial farm households were among the first to adopt a mosaic virus–resistant cassava variety, and this is seen as an indicator of their general innovativeness. These farmers form the only household group that conducted farm trials in cooperation with CIAT and A2N. They applied the highest amounts of inorganic fertilizers and other agrochemicals and are the only group of farmers who participated in a significant number of different types of training. Furthermore, farmers in this group adopted the highest number of technologies within the last 10 years. Only the household heads and spouses of the commercial farm households had more years of schooling than those of trial farm households. Commercial farm households achieved the highest mean values for the following variables: value of residence and other structures of the household, value of agricultural equipment per person involved in farming, total value of agricultural production, value of agricultural production per acre cultivated land, years of schooling of household head and wife, value of radios, intensity of land use, and quantity of total agricultural production sold. These values indicate a relative abundance of human and physical assets as well as a relatively high degree of market orientation, although the low participation in different types of training reveals a lack of regular contact with programs, organizations, and extension services between 1990 and 2000.

That this group of farmers adopted the mosaic-resistant cassava variety later than others can be explained by the facts that (1) cassava is not important as a cash crop, and therefore not of major interest to commercial farmers, and (2) wealthier households are excluded from the communication process of the average farm household (Miiro, Esilaba, and Soniia 2002). Subsistence and semisubsistence farm households attain relatively low mean values for the following variables: years of schooling of the household head and spouse, value of household assets, quantity of total agricultural production sold (especially low value for the subsistence farm household), value of agricultural production (total and per acre of cultivated land), and number of inorganic fertilizers and other agrochemicals applied. These values reveal a shortage of human and physical assets, low productivity, and low degrees of innovativeness and market orientation. Furthermore, subsistence farmers were confronted with long distances to the nearest output markets and were late in adopting new technologies. Moreover, the highest value of labor-land ratio is reported for this group indicating a relative abundance of unskilled labor and relative scarcity of land. The number of different types of training undergone within the last 10 years is insignificant for both of these groups.

Out of each group, the households closest to the cluster centers were selected for the second round of the household survey. The main objective of the second round was to collect biophysical data at plot level, detailed input–output coefficients, estimates of farm income, and information on household preferences, decision rules, and goals. Additionally, CIAT provided farm trial data from four seasons in 2000 and 2001, together with soil data for the estimation of yield responses to fertilizer application.

Table 15.2 Characteristics of the identified household groups

Characteristic	Subsistence farm households (30%)	Semisubsistence farm households (53%)	Trial farm households (7%)	Commercial farm households (10%)
Education				
Years of schooling head	5.5	4.4	7.7	12.4
Years of schooling wife	3.3	4.3	5.6	8.1
Number of different types of training participated in since 1990	0.3	0.7	4.2	1.0
Household assets				
Value of residence and other farm structures (10^3 USh)[a]	1,267	837	1,951	7,601
Value of radios (10^3 USh)	16	22	43	74
Value of agricultural equipment per person involved in farming (USh)	4,358	5,261	5,778	9,739
Agricultural production				
Total value of agricultural production (10^3 USh)	455	833	1,066	1,635
Value of agricultural production per acre cultivated land (10^3 USh)	182	182	207	224
Quantity of total production sold (%)	23	52	35	64
Perceived walking time to output market (minutes)	142	45	81	64
Intensity of land use[b]	0.9	1.2	1.1	1.4
Labor-land ratio[c]	260	131	159	165
Innovativeness				
Time of adoption (improved cassava variety) compared to opinion leader (years)[d]	+4.6	+0.7	–2	+5.8
Time of adoption (improved cassava variety) compared to personal agricultural information network (%)[e]	66	41	33	73
Number of technologies adopted within the past 10 years	5	5	8	6
Number of trial types conducted	0	0	7	0

Source: Woelcke (2003).

[a]USh, Ugandan shilling.

[b]Intensity of land use: The ratio of the land area cultivated in the past 12 months to the total land size.

[c]Labor-land ratio: The ratio between labor use on farm (person-days) and cultivated land size.

[d]Opinion leader: An individual who leads in influencing others' opinions about innovation (Rogers 1995).

[e]Personal agricultural information network: The network of people with whom farmers discuss agriculture related issues. In the case of subsistence farm households, 66 percent of the farmers who are in the personal network of this household type adopted the improved cassava variety before this type itself decided to adopt the new technology.

Modeling Approach

Bioeconomic models combine socioeconomic factors influencing farmers' objectives and constraints with biophysical factors affecting production possibilities and the effects of land management practices (Oriade and Dillon 1997).[6] The bioeconomic modeling approach chosen for this study helps to identify the optimal level of technology adoption and its effect on household welfare and natural resource conditions for heterogeneous household agents (normative analysis). The model consists of three major components: a mathematical programming model at the farm household level, to reflect the decisionmaking processes under different constraints; artificial neural networks (ANN)[7] as a yield estimator; and nutrient balances as sustainability indicators.[8] The household's decisionmaking problem is based on a lexicographic utility concept; that is, the household first satisfies the consumption needs of its members before the household income is maximized. Household income includes both on-farm and off-farm activities.[9] The mixed-integer linear programming models developed for each of the four representative household types consist of 507 variables and 201 constraints. The main activities captured are crop production, livestock production, consumption and selling of agricultural products, permanent off-farm employment, hiring in/out temporary labor, labor exchange,[10] labor transfer, hiring a tractor, investment activities (e.g., treadle pump for irrigation), credit application, and technology options based on CIAT farm trials. The main resources and constraints considered are total land area, crop rotation, labor, nutrient requirements of household members, consumption preferences, capital constraints (including credit limits), and nutrient balances as a sustainability indicator. The results of the yield estimator and computations of nutrient balances are incorporated into the comparative static programming model.

Policy Scenarios and Results

Scenarios on Binding Constraints and Feasibility of Nonnegative Nutrient Balances under Current Market Conditions

In the following we discuss whether, under current conditions, the private goals of farm households, that is, the satisfaction of basic food needs and the maximization of incomes, and the social goal of conserving soil fertility, measured by nonnegative nutrient balances, can be reached simultaneously. Additionally, we explore whether the relaxation of technical constraints (through introduction of new technologies promoted by CIAT) and capital constraints (through provision of credit) can harmonize private and social goals. For this purpose the bioeconomic model is used to run different scenarios for all household types (scenarios 1–6 are defined in Table 15.3).[11]

Table 15.3 Feasibility of private and social goals under current market constraints

Scenario	Subsistence farm household	Semisubsistence farm household	Trial farm household	Commercial farm household
Current constraints				
Income (10^3 USh)	1,299	1,490	2,395	4,800
N balance (kilograms/hectare)	–28	–52	–43	–77
P balance (kilograms/hectare)	–8	–12	–11	–15
K balance (kilograms/hectare)	–39	–62	–47	–71
+ Sustainability constraint				
Income (10^3 USh)	Not feasible	Not feasible	Not feasible	Not feasible
N balance (kilograms/hectare)				
P balance (kilograms/hectare)				
K balance (kilograms/hectare)				
+ New technologies				
Income (10^3 USh)	1,310	1,524	2,452	5,204
N balance (kilograms/hectare)	–29	–66	–60	–96
P balance (kilograms/hectare)	–6	+24	+21	+58
K balance (kilograms/hectare)	–40	–83	–69	–100
+Sustainability constraint +new technologies				
Income (10^3 USh)	Not feasible	Not feasible	Not feasible	Not feasible
N balance (kilograms/hectare)				
P balance (kilograms/hectare)				
K balance (kilograms/hectare)				
+Sustainability constraint +new technologies +credit				
Income (10^3 USh)	Not feasible	Not feasible	Not feasible	3,373
N balance (kilograms/hectare)				0
P balance (kilograms/hectare)				+47
K balance (kilograms/hectare)				0
+New technologies +credit				
Income (10^3 USh)	1,356	1,633	2,575	5,223
N balance (kilograms/hectare)	–39	–79	–69	–104
P balance (kilograms/hectare)	+12	+59	+35	+56
K balance (kilograms/hectare)	–51	–94	–81	–106

Source: Woelcke (2003).

Note: The new technology options are available only for maize. For more details refer to Woelcke (2003).

The model's objective function value, the household income, is used as an indicator for household welfare, and the nutrient balances are used as an indicator for ecological sustainability. The scenario results reveal difficulties in achieving the goal of nonnegative nutrient balances under current market conditions, especially for the subsistence, semisubsistence, and trial farm household types. For all household types, current land management practices lead to high negative nutrient balances under present constraints (scenario 1).

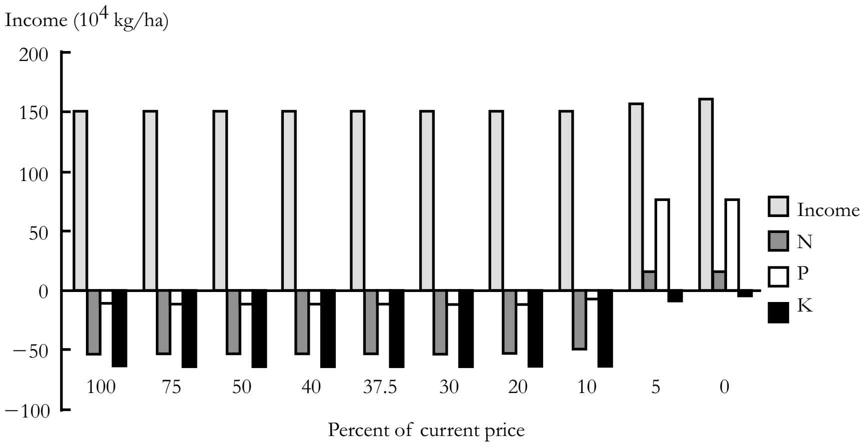
Because of higher yields and consequent higher nutrient losses from fields as a result of produce and stover removal, the nutrient balances for commercial farm households are more negative than those for other farm household types. For no household type did the introduction of the sustainability constraint of nonnegative nutrient balances lead to feasible model solutions (scenario 2). Sensitivity analyses indicate that consumption preferences and consumption needs, articulated during household interviews, would have to be adjusted significantly to halt nutrient depletion.[12] In most cases, neither the relaxation of technical constraints nor the relaxation of capital constraints contributes to reaching the goal of ecological sustainability (scenarios 3–6). The reason for this model result is the nonprofitability of the promoted technologies under existing market conditions. Yield increases are not sufficient to contribute to positive net benefits of technology adoption. The simultaneous introduction of new technologies and credit enables only the commercial farm household to attain nonnegative nutrient balances (scenario 5). A comparison of the household income levels of the commercial farm household in scenarios 5 and 6 reveals trade-offs between economic and ecological goals. The household income in scenario 5, where the household is forced into nonnegative nutrient balances, is much lower than that in scenario 6, where the sustainability constraint is relaxed again.

Effects of Promoted Technologies under Market Improvements

Because the social goal of nonnegative nutrient balances could not be reached in most of the above scenarios, and direct market interventions are not considered to be appropriate policy instruments for Uganda, the subsequent model scenarios deal with the potential of market improvements to simultaneously increase household welfare and nutrient balances. The results of these scenarios are presented only for the semisubsistence farm household, the most frequent household type in the study region. For the other three remaining household groups, the reader may consult Woelcke (2003).

Effects of decreasing fertilizer prices. This group of scenarios focuses on the economic and ecological influences of a stepwise decrease of fertilizer prices. Sensitivity analyses were conducted to identify critical levels of fertilizer prices at which a significant improvement of nutrient balances could be achieved. Results from these sensitivity analyses were then compared to the potential decrease in fertilizer prices through changes in the market environment. The changes in household income and nutrient balances (nitrogen, phosphorus, and potassium) in response to stepwise decreased fertilizer prices are illustrated for the semisubsistence farm household type in Figure 15.1. The table below the diagram indicates the percentage of

Figure 15.1 Sensitivity analysis of fertilizer price for semisubsistence farm households



Percentage of current price	100	75	50	40	37.5	30	20	10	5	0
"Reduced costs" (10^3 USh)										
Maize+N1	505	392	279	234	222	189	143	72	118	151
Maize+NP1	833	606	380	290	267	200	109	3	12	26
Maize+NPK1	1154	841	528	403	372	288	153	20	0	0
Maize+N2	464	351	238	193	182	148	103	69	94	127
Maize+NP2	792	566	340	249	227	159	69	0	0	14
Maize+NPK2	1114	801	488	363	331	237	112	17	0	0
Area adopted (ha)	0	0	0	0	0	0	0	NP2 0.08	NPK1 0.76 NP2 0.13 NPK2 0.83	NPK1 0.76 NP2 0.96

Source: Woelcke (2003).

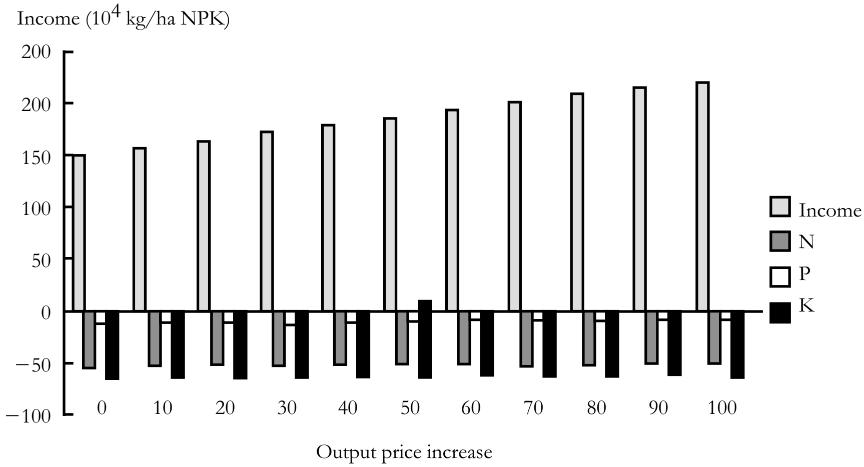
Abbreviations: Maize+N1 = nitrogen fertilizer application on maize in season 1; Maize+NP1 = nitrogen and phosphorus fertilizer application on maize in season 1; Maize+NPK1 = nitrogen, phosphorus, and potassium fertilizer application in season 1. Maize+N2, Maize+NP2, and Maize+NPK2 indicate the same fertilizer application in the second season.

fertilizer price reduction (first row), the level of "reduced costs"[13] of farming activities involving fertilizer application (second row), the type of fertilizer applied, and the total area of application (third row). Even though fertilizer prices are reduced substantially, the "reduced costs" for production activities involving fertilizer application remain high, indicating that these activities are far from being included in the farm plan. Sensitivity analyses show that fertilizer prices have to be cut down to 10 percent of the current price level before the semisubsistence farm household profitably adopts one of the new technologies. Fertilizer prices have to decrease to 5 percent of the current price or less to achieve nonnegative nutrient balances.[14] The balance for potassium would still be negative, but the high negative value of –63 kilograms/hectare in the baseline scenario could be reduced to –8 kilograms/hectare. Under this price scenario, NPK fertilizer could be adopted profitably on 1.59 hectares, and NP fertilizer on 0.13 hectare.

The overall effect of fertilizer price reduction on household income is very modest, reaching a 5.5 percent increase when fertilizer prices are reduced to 5 percent of the current price. Free availability of fertilizer would lead to further slight increases of income and nutrient balances. Considering the extreme fertilizer price reduction needed to induce farmers in eastern Uganda to switch to a more sustainable intensification of agricultural practices, policy options focusing only on input market improvements would probably not be a promising strategy. However, even direct fertilizer subsidies alone will probably not provide sufficient incentives for the semisubsistence farm households to adopt improved practices.

Effects of increasing agricultural output prices. The next group of scenarios focuses on the effect of stepwise increased agricultural product prices on household welfare, ecological sustainability, and production structure. Figure 15.2 illustrates the results for the semisubsistence household type as an example. The table below the diagram indicates how the production structure changes in response to changing output prices. Sensitivity experiments reveal that higher agricultural product prices alone do not lead to a profitable adoption of new fertilizer technologies. In comparison to the baseline scenario, the household income would increase by 23 percent with an output price increase of 50 percent, and by 47 percent with an output price increase of 100 percent. The production structure of the semisubsistence farm household type remains relatively stable because of a relatively low degree of market orientation. A significant change of the production structure of the semisubsistence farm household is observed when output prices are increased by 70 percent. The area under improved maize would then increase from 0.21 to 0.37 hectare, whereas the area under intercropped coffee and bananas decreases. This

Figure 15.2 Sensitivity analysis of output prices for semisubsistence farm households



Percentage of output price increase	0	10	20	30	40	50	60	70	80	90	100
Production structure (ha)											
Maize	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.37	0.37	0.37	0.37
Maize/cassava	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.73	0.73	0.73	0.73
Sweet potato	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Millet	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Sorghum	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Coffee/banana	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.2	0.2	0.2	0.2

Source: Woelcke (2003).

change in production structure is induced by changes of the relative competitiveness of production activities and leads to a slight deterioration of nutrient balances.

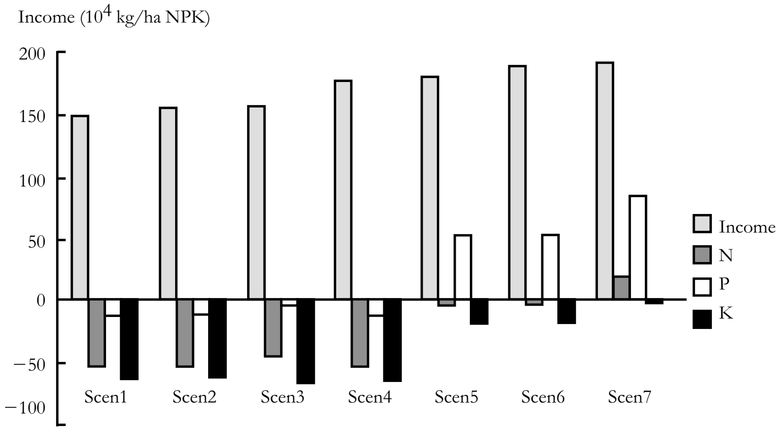
Introduction of credit, improvement of price relations, and promotion of labor exchange. The sensitivity analyses discussed above indicate that neither a sole decrease of fertilizer prices to a realistic degree nor a sole increase of agricultural output prices will lead to the harmonization of private (household welfare) and social (ecological) goals. In the following we examine whether combined price effects and additional policy interventions, such as the provision of credit or the promotion of alternative forms of labor acquisition, could improve the current situation, which is characterized by highly negative nutrient balances.

For this purpose, sensitivity experiments of both decreasing fertilizer prices and increasing agricultural product prices are conducted to identify those price relations that would potentially induce farmers to apply more fertilizers and improve their nutrient balances. Again, we show only simulation results for the semisubsistence farm household and refer the reader for the other household types to Woelcke (2003). Results for the semisubsistence household are of special relevance in Uganda, not only because of its frequency but also because of the government's objective of commercializing farm production.

Figure 15.3 illustrates the potential effects that technology adoption and reduction of market distortions will have on household welfare and ecological sustainability. The reduction of market distortions is represented in the model through changes of input and output prices to the levels discussed above. Provision of credit is included for assessing the influence of removing capital shortages on the adoption of new technologies. Another constraint frequently quoted as a major obstacle to the adoption of new technologies is the shortage of farm labor, especially during peak periods of the vegetation cycle. Farm labor exchange, a traditional form of labor acquisition in the study region, was included in the model to investigate whether it would be an appropriate option to overcome the problem of labor shortages. The table below the diagram defines the scenarios considered and indicates the area on which specific technologies have been adopted. The first scenario reflects the current socioeconomic conditions and includes the provision of new technologies. The second scenario is identical to the first scenario except that it assumes prices changes for fertilizers and outputs (fertilizer prices are reduced to 30 percent of the current prices, and output prices are increased by 10 percent of current prices). Scenario 3 assumes the same input and output prices but does not assume credit constraints. In scenario 4, credit constraints are introduced again, but the extent of prices changes have been increased. Scenarios 5 and 6 are identical except that the latter assumes slightly higher output prices. Finally, scenario 7 introduces labor exchange.

The model results suggest that improved input–output price relations in combination with provision of credit and labor exchange can induce a simultaneous significant improvement of household incomes and nutrient balances. In addition to credit provision, input prices will have to be reduced to at least 30 percent of the current price level, and output prices increased to 110 percent before the semisubsistence farm household type profitably adopts NP fertilizer on 0.21 hectare. NPK fertilizer adoption becomes profitable when input prices are decreased to 25 per-

Figure 15.3 "Combined effects" scenarios for the semisubsistence farm household type



	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Characteristics	Current conditions trial technology	Trial technology input price 30 percent of c.p. Output price: +10 percent	Trial technology input price 30 percent of c.p. Output price: +10 percent credit	Trial technology input price 25 percent of c.p. Output price: +40 percent	Trial technology input price 25 percent of c.p. Output price: +40 percent credit	Trial technology input price 25 percent of c.p. Output price: +50 percent credit	Trial technology input price 25 percent of c.p. Output price: +50 percent credit labor exchange
Area adopted (ha)	0	0	NP 0.21	0	NPK 1.28	NPK 1.28	NPK 1.72

Source: Woelcke (2003).

Abbreviation: Percent of c.p. = percentage of current price.

cent of the current value, output prices are increased to 140 percent, and credit is provided. The application of NPK fertilizer on 1.28 hectares significantly increases nutrient balances (nitrogen –2 kilograms/hectare, phosphorus +53 kilograms/hectare, potassium: –17 kilograms/hectare). Labor exchange seems to be an interesting option to overcome technology adoption constraints, especially for the semisubsistence farm households. Although this household type is partly engaged in off-farm activities, it still can offer enough labor for labor exchange, which enables it to receive agricultural labor support in seasonal peaks. Scenario 7 in Figure 15.3

illustrates that labor exchange in combination with credit provision, input price decreases (25 percent of current price), and product price increases (to 150 percent) lead to an adoption of NPK fertilizer on 1.72 hectares. This fertilizer application would have increasing effects on household income (increase by 27 percent in comparison to the baseline scenario) and the nutrient balances, of which only the K balance would remain slightly negative (–2 kilograms/hectare). Although increases in output prices might be realistically achieved through price information systems, an input price reduction to this extent is difficult to attain. In regard to the discussion above on feasible changes of fertilizer prices, economies of scale in transport, improvements in the marketing chain, and increased competition would have to be attained simultaneously.

Summarizing the normative simulation experiments, we conclude that the central reason for nutrient depletion at the household level is the nonprofitability of ecologically sustainable farming practices under current socioeconomic and agro-ecological conditions. Low economic incentives to adopt improved land management practices are caused by market imperfections reflected by high transaction costs. In addition, insufficient access to credit markets reduces the ability to adopt technology. Consequently, the necessary condition for technology adoption, positive net benefits, is not satisfied for inorganic and organic fertilizers, which could contribute to more positive nutrient balances. Significant improvements of the socioeconomic environment are essential for successful promotion of more intensive and ecologically sustainable farming practices.

The scenario results reveal that a fertilizer price reduction to about 25 percent of the current prices and an agricultural product price increase of about 50 percent are simultaneously needed to achieve significant improvements of household welfare and nutrient balances. Considering the high price mark-ups from farmers to wholesalers to retailers, a producer price increase to this extent might be attainable if farm households would have access to relevant market information (see above). A fertilizer price reduction to the extent indicated above might be more difficult to achieve. Exploiting economies of scale in transport and removing marketing inefficiencies might reduce the fertilizer price to 37 percent of current prices. To contribute to further price reduction, increased competition on the input market is needed (FAO 1999). It should be taken into account that improved effects of promoted technologies on yields could reduce the extent of price changes needed for reaching economic and ecological goals at the farm household level. However, isolated improvements of price relations are not sufficient. Improved access to financial markets is simultaneously needed for promotion of sustainable land management practices.

Summary and Conclusions

This chapter presents the results of a bioeconomic simulation model that reflects the objectives and constraints of farm households in the Iganga District of eastern Uganda. In terms of the defined research objectives, the developed static bioeconomic model is an appropriate and straightforward model choice. The model computes the optimal choice of farming activities and quantifies the financial consequences for heterogeneous household agents in a changing socioeconomic environment. It also includes a yield estimator and nutrient balances to simultaneously assess the ecological influences of these farming practices. The developed model provides useful insights for policy development because it identifies unprofitable production activities and therefore eliminates these unlikely alternatives. The simulation experiments show that under current constraints, the farm households have no alternatives but to deplete their soils' nutrients. Even with the introduction of new fertilizer technologies and the provision of credit, nonnegative nutrient balances are not feasible for most households. Only very drastic changes in input and output prices would induce the farm households to conserve their soil nutrient stocks while simultaneously satisfying their consumption needs.

Several preliminary policy conclusions can be derived from the bioeconomic model. First, the model results strongly encourage the completion of market reforms in Uganda based on an improved regulatory and legal framework. The process of market liberalization has removed some major distortions but has not been sufficient to create a business environment fostering private sector activities and trade, nor has it succeeded in linking small farms to high-value markets.[15] As discussed, there exists an enormous potential to significantly improve price relations for farmers through reduction of transportation costs, increased marketing efficiency, and increased competition on the fertilizer markets. Second, the model results emphasize that the provision of credit alone does not necessarily lead to the adoption of sustainable farming practices. However, improved credit access for small-scale farmers is one essential reform pillar if provided in combination with other measures. Therefore, more creative thinking and innovative approaches are needed to overcome the household's capital constraints. Developing a legal and regulatory framework governing microfinance and improving operating capacity of microfinance institutions should be of high priority. Third, more agricultural research is needed for new and better-targeted technologies that will provide farm households with the opportunities to intensify their agricultural production without increasing nutrient extraction. Several national research institutions are currently carrying out encouraging field experiments, but significant efforts and new ways of funding are required to revitalize the National Agricultural Research System in Uganda. Participatory research approaches, as conducted by CIAT and A2N in the study region, are certainly a promising tool to improve responsiveness to farmers' needs. Nonetheless, it obviously involves a long-term learning process for both researchers and farmers to make this approach more effective. To close the gaps among research, farmers, and markets, an effective agricultural advisory service has to be implemented. Fourth, access to agriculture-related market information is essential to overcome information asymmetries and attain higher output prices for farm households. Promising options to spread relevant information through modern information and communication technologies already exist (Bertolini et al. 2002). Miiro, Esilaba, and Soniia (2002) confirmed the importance of social networks for the diffusion of information in the study region.

It should be noted again that these policy conclusions depend on the model specification. First, the bioeconomic model does not capture the effect of increased production levels on local market prices. Second, it does not capture nutrient dynamics in the soil and the feedback effects among nutrient depletion, soil nutrient content, and crop yield. Capturing these links is essential for further research in the field of sustainable land management. It is clear that high negative nutrient balances reduce crop yields in the long run, but it is less clear how the size of negative nutrient balances is related to output levels. International and national researchers, extension staff, and policy makers assume that the perceived decline of yield levels in Uganda is mainly caused by nutrient depletion. To our knowledge, long-term yield data are still lacking on which to confirm or reject this hypothesis. The question of the critical rate at which nutrient depletion causes irreversible and not manageable soil deterioration still remains. If the farm households operate with modest levels of nutrient extraction below this critical rate, they may be able to invest returns from agricultural production in physical, human, or social capital and increase yield levels and household income in the long run.

Notes

1. In this chapter ecologically sustainable agriculture is referred to as the achievement of nonnegative nutrient balances. This definition is related to the "strong" sustainability definition that does not allow for substitution of different forms of capital and implies constant stocks of natural resources (Hazell and Lutz 1998). The "weak" definition of sustainability, in contrast, permits substitution and thus more flexibility between growth and sustainability objectives. Nutrient imbalances are just one chemical process beside other chemical, physical, and biological degradative processes (e.g., acidification, crusting, soil biodiversity reduction). However, because of their comprehensive role in evaluating the biophysical effects of land management and importance as a major determinant of yield levels, nutrient balances are widely accepted as sustainability indicators (Lynam, Nandwa, and Smaling 1998).

2. For more details see Pender et al. (2001b).

3. Hence, identified development domains can deliver valuable information for the selection of relevant policy scenarios.

4. A detailed description of the farm trials in the Iganga District is given in Esilaba et al. (2001).

5. Stratified random sampling was used to select 107 households for the identification of representative household types. Details of the statistical data analysis and the sampling strategy can be found in Woelcke (2003).

6. For more details on the modeling approach see Woelcke (2003).

7. The concept of ANN is described in Bishop (1995) and Principe, Euliano, and Lefebvre (2000). As far as the authors know, neural networks have not been used for yield estimation purposes before. Park and Vlek (2002) examined the possibility of predicting soil property distribution with ANN.

8. The appropriateness of nutrient balances as an indicator for soil productivity and sustainability assessment has been intensely debated in the literature (Lynam, Nandwa, and Smaling 1998). However, for normative and comparative-static analyses as in this chapter, the indicator is useful despite its well-known limitations.

9. Permanent off-farm activities were included as binary variables if the interview indicated relevance of the question. These activities can be of essential economic importance (e.g., in the case of the commercial farm household, permanent off-farm activities contribute about 60 percent to the household income).

10. Labor exchange is a traditional form of labor acquisition, where men or women form working groups, based on the idea of overcoming the labor constraints of its members. It is not common among group members to pay for labor: occasionally labor is paid in kind.

11. Table 15.3 indicates the model results for the four farm household types on the predominant soil class. The model results for all identified soil classes in the region are presented in Woelcke (2003).

12. For more details see Woelcke (2003).

13. The "reduced costs" indicate how far each activity is from entering the optimal model solution. That is, they indicate by how much the objective function value of each activity would have to be improved before the activity would be selected as part of the farm plan. The second row in the table of Figure 15.1 provides a list of potential activities and the changes in their "reduced costs" in response to changing fertilizer prices. As an example, Figure 15.1 indicates reduced costs of 69,000 Ush for the introduction of the production activity "Maize+NP2," assuming the current fertilizer prices are reduced up to 20 percent of the current prices. This means that the costs of this production activity have to be reduced by 69,000 Ush before it is profitable to be included in the farm plan.

14. It should be emphasized that high positive nutrient balances also have negative impacts on the environment (eutrophication). This effect is neglected in this study because of its low relevance in the study region.

15. For more details see Woelcke (2003).

Chapter 16

Strategies for Sustainable Land Management in the East African Highlands: Conclusions and Implications

John Pender, Frank Place, and Simeon Ehui

The studies in this book sought to understand the factors affecting rural households' choice of income strategies and land management practices and the implications of these decisions and of policy- and program-relevant factors for agricultural production, household welfare, and land degradation. We noted at the outset that the factors influencing these decisions and outcomes are many and complex and that their effects may be very context-dependent in a region as diverse as the East African highlands. The findings in the preceding chapters amply support this hypothesis.

The material presented in Chapters 3–15 of this book provides a rich and diverse set of findings. It is impossible to summarize all of these findings in a few sentences or provide a simple prescription to solve all of the problems of rural people in the East African highlands based on these results. Because the problems are complex and situations are diverse, the solutions to the problems are also likely to be complex and diverse. Still, in this chapter we seek to synthesize what has been learned from these studies as briefly as possible, relate these findings to the broader literature on determinants and effects of livelihoods and land management, and draw implications for policy makers, development agencies, researchers, and others seeking to address these problems in East Africa and elsewhere.

Synthesis of Research Findings

The qualitative findings of Chapters 3–15 are summarized in Table 16.1. We organize the discussion according to the factors about which hypotheses were developed in Chapter 2, including the effects of factors determining local comparative advantages (agricultural potential, access to markets and infrastructure, and population pressure), income strategies, land management practices, and other policy-relevant factors (irrigation, agricultural technical assistance, credit, other programs and organizations, land tenure institutions, education, and gender). We will discuss the empirical relationships observed in these studies as "associations" rather than as "effects" because causality is difficult to prove in any empirical study.[1] In some cases, the findings are based on results of bioeconomic modeling; such findings are discussed as "predictions" rather than "conclusions," although these models are based on empirical data collected in the study locations.

Agricultural Potential

Agricultural potential is clearly important in influencing rural households' choice of livelihood strategies in the East African highlands. In more humid areas having bimodal rainfall patterns and sufficiently good soils, production of perennial cash crops such as coffee is common, as in the highlands of central Kenya (Chapter 8), the Lake Victoria region and the eastern highlands of Uganda (Chapter 7), and much of southwestern Ethiopia. Perennial food crops are also common in such areas, but annual food crops (especially maize) are also important in many such areas. Dairy production and woodlots are also more common in higher-rainfall areas (Chapter 3), though these also depend on sufficient market access (Chapters 3, 8, and 14).

In less humid environments, cereals and livestock are more dominant in the farming system, as in northern Ethiopia (Chapters 4–6 and 9) and in parts of southwestern and much of northern and eastern Uganda (Chapter 7). Differences in rainfall, altitude, and other agro-ecological factors influence the choice of cereals and livestock within the cereal–livestock system. However, other factors besides agricultural potential also influence the mixed cereal–livestock system. For example, maize–livestock production is the dominant farming system in western Kenya, even though soil and climatic conditions are suitable for production of higher-value cash crops in this region (Chapter 8). Lack of access to the large Nairobi market and to market institutions (e.g., cooperatives) is one of the key differences between western Kenya and the much more prosperous region of central Kenya (Chapter 8).

Land management practices differ between areas of high and low agricultural potential in complex ways. Several intensive practices are more common in higher-potential areas (HPAs) where rainfall and soils are more favorable (Chapters 4 and

9). This is probably because the productivity effects of soil fertility management practices such as inorganic fertilizer and leguminous cover crops (LCC) are often greater in HPAs (Chapters 9 and 13). However, this is not always the case. For example, fertilizer use is less common on more fertile soils in Uganda (Chapter 11), probably because it has less influence on productivity on such soils.

As expected, incomes and other welfare indicators are often better in areas of higher agricultural potential (Chapters 3, 4, and 8). However, the risk of land degradation can be greater in such areas as well, especially in steeply sloping highlands as in Uganda (Chapter 7).

Market Access

Because of its favorable market access as well as its high agricultural potential, central Kenya stands out as a fairly anomalous success story in the East African highlands. Livelihoods of smallholders in this region are highly diversified, including cash crops, dairy production, and high levels of nonfarm income (Chapter 8). These different livelihoods complement each other, with cash and credit from cash crop production helping to facilitate demand for and investments in other income strategies such as dairy production and nonfarm activities, and vice versa. As a result of production of higher-value commodities and greater liquidity, farmers in central Kenya are able to adopt much higher levels of use of fertilizer and land improvements than elsewhere and attain higher productivity and more perceived improvement in soil conditions. This suggests that a virtuous circle of land improvement and higher productivity and incomes is possible in areas with sufficiently favorable agricultural potential and sufficient access to markets and market institutions to promote high-value commodity production and nonfarm activities.

The effects of better access to markets on income strategies in Kenya are demonstrated in Chapter 3 by Place et al., who showed that maize is less common and cash crops are more common closer to urban areas. Similarly, Kruseman et al. (Chapter 4) found that *teff* production (an important cash crop in northern Ethiopia) is more common, and sorghum and various livestock are less common, closer to urban markets in Tigray. Place et al. (Chapter 3) also found that woodlots are more common closer to urban areas in Kenya, consistent with the prediction by Holden et al. (Chapter 14), based on their bioeconomic model, of large potential income gains from increased tree-planting activities in northern Ethiopia close to roads and markets. In these regions, better market access is associated with income-enhancing strategies and, not surprisingly, with indicators of better welfare outcomes (e.g., better housing quality) (Chapters 3 and 4).

However, there may be trade-offs between improved income and some natural resource conditions resulting from better market access. In Kenya, better market

Table 16.1 Summary of qualitative findings of Chapters 3–15

Characteristics of development domains	Income strategies/assets	Labor intensity	Land management practices	Value of crop production per hectare	Land degradation	Income/cap welfare
Higher agricultural potential	+ higher-value cash crops (3,7,8) +/– cereals (4) + ox ownership (4) – improved livestock (6) + dairy production (3) + woodlots (3)		Mixed impacts *In higher rainfall areas:* + gully checks, drainage, compost (4), reduced tillage, contour plowing, manure, household refuse (9) – terraces, manure, tree planting (4) *On better soils:* + gully checks, drainage, soil bunds, tree planting (4) – Fertilizer (4, 11), reduced tillage, crop residues (9, 11)	+ in high-potential eastern highlands of Uganda (7) + productivity impact of fertilizer in higher-potential areas (9, 13) + productivity impact of leguminous cover crops in HPA[a] (13)	+ erosion in high potential Highlands of Uganda (7)	+ (3,4,8)
Higher market/road access	+ cash crops (3,4,8) – subsistence food crops (3,4,8) – oxen, cows, beehives (4) + oxen, goats (5) + dairy (8) – improved livestock (6) + woodlots (3, 14)	+ (5) – in HPA (9) – collective woodlot management (10)	*Closer to urban centers, towns:* + fertilizer use (4,8), oxen power (5), land investment (8), reduced tillage, contour plowing (9) – contour plowing (5), crop rotation, crop residues (9, 11), mulch (11), tree planting in community woodlots (10), guards and penalties in grazing land management (10) *Closer to roads:* + fertilizer use (4,5), burning (5), crop rotation (9) – reduced tillage, contour plowing (9)	+ (5) – in HPA (9) (road access)	– tree cover (3) + erosion in highlands (7) – perceived land degradation in C. Kenya (8) – tree survival in woodlots (10)	+ (3,4,8)
Higher population pressure	– barley, maize (4) + cattle density (3) – oxen, sheep ownership per household (4) – cattle ownership (6)	+ (5) + woodlot management at moderate population	+ fertilizer (4,5), oxen power (5), intercropping (5), crop residues (9), improved seed in LPA (9) – fallow (4), reduced tillage (9), contour plowing (9), fertilizer use in LPA (9),	– (9) (in structural model)	– tree cover (3) – availability and quality of grazing land (6) + erosion in highlands (7)	+ (3, 4)

	+ improved livestock (6) + beehives (4) + woodlots (3)	density (10)	– improved fallow (13) ∩ more tree planting density in woodlots at moderate population density (10)[b] ∩ more hiring of guards to protect grazing lands and ∪ fewer violations of grazing restrictions at moderate population level of community (10)			
Irrigation	+ barley (4)	+ (5) + in HPA (9)	+ drainage, stone terraces, tree planting (4), improved seed, reduced tillage (5), ox power in LPA (9), seed in HPA (9), private pastures (6), household refuse (9) – compost (4), fertilizer (9), improved seed in LPA (9)	+ in LPA (9)		
Government agricultural extension	– goats (4)		+ fertilizer (9, 11), contour plowing in HPA (9), crop residues in LPA (9), manure and mulch (11) – ox power (5) – community contribution to protection of community woodlots and grazing areas (10)	+ in lowlands (7) + in HPA (9)	+ erosion in highlands (7) – tree survival in woodlots (10)	
NGO agricultural technical assistance			+ fertilizer (11) – manure (11)	+ in highlands (7) – in lowlands (7)	– erosion in lowlands and highlands (7)	
Cooperatives	+ maize, oxen ownership (4) – barley (4)	+ in HPA, input coop. (9) – in LPA, mktg. coop. (9)	+ irrigation canals (4), seeds (5) – burning (5) *Input cooperatives:* + reduced tillage (9), improved seed in HPA (9), ox power in HPA (9) – crop rotation in LPA manure, household refuse (9) *Marketing cooperatives:* + crop rotation in LPA (9) – reduced tillage (9)	+ (5) Input coops: + in HPA (9) – in LPA (9)		+ (4,5)

(*continued*)

Table 16.1 (continued)

Characteristics of development domains	Income strategies/assets	Labor intensity	Land management practices	Value of crop production per hectare	Land degradation	Income/cap welfare
Local organizations (in general)			+ household contributions to protect restricted grazing lands (10)			
Food-for-work (FFW)			+ soil and water conservation (SWC) investment if FFW used to promote SWC (14) – SWC if FFW not used to promote SWC (14)	– if FFW not used to promote SWC on farm (14)	– erosion if FFW promotes SWC, + erosion if not (14)	+ (14)
Credit	+ Maize prod. (4) + Dairy, cash crops in C. Kenya (8) – Cattle ownership (ACSI credit) (9) + Oxen ownership, improved livestock (other NGO credit) (9) + in LPA (9)	+ in LPA (9) – in HPA (9) Limited effect of credit only (14)	+ drainage ditches, tree planting (4), fertilizer (5,8), fertilizer in HPA (9), improved seeds (5), stall feeding (6), reduced tillage (9), crop residues in HPA (9) – improved seed in LPA (9), manure (11) Limited effect of credit only on SWC investment (14) and fertilizer use (15)	+ in LPA (9) Limited effect of credit only (14, 15)	Limited effect of credit only (14, 15)	Limited effect of credit only (14, 15)
Income strategies (cf. food crops)	Cash crops	+ (5)	+ improved seeds, reduced tillage (5) – burning (5)	+ (7,9)		+ in central Kenya (8)
	Livestock	– (5)	– ox power, burning (5)	+ (7)		+ due to dairy in C. Kenya (8)
	Nonfarm/off farm	– (5,14)	+ fertilizer, improved seeds, reduced tillage (5) – manure/compost, ox power (5), SWC investment (14)	+ (7) – (14)	+ erosion (14)	+ (14)
	Food aid/other asst.	– (5)	– manure/compost, burning, intercropping, ox power (5)	+ (5)		
	Forestry/woodlots			– (7)	+ tree cover (3)	+ (3, 14)

Household endowments	Land/farm size		+ reduced tillage (5), contour plowing and improved seed in LPA (9), fertilizer in HPA (9), mulch (11) – fertilizer (5,11), manure (11)	– (7) – in LPA (9)		
	Labor	+ (5)	+ reduced tillage, crop residues (9), improved seed in HPA, crop rotation in HPA (9), manure (11), fertilizer (11) – manure, household refuse (9)		+ erosion (7)	– (5)
	Education	+ (5)	+ improved seed in HPA (9), crop residues (11) – reduced tillage (9), crop rotation and crop residues in HPA (9), manure (11)		+ availability of grazing land (6) + erosion (7)	+ (5)
	Gender: female head	– (5) – in LPA (9)	+ reduced tillage (5,9), fertilizer (11) – manure/compost (5), ox power (5), contour plowing (5), crop residue incorporation (9)	– (5) – in HPA (9)		– (5)
	Livestock: oxen	+ (5) – in HPA (9)	+ ox power (5), manure/compost (5), contour plowing (5), reduced tillage (9), fertilizer in HPA (9), crop residues in LPA (9) – reduced tillage (5), crop rotation in LPA (9), household refuse (9)	+ in HPA (9)		
	Livestock: other	– (5)	+ crop rotation, manure, household refuse (9) – ox power, burning, intercropping (5), reduced tillage (9), fertilizer in HPA (9), crop residues in LPA (9)	+ (5,7)		+ (5, 12)
Land tenure/rights						
– Land redistribution	+ household ownership of up to two oxen (6) – ownership of more than two oxen (6) + ownership of other livestock, improved breeds (6)		+ crop residue incorporation in HPA (9), use of stall feeding, crop residues as a feed source (6) – ox power, contour plowing, crop rotation and crop residue incorporation in LPA (9); fertilizer use in HPA (9)	+ (9) (in structural model)	– quality of grazing land (6)	

(*continued*)

Table 16.1 (continued)

Characteristics of development domains	Income strategies/assets	Labor intensity	Land management practices	Value of crop production per hectare	Land degradation	Income/cap welfare
– Tenure security			+ manure use (9), ox power in LPA (9) – fertilizer and crop residue incorporation in HPA (9)	+ (9)		
– Mode of land acquisition (owner-operated versus other)		+ on owner-operated in HPA (9)	– manure (9), improved seeds in HPA (9); ox power, contour plowing and seeds in LPA on owner-operated plots (9)	– owner–operated plots in LPA (9) + purchased versus inherited plots (7)		
– Land rights system			+ crop residue incorporation and mulching on *mailo* versus freehold plots (11) – fertilizer use on customary versus freehold plots (11)		– erosion on *mailo* versus freehold plots (7)	
– Village level management of grazing lands					+ grazing land availability and quality (6)	
Land management						
– Investments		+association of stone terraces with labor use in LPA (9), fences with labor use (5,9)	+ association of stone terraces with fertilizer use (5,9) and contour plowing (5,9) – association of stone terraces with household refuse (9) + association of fences with manure (5,9), contour plowing (9), household refuse (9), ox power in HPA (9), seed use in LPA (9) – association of live fences with reduced tillage (9), crop residue incorporation in LPA (9)	+ impact of stone terraces in LPA (5,9) + impact of live fences and drainage ditches in HPA (9)		
– Fertilizer				+ (5) + in HPA (9, 13)		

– Agronomic practices		– reduced labor requirement of reduced tillage (with herbicides) (12) + increased labor requirement for leguminous cover crops and biomass transfer (13)			+ ox power in LPA (5,9), seed use (5,9) + improved seed in HPA (9) + reduced tillage (5) + reduced burning (5) – crop residues in LPA (9) + leguminous cover crops and *tithonia* biomass transfer (13) Limited productivity impacts of most soil fertility practices in eastern Uganda (15)	+ reduced/zero tillage reduces erosion, increases carbon sequestration, increases soil moisture (12) + grazing enclosures reduce erosion, increase biodiversity (12) + leguminous cover crops improve nitrogen balance (13) +/– biomass transfer improves nutrient balance in recipient areas, depletes source areas (13)	+ reduced tillage by promoting higher-value livestock (12) + area enclosures (12) Limited income impacts of most soil fertility practices in eastern Uganda (13, 15)

Note: Chapter numbers in parentheses.

[a]HPA = higher-potential areas; LPA = lower-potential areas.

[b]U = U-shaped relationship (e.g., lower at moderate population density); ∩ = inverted U-shaped relationship.

access is associated with less tree cover (Chapter 3), and in Tigray better market access is associated with lower tree survival rates in community woodlots (Chapter 10). These findings are consistent with others showing that road development is associated with many indicators of improved welfare, but also with deforestation, in Uganda (Pender et al. 2004a), as in many other developing countries (e.g., Chomitz and Gray 1996; Mertens and Lambin 1997; Nelson and Hellerstein 1997).

Market access also influences access to nonfarm opportunities. In the highlands of central and western Kenya, nonfarm income accounts for nearly 40 percent of total household income (Chapter 8). The similar share of nonfarm income in these two regions, despite large differences in total household income between these regions, suggests that nonfarm activities do not hinder agricultural income in the more prosperous central highlands. Households in central Uganda close to Kampala earn a similar share of income from nonfarm activities (Ehui and Pender 2003), but nonfarm income generally accounts for a much smaller share of income elsewhere in Uganda (Ehui and Pender 2003) and in the northern Ethiopian highlands (Pender 2004), where access to urban centers is much less. This is similar to findings of other literature showing that nonfarm activities and off-farm income tend to be higher in areas close to urban markets and roads in Africa (Haggblade, Hazell, and Brown 1989; Reardon 1997; Barrett, Reardon, and Webb 2001).

As expected, market access and high-value crop production contribute to intensification in use of fertilizer and many other inputs in central Kenya (Chapter 8). Market access also contributes to use of fertilizer and other inputs in Tigray (Chapters 4 and 5). However, better market access sometimes reduces adoption of labor-intensive land management practices by increasing the opportunity costs of labor (Chapters 5, 9, and 11).

Market access also influences collective land management decisions. Gebremedhin et al. (Chapter 10) found that communities with better access to markets contribute less labor and plant fewer trees on community woodlots (and have lower survival rates of the trees planted, as mentioned above), probably because of higher opportunity costs of labor in such areas and/or because market access increases people's ability to avoid sanctions for not participating in collective action (Bardhan 1993). Communities with better market access are also less likely to establish penalties for violations of grazing restrictions or to pay a guard to monitor their restricted grazing areas (Chapter 10). Thus, better market access does not assure better management of natural resources.

Population Pressure

Population pressure also affects households' income strategies. In Kenya, higher population density is associated with higher cattle density and more woodlots (Chapter 3). Livestock and tree-planting activities thus appear to be intensification responses to population pressure. However, although population pressure appears to contribute to higher livestock density per hectare in Kenya, it is associated with fewer large animals owned per household in northern Ethiopia (Chapters 4 and 6). Adoption of improved livestock breeds (Chapter 6) and beekeeping (Chapter 4) are also associated with population pressure in Ethiopia, suggesting that these are intensification responses to declining availability of land for extensive livestock production.

Population pressure contributes to more intensive land management practices, as hypothesized by Boserup (1965) and many others. Higher population density is associated with less use of fallow (Chapter 4), higher labor and oxen intensity in crop production (Chapter 5), more use of fertilizer (Chapters 4, 5, and 11), and with use of some labor intensive land management practices (Chapters 5, 9, and 11). However, high population density in much of the East African highlands likely limits the use of leguminous cover crops in improved fallows because land scarcity limits farmers' ability to fallow land, even for only one season (Chapter 13). This argument is supported by other research findings showing that larger farms are more likely to adopt improved fallows in western Kenya (Place et al. 2002a, 2004) and Malawi (Gladwin et al. 2002). Population pressure also limits use of terraces by small farms, because these occupy scarce land (Chapter 14).

Moderate population pressure is associated with more effective collective action to manage communal resources than low or high levels (Chapter 10). This may be because the benefits of collective action to manage resources are too low relative to the fixed cost of organizing it at low population density, whereas the variable costs of achieving effective collective action and the incentives to violate collective agreements become too high at high population density (Olson 1965; Ostrom 1990; Sandler 1992; Pender 2001).

Population pressure indirectly affects agricultural production by leading to smaller farm sizes. Pender et al. (Chapter 7) found that smaller farms achieve higher crop yields in Uganda, as did Benin (Chapter 9) in lower-rainfall areas of the Amhara region in northern Ethiopia. These findings are consistent with a large body of literature showing an inverse relationship between farm size and agricultural productivity in developing countries (e.g., Chayanov 1966; Sen 1975; Berry and Cline 1979; Carter 1984; Barrett 1996; Heltberg 1998).

Population pressure is associated with better indicators of some aspects of welfare but worsening of natural resource conditions in some parts of the East African highlands. For example, housing quality (indicated by houses with metal roofs) is better in more densely populated areas of Kenya and northern Ethiopia (Chapters 3 and 4). On the other hand, tree cover is lower in more densely populated areas of

Kenya (Chapter 3), there has been more decline in grazing land availability and quality in communities where population growth has been more rapid in the Amhara region of Ethiopia (Chapter 6), and soil erosion is higher in more densely populated areas of the highlands of Uganda (Chapter 7). These findings are consistent with those of Pender et al. (2001a), who found that more rapid population growth was associated with many worsening resource conditions in northern Ethiopia, and Grepperud (1996), who found greater land degradation in more densely populated areas of the Ethiopian highlands. They are not consistent with the more optimistic "more-people, less-erosion" hypothesis that Tiffen, Mortimore, and Gichuki (1994) found in the Machakos district of Kenya. However, access to urban markets and technical assistance may have been more responsible than rural population growth for improved land management in the Machakos district, consistent with the findings of Chapter 8 of improved land management in central Kenya as a result of these advantages.

Income Strategies

In central Kenya, cash crop production is associated with investments in land improvement and with greater use of fertilizer and other inputs, resulting in higher value of crop production, higher incomes, and perceived improvements in land quality (Chapter 8). In Uganda, bananas, coffee, and horticultural crop production are also associated with adoption of various intensive land management practices and higher value of production (Chapter 7; Nkonya et al. 2004). These findings are consistent with those of Pender et al. (2004a) and Pender et al. (2001a), who found, based on community surveys in Uganda and Ethiopia, that perennial crops were associated with more use of several resource conservation practices and more improvement in several indicators of productivity, human welfare, and natural resource conditions. Horticultural crops are associated with more use of improved seeds in Tigray (Chapter 5), although no significant difference in the value of crop production or income as a result of horticultural production was found there. Thus, cash crop production contributes to intensification and improved outcomes in many cases, but not everywhere.

Livestock production is associated with higher value of crop production and incomes in much of the East African highlands. Dairy production is associated with higher incomes and better housing quality in Kenya (Chapters 3 and 8). In Uganda, livestock are associated with more use of manure in crop production (Chapter 11), higher value of crop production (Chapter 7), and higher household income (Nkonya et al. 2004). Livestock ownership (especially oxen and other cattle) is also associated with intensification of crop production in northern Ethiopia (Chapters 5 and 9) and with higher incomes in Tigray (Chapter 5).

Tree planting also can contribute to higher incomes and welfare and improved resource conditions in suitable areas of the East African highlands. In Kenya, Place et al. (Chapter 3) find that woodlots are associated with better housing quality and more tree cover. Holden et al. (Chapter 14) predict that eucalyptus tree planting on degraded lands could substantially increase incomes in their study site in northern Ethiopia, with limited effects on soil and water conservation or erosion of croplands. These findings are consistent with those of several other studies of the economic and ecological impacts of woodlots in Ethiopia (Okumu et al. 2002; Gebremedhin, Pender, and Tesfay 2003; Getahun 2003; Jagger and Pender 2003). Tree crops are also important sources of income, especially coffee and tea in suitable areas, but fruits and nuts also can be important. For example, macadamia trees are an important source of income in central Kenya (Chapter 8).

Nonfarm activities and off-farm employment can have mixed impacts on agricultural production, reducing labor intensity but increasing farmers' ability to purchase inputs. For example, these activities are associated with less labor-intensive crop production in Tigray but more use of improved seeds (Chapter 5). The net effect on crop production is insignificant, but household involvement in nonfarm activities and off-farm employment increase household incomes (Chapter 5). Holden et al. (Chapter 14) predict that increased off-farm employment opportunities in the northern Shewa zone of the Amhara region would substantially increase household incomes but would also reduce investment in soil and water conservation (SWC) measures and crop production and increase soil erosion unless off-farm employment is targeted to promote SWC investment, for example, through food for work (FFW) programs. These findings indicate potential trade-offs between promoting increased incomes, increased agricultural production, and reduced land degradation via income diversification into nonfarm activities. Such trade-offs appear to be dependent on the context and type of land degradation considered, however. In Uganda, for example, nonfarm activities are associated with higher value of crop production (Chapter 7) and less soil nutrient depletion (Nkonya et al. 2004).

Land Management Practices

Investments in stone terraces were found to have substantial positive influences on crop production in lower-rainfall areas of the northern Ethiopian highlands (Chapters 5 and 9) but not in higher-rainfall areas (Chapter 9). This suggests that the short-term yield benefits of these investments are largely through conservation of soil moisture. Pender and Gebremedhin (Chapter 5) estimate that the rate of return of investments in stone terraces in Tigray averages close to 50 percent, similar to the rate of return from such investments estimated by Gebremedhin, Swinton, and Tilahun (1999) based on experiments conducted in Tigray. In earlier research, Herweg (1993a,b) also noted greater yield effects of soil and water conservation measures in lower-rainfall environments in the Ethiopian highlands. In higher-rainfall areas of the Amhara region, Benin (Chapter 9) found that investments in drainage ditches and live fences have significant positive effects on crop yields, suggesting that management of excess water and livestock are of more concern for crop production in higher-rainfall environments.

By increasing the availability of soil moisture, SWC investments can increase the profitability and reduce the risks associated with use of inputs such as inorganic fertilizer (Hengsdijk, Meijerink, and Mosugu 2005). Consistent with this, Pender and Gebremedhin (Chapter 5) and Benin (Chapter 9) find greater use of inorganic fertilizer on plots where stone terraces have been constructed. Some organic land management practices such as manuring are more common on plots where fences have been constructed (Chapters 5 and 9), possibly because such plots are where livestock are kept. Exploiting such complementarities can substantially enhance the profitability and sustainability of land management approaches.

Inorganic fertilizer can contribute to higher productivity, especially in more favorable environments with sufficient rainfall and good access to markets. Use of inorganic fertilizer is yielding high returns in the high-potential highlands of central Kenya, especially on higher-value crops (Chapter 8). It is also contributing to substantially higher yields in the higher-potential parts of the Amhara region in Ethiopia, increasing average cereal yields by more than 50 percent (Chapter 9). Improved seeds are having a similarly large effect in this favorable environment (Chapter 9).

However, in less favorable environments, inorganic fertilizer use is much less profitable and is risky. In drought-prone areas of the northern Ethiopian highlands, inorganic fertilizer use is not profitable on average (Chapters 5 and 9). A recent study by Kruseman (2004) confirms the low profitability and high risk of using inorganic fertilizer in the drought-prone environment of eastern Tigray, predicting with a bioeconomic model that fertilizer prices would have to be about 50 percent lower to induce sufficient adoption of fertilizer to stem soil fertility decline. The results of Holden et al. (Chapter 14) also imply relatively low returns to use of inorganic fertilizer in their study community in North Shewa. Inorganic fertilizer is also not very profitable in much of Uganda (Chapter 7; Pender et al. 2004c; Nkonya et al. 2005b), in part because of low yield response and in part because of high fertilizer prices relative to commodity prices (Chapter 15). Woelcke et al. (Chapter 15) predict using their bioeconomic model that fertilizer prices would have to fall by more than 90 percent before substantial adoption would be profitable in maize production in their study villages in eastern Uganda. Inorganic fertilizer will thus not likely be a panacea for soil fertility depletion and low productivity in much of the East African highlands.

Organic approaches to soil fertility management also have context-dependent effects. Manure and compost use are associated with higher crop yields in Tigray, as are reduced tillage and reduced burning (Chapter 5). However, in the Amhara region and in Uganda, organic practices have statistically insignificant or negative associations with crop yields (Chapters 7 and 9). The apparently better response of soils in Tigray to organic inputs may be because of the extremely low organic matter content of soils in this region, where over 90 percent of the soils are very low in organic carbon (Haile, Gebremedhin, and Belay 2003) and where soil moisture is a severe constraint. In drier environments, the benefits of soil organic matter often result more from its effects on soil moisture infiltration and retention than on nitrogen availability (Giller et al. 1997). Where soil moisture and organic matter are less constraining, application of organic materials may be less immediately beneficial and can actually reduce yields in the near term if the carbon-to-nitrogen ratio or lignin content of the organic matter is too high because such organic materials can immobilize available nitrogen (Giller et al. 1997; Chapter 13). The quality of manure and other organic materials can vary greatly as a result of differences in animal type and feed sources, soil fertility, how the material is stored, and other factors (Giller et al. 1997). Such variations may contribute to the low returns to organic inputs in many cases.

Reduced tillage has more favorable effects on crop productivity in the Tigray region (Chapter 5) than in the Amhara region (Chapter 9). As with application of organic inputs, reduced tillage helps to conserve soil organic matter (Chapter 12; Giller et al. 1997) and improve soil moisture retention, which are critical needs in Tigray. Aune et al. (Chapter 12) report somewhat higher maize yields on demonstration plots using reduced tillage than on plots using normal tillage in higher-potential areas of the Amhara and Oromiya regions of Ethiopia. Whether such yield advantages exist under farmers' normal practices in higher-potential areas, when herbicides are rarely used, is not clear, however. Nevertheless, even if farmers are able to obtain similar yields with reduced tillage, its use may still be advantageous by helping to reduce tillage costs and land degradation, providing an option to oxen-poor households, and promoting more remunerative investment in other kinds of livestock besides oxen (Chapter 12).

Transfer of high-quality biomass sources of nitrogen and phosphorus, such as *Tithonia diversifolia,* a common shrub in western Kenya and eastern Uganda, has shown promising effects in increasing maize yields (Chapter 13). However, using nonleguminous plants such as *Tithonia* for biomass transfer only redistributes soil nutrients within the landscape, increasing fertility in one place by decreasing it in another, and is limited by the high labor costs involved (Chapter 13).

Planting leguminous cover crops, shrubs, or trees as part of an improved fallow also shows significant potential to increase crop yields in parts of the East African highlands (Chapter 13). However, such yield increases are often insufficient to compensate for the loss of at least one season of production and the additional management and labor costs (Chapter 13). Thus, such improved fallow technologies are less suited to areas of high population density, where land scarcity is extreme and fallowing is uncommon (Chapter 13), as in much of the East African highlands, except in spatial niches such as field boundaries or by farmers who have relatively large farms (Place et al. 2004). These technologies are also more suited to areas of higher agricultural potential because the productivity of these leguminous crops is higher in areas of higher agricultural potential (Place et al. 2004; Chapter 13).

The results in this subsection highlight the context dependence of the effects of land management technologies. Inorganic fertilizer is most profitable in areas of high agricultural potential and market access, and vegetative practices such as improved fallows also appear better suited to areas of high agricultural potential but intermediate population density. By contrast, some soil and water conservation investments, organic inputs, and reduced tillage appear to be more profitable in lower-rainfall areas where their effects on soil moisture retention appear to be more beneficial.

Effects of Other Factors

The studies in this book also shed light on the effects of several policy-relevant factors, including irrigation, technical assistance, and credit programs, presence of and participation in various types of organizations, education, gender, and land tenure issues. We consider the findings related to these issues in this subsection.

Irrigation

Not surprisingly, irrigation is associated with increased intensity of crop production in northern Ethiopia (Chapters 4, 5, and 9). Despite this, Pender and Gebremedhin (Chapter 5) find insignificant effects of irrigation on the value of crop production and household income in Tigray, controlling for use of inputs, land quality, household characteristics, and other factors. These findings are consistent with those of Amacher et al. (2006), who also studied effects of irrigation dams in Tigray. That study and others also found that access to irrigation dams contributes to increased incidence of diseases such as malaria and schistosomiasis (Tedros et al. 1999; Amacher et al. 2006). Such costs should be borne in mind in efforts to promote irrigation or other water-harvesting methods (especially at lower elevations). Nevertheless, where irrigation is profitable, households may be willing to pay for mosquito nets and other preventive measures (Lampietti et al. 1999).

Part of the reason for low returns to irrigation in Tigray is that farmers' traditional methods of irrigation use water inefficiently and obtain significantly lower yields than is possible (Mintesinot et al. 2004). Irrigation dams in Tigray are also beset by problems of sedimentation because of inadequate conservation of the catchment areas, salinity buildup from seepage and lack of adequate drainage, and biological contamination of the reservoirs (Mintesinot and Mitiku 2003). In addition, several institutional and market problems also appear to be limiting the beneficial economic effect of irrigation investments, including lack of skilled manpower to ensure proper design of the dams (Egziabher 2003); lower actual than nominal irrigation capacity of the dams (Hagos, Pender, and Gebreselassie 1999); separation of organizational responsibilities for constructing the dams, conserving the catchment, and maintaining the irrigation structures (Hagos, Pender, and Gebreselassie 1999); lack of farmer experience with irrigation or with production and marketing of higher-value perishable crops (Hagos, Pender, and Gebreselassie 1999); lack of development of marketing facilities and institutions for such crops (Hagos, Pender, and Gebreselassie 1999); lack of clarity about water rights and their relationship to land access rights (Tesfay et al. 2000); and lack of a comprehensive irrigation policy addressing issues of water rights, cost recovery, and other issues (Tesfay et al. 2000).

Benin (Chapter 9) found positive effects of irrigation on crop production in drought-prone areas of the Amhara region but not in high-potential areas. As in Tigray, the positive effects of irrigation on crop yields appear to be related to increased intensity in use of inputs (especially draft power). The effects of irrigation on crop production may be year specific as well as location specific: there was a major drought affecting the survey year in Amhara but not in Tigray, which may account for larger effects of irrigation in drought-prone areas of Amhara than in Tigray.

Irrigation is also associated with more intensive livestock production, including greater use of improved breeds, animal health services, and private pastures (Chapter 6). These associations may result from indirect influences. For example, irrigation may increase farmers' income and ability to finance purchase of improved breeds and to provide feed and health care for improved animals. It may also increase the scarcity of land available for common pasture, thus contributing to privatization of pastures.

Agricultural Technical Assistance Programs

Access to government agricultural extension contributed to adoption of inorganic fertilizer and contour plowing in the Amhara region and to higher crop yields in higher rainfall areas of this region (Chapter 9). However, extension has small and statistically insignificant effects on production in lower rainfall areas of Amhara and Tigray (Chapters 5 and 9). Hagos (2003) also found statistically insignificant effects of agricultural extension on income in Tigray, and Demeke and Egziabher (2003) even found negative effects of the extension and credit program on production and income in marginal agricultural areas of Tigray. This is because the technologies most promoted by the extension program in Ethiopia during the period studied, inorganic fertilizers and improved seeds for cereals, are profitable mainly in the high-rainfall areas but less profitable and risky in low-rainfall areas, as noted earlier.

Involvement of the Bureau of Agriculture's development agents in promoting establishment of community woodlots in Tigray also tended to undermine collective action in managing these resources (Chapter 10). Thus, agricultural extension and regulatory efforts of agricultural bureaus in low-rainfall areas of northern Ethiopia appear to have been of limited benefit to farmers during the period studied.

In Uganda, Jagger and Pender (Chapter 11) find a positive association of government agricultural extension with adoption of several land management practices, including use of fertilizer, pesticides, manure, and mulching. Extension and training programs also are associated with increased value of crop production (Chapter 7), especially in the lower-elevation areas. However, agricultural extension is also associated with greater soil erosion in the higlands of Uganda (Chapter 7), and in eastern Uganda, extension contributes to soil nutrient depletion by promoting adoption of higher-yielding varieties without sufficient adoption of soil fertility management practices (Nkonya et al. 2004). Thus, agricultural extension may lead to trade-offs between production and sustainability objectives unless the extension program provides a sufficiently intensive effort to promote improved land management practices.

Agricultural technical assistance programs of nongovernmental organizations (NGOs) also appear to have significant effects on agricultural production in Uganda, but these are also context dependent. Such organizations are associated with increased use of fertilizer and pesticides (Chapter 11), with higher crop production in highland areas, and with lower erosion in general (Chapter 7).

In Kenya, Place et al. (Chapter 8) argue that differences in access to technical assistance cannot account for the large differences in technology adoption and productivity between the central and western highlands. Although Chapter 8 does not statistically test the effects of technical assistance, their argument is supported by findings of Gautam and Anderson (1999), who found statistically insignificant effects of the agricultural training and visit extension system in Kenya. Thus, the effects of extension may not be uniformly positive even in areas of high agricultural potential and favorable market access.

Credit Programs

The availability of credit appears to have had important positive effects on the extent of agricultural commercialization, diversification, and intensification in central Kenya (Chapter 8). In Ethiopia, we see less positive influence of credit. In Tigray, formal credit use is associated with greater use of improved seeds and fertilizer but has little effect on crop production and income because of limited influences of these technologies in this environment (Chapter 5; Hagos 2003; Demeke and Egziabher 2003). Holden et al. (Chapter 14) also predict limited effect of fertilizer credit on crop production and income in their study community because of the limited profitability of fertilizer use.

Credit programs also appear to have had relatively limited effect on land management and crop production in Uganda (Chapters 7, 11, and 15; Nkonya et al. 2004). Unless profitable technologies are available that can be financed by credit, there is little reason to expect credit to have a major influence on agricultural production.

Credit can also affect livestock ownership and management. Availability of credit from the Amhara Credit and Savings Institution is associated with declining livestock ownership, perhaps because of forced livestock sales to repay fertilizer loans during a drought (Chapter 6). By contrast, other NGO sources of credit are associated with increased ownership of oxen and improved cattle breeds, increased stall-feeding, and reduced feeding of crop residues (Chapter 6). The effects of credit thus appear to depend greatly on the focus of the credit program, with programs oriented toward livestock development having more positive effect on livestock ownership and management.

Local Organizations

Cooperatives and other local organizations appear to have important effects in some circumstances. In Tigray, cooperatives are associated with more use of irrigation (Chapter 4), more use of seeds and less burning (Chapter 5), higher value of crop production and income (Chapter 5), and better housing quality (Chapter 4). In Amhara, the effects of cooperatives are more mixed (Chapter 9). Input cooperatives are associated with greater use of improved seeds and some other inputs but have mixed effects on yields in Amhara (Chapter 9). Such cooperatives appear to be promoting use of purchased inputs as a substitute for other inputs in this case.

Local organizations also can influence collective action to manage community resources. Gebremedhin et al. (Chapter 10) found that communities that have more local organizations were more likely to establish a penalty system to protect restricted grazing lands, contributed more per household to protect the grazing land, and had fewer violations of restrictions. Social capital is thus an important asset contributing to collective as well as private natural resource management, as emphasized in much of the literature on collective action and common property resource management (e.g., Wade 1988; Ostrom 1990; Rasmussen and Meinzen-Dick 1995; White and Runge 1995; Baland and Platteau 1996; Agrawal 2001; McCay 2002; Pender and Scherr 2002).

Education

Education can influence agricultural production and household income in complex ways. In western Kenya, the level of education is strongly correlated with use of chemical fertilizer and higher off-farm income (Chapter 8). In Tigray, primary education of the household head is associated with more intensive labor use (Chapter 5), and in Amhara, education is associated with more use of improved seeds in HPAs but less use of reduced tillage, crop rotation, or incorporation of crop residues (Chapter 9). In Uganda, education is associated with less use of manure (Chapter 11). However, formal education has little association with the value of crop production per hectare or income in northern Ethiopia (Chapters 5 and 9), probably because of the generally low level of education of rural households. In Uganda, education is associated with higher value of crop production in the highlands but lower production in the lowlands, perhaps because of greater off-farm opportunities available to more educated people in lowland areas close to the main urban centers of Kampala and Jinja (Chapter 7). Nevertheless, education contributes substantially to higher incomes in rural Uganda (Appleton 2001; Deininger and Okidi 2001; Nkonya et al. 2004).

Gender

Gender also influences household income strategies, agricultural and land management practices, and outcomes. In western Kenya, female-headed households plant fewer crops in general and fewer high-value crops and use less fertilizer (Chapter 8). In northern Ethiopia, female-headed households use less labor and oxen power, reflecting a cultural taboo against women plowing (Chapters 5 and 9). As a result, female-headed households in northern Ethiopia obtain substantially lower crop yields and incomes than male-headed households (Chapters 5 and 9). In Uganda, female-headed households are more likely than male-headed households to use fertilizer, and households with more men use more of some labor-intensive land management practices (Chapter 11). Nevertheless, the difference in crop production between male- and female-headed households is insignificant in Uganda (Chapter 7). Thus, in Uganda female-headed households appear able to overcome labor shortages in agricultural production by using other inputs.

Land Tenure

Land tenure also influences land management and productivity in mixed and context-specific ways. In the Amhara region of Ethiopia, productivity is higher in villages where land redistribution has occurred since 1991, even though use of several inputs and management practices was lower (Chapter 9). This finding is consistent with findings of Benin and Pender (2001), based on community-level data for the Amhara region, and suggests that an important short-term effect of land redistribution is to enable land-poor households who are able to use land productively to access land.

This does not prove that redistribution increases productivity in the longer term because this may be undermined by lack of investment in soil and water conservation or in soil fertility improvements caused by tenure insecurity related to expected future land redistributions. For example, other findings in Chapter 9 show that expected tenure insecurity is associated with less use of manure but more of inorganic fertilizer, probably reflecting incentives to use inputs that yield short-term benefits where tenure is insecure. In another study in Ethiopia, Deininger et al. (2003) found that land redistributions are associated with less investment in terraces, and expectations of future redistributions are associated with less investment in both terraces and tree planting.[2] Several other studies have also found negative effects of perceived tenure insecurity on land investments in Ethiopia (Alemu 1999; Gebremedhin and Swinton 2003a; Gebremedhin, Pender, and Ehui 2003). However, other studies have found insignificant associations of tenure security with land investments in Ethiopia (Shiferaw and Holden 1998; Holden and Yohannes 2002; Yesuf 2004; Hagos and Holden 2005), so the evidence is not fully clear.

Land redistribution can also influence livestock ownership and management. Benin et al. (Chapter 6) find that land redistribution was associated with reduced household ownership of more than two oxen but an increase in ownership of fewer oxen and in ownership of other livestock. Land redistribution is also associated with increased adoption of improved animal breeds, stall feeding, and use of animal health services (Chapter 6). Nevertheless, land redistribution is associated with more degradation of grazing land quality, probably because it contributes to increased livestock numbers overall (Chapter 6). Other effects of land redistribution can include changes in intrafamily relationships (e.g., dependence of children on their parents for access to land), conflicts over land access, reduction in social differentiation and economic mobility, changes in poverty and destitution, effects on migration, and others (Bauer 1987; Amare 1994; Abate 1995; Amare 2003), though these were not examined in the studies in this book.

Studies in this book found mixed effects of the mode of land acquisition. In Amhara, Benin (Chapter 9) found that use of several inputs and land management practices is lower on owner-operated plots than on leased in (mostly through sharecropping) or borrowed plots and that yields were also lower on owner-operated plots in low-rainfall areas. This is contrary to predictions of inefficiency of sharecropping (Shaban 1987; Otsuka and Hayami 1988) and findings from studies elsewhere in Ethiopia, which find that productivity is either lower (Ahmed et al. 2002; Pender and Gebremedhin 2004) or insignificantly different on sharecropped than on owner-operated plots (Gavian and Ehui 1999; Pender and Fafchamps 2005). Benin's finding of lower productivity on owner-operated plots was not robust when a household-fixed effects model was estimated, however, so not too much should be inferred from this anomalous result.

Land tenure also has mixed effects in Uganda. Ugandan farmers are less likely to use fertilizer on customary than freehold plots but are more likely to incorporate crop residues and use mulching on *mailo* than freehold plots (Chapter 11). Farmers with freehold plots appear to be more oriented toward using cash inputs than other farmers, whereas *mailo* holders use more labor-intensive methods. Nevertheless, Pender et al. (Chapter 7) do not find statistically significant differences between the value of crop production on plots of different tenure, though they do find lower erosion on *mailo* plots, probably because of greater production of less erosive perennial crops on *mailo* land. The limited productivity effect of freehold land tenure in Uganda is similar to findings of several other studies of the effects of land titling in Africa (e.g., Atwood 1990; Barrows and Roth 1990; Migot-Adholla et al. 1991; Place and Hazell 1993; Platteau 1996). Interestingly, the value of crop production is greater on purchased than inherited plots in Uganda, suggesting that farmers adopt a more commercial and intensive approach to use of purchased plots in order to justify their investment (Chapter 7).

Summary of Findings

As hypothesized, many of the factors considered have complex and context-specific associations with households' income strategies, land management practices, agricultural productivity, household income, and land degradation. Among the more general and robust findings are the findings that:

- Agricultural productivity, household incomes, and welfare indicators tend to be greater in areas of higher agricultural potential and better market access.

- Adoption of purchased inputs such as inorganic fertilizer tends to be greater in areas of better market access.

- Population pressure and smaller farm sizes are associated with intensification of agricultural production, but also with land degradation, in many cases.

- Cash crop production is associated with adoption of purchased inputs and higher value of crop production per hectare.

- Nonfarm activities are associated with increased adoption of purchased inputs and household income but also with lower labor intensity in agricultural production.

- SWC investments and some organic measures have more immediate effect on productivity in moisture-stressed environments, whereas inorganic fertilizer and some vegetative agronomic practices are more effective in HPAs.

- Access to credit has limited influence on technology adoption and outcomes unless the market environment and the profitability of technologies is adequate.

The effects of other factors, such as irrigation, agricultural technical assistance, local organizations, education, and land tenure systems appear to be more context dependent. Further research efforts could usefully focus on such context-dependent effects, investigating what about the context leads to better land management and outcomes in some circumstances and less so in others, and how to devise more effective strategies for sustainable land management taking such contextual factors into account.

Although further research on effects of specific factors in specific domains is still needed, several implications for policies and programs can be suggested based on the findings of this book.

Policy and Program Implications

The research findings discussed above imply that no single policy strategy or program will be able to solve the problems of land degradation, low agricultural productivity, and poverty throughout the East African highlands. To achieve positive and sustainable effects, policies and programs must account for the diversity and complexity of situations in the East African highlands. A broad portfolio of investments by both public and private sectors in physical, human, natural, financial, and social capital will be needed to achieve sustainable effects, but the socially profitable mix of those investments will vary as a result of differences in comparative advantages of different livelihood and land management options in different contexts, as influenced by differences in agricultural potential, access to markets, population density, and other factors. In this section we suggest strategies for different development domains in the East African highlands, followed by consideration of more general lessons relating to some specific policy and program issues, drawing on the broader literature as well as the findings in this book.

Although we seek to account for the heterogeneous environments in the East African highlands, it is not practical to develop strategies for every possible situation. The conceptual framework and research findings in this book can be helpful to target strategies to the most important domains in the highlands. For simplicity, we consider options for only three broad domains: (1) areas with high agricultural potential and favorable market access, (2) areas with high agricultural potential but less favorable market access, and (3) areas with lower agricultural potential. We consider variations in other dimensions, such as population pressure, where relevant to the discussion.

Areas of High Agricultural Potential and Favorable Market Access

In areas of high agricultural potential and favorable access to large urban markets, a virtuous circle is possible, involving increased production of high-value commodities and increased nonfarm activities, all contributing to higher incomes and increased ability and incentive of farmers to invest in land-improving and productivity-enhancing technologies, helping to increase production of high-value commodities. In central Kenya, this virtuous circle was stimulated by the availability of the large and growing market in Nairobi, the development of infrastructure and proximity of processing facilities, and the presence of cooperatives providing credit and market outlets for high-value products (Chapter 8). It also built on the presence of a local merchant class with considerable international trading experience and development of long-term relationships between Kenyan exporters and overseas buyers and distributors (Jaffee 1995).

These advantages are not present to the same extent elsewhere in the East African highlands, though government policies and government and NGO programs can help to develop some of these advantages. For example, cooperative development in Ethiopia and Uganda has been set back by the politicization and poor performance of cooperatives in these countries during the tenures of the Marxist Derg regime in Ethiopia and of Idi Amin and Milton Obote in Uganda. Cooperatives are again developing in these countries. For example, dairy cooperatives are being promoted in periurban areas around Addis Ababa, though their coverage is still quite limited (Holloway et al. 2000). It will take significant investment capital and a supportive policy environment (e.g., avoidance of politicization or excessive government regulation and taxation) to help nurture the development of such organizations. Development of infrastructure in periurban areas, including roads, electricity, and communications, is also needed to promote such private sector development.

Where such investments in high-value commodities are taking place, small farmers' opportunities to profitably use purchased inputs such as fertilizer, improved seeds, pesticides, and animal feed will be increasing. In this context, provision of agricultural technical assistance and credit promoting adoption of such high-value commodities and inputs can yield high returns, as seen in central Kenya. The potential to adopt labor-intensive land management practices such as use of manure, compost, and biomass transfer is also likely to increase, both because of higher return to labor inputs in high-value commodity production and because of increased availability of manure as a result of dairy and other intensive livestock development. Technical assistance and credit programs should be designed with these opportunities in mind.

In some areas of high agricultural potential and favorable market access, such as in central Uganda, pest and disease pressure are severe constraints to intensive livestock and high-value crop production because of the lower elevation and more humid climate in this region. Efforts to address these pest and disease problems (for example, tsetse fly eradication or control efforts) are important public goods that are required before substantial realization of the potential will be possible. Even when pest control can be done privately, such as using pour-on insecticides, the degree of collective cooperation in such efforts is critical to their success (Swallow et al. 2002). Thus, factors affecting the ability to attain cooperation, such as distance to treatment centers, ethnic heterogeneity, and the nature of local governments, should be taken into account in designing programs for pest and disease control.

Areas of High Agricultural Potential but Less Favorable Market Access

In areas of relatively high agricultural potential but more remote from major markets, such as the highlands of western Kenya, eastern and western Uganda and much of the southern and western highlands of Ethiopia, the comparative advantage is likely more in nonperishable and readily transportable commodities such as coffee and cereals (coffee in more humid areas, cereals in less humid areas) and livestock (more in live animals and skins than dairy). These areas have been suffering from low world prices of both cereals and coffee in recent years, which, together with elimination of input subsidies, liberalization of foreign exchange markets, and regional trade restrictions (especially affecting livestock), has reduced the profitability of using inputs in agricultural production. Pests and diseases are also serious problems for these commodities in many areas and reduce the expected return and increase the risks of expenditures on inputs. As a result, use of such inputs is not very profitable in many of these areas, and efforts to promote their use through extension and credit are unlikely to be very successful without major changes in the market environment.

In such environments, promotion of improved technologies can lead to increased soil nutrient mining as farmers adopt improved seeds (which are often profitable) without adequate use of fertilizer or other soil fertility management practices (which are often unprofitable in the near term) to restore the nutrients, thus increasing depletion of soil nutrients through increased harvest. Identifying and disseminating profitable technologies for restoring and maintaining soil fertility are critical in such circumstances. Positive results have been demonstrated for some agroforestry practices such as improved fallows and biomass transfer, but widespread adoption has been limited by land and labor constraints as well as by limited awareness of these technologies in much of the East African highlands. These technologies have shown sufficient promise that broader efforts to disseminate them are warranted, but the importance of land and labor constraints implies that these practices are unlikely to be widely adopted everywhere, even when they are capable of increasing crop yields substantially. Thus, efforts to develop suitable and profitable technologies consistent with the constraints faced by small farmers in these environments are still urgently needed.

Agroforestry and other vegetative approaches to livelihood diversification, provision of fodder and fuel supplies, and soil fertility improvement also may be constrained by free grazing of livestock, as is common in the Ethiopian highlands (Amede 2003). Development and enforcement of local community bylaws regulating this practice may be necessary to attain the potential of such technologies (Amede 2003). Given the long-standing tradition of the free grazing system and its importance to the livelihoods of rural households in Ethiopia, such changes should not be imposed by governments or widely promoted without adequate understanding of the implications of such changes. Any changes in such long-standing institutions are likely to fail unless they are initiated and owned by local communities themselves and brought about through processes that are perceived as fair by all stakeholders at the local level.

Although not profitable in all areas, some use of inorganic fertilizer is usually necessary to address deficiencies of some plant nutrients (such as phosphorus). This is profitable (often in combination with other technologies) in many higher-potential areas of the highlands, such as in western Amhara in Ethiopia and in parts of the eastern highlands of Uganda and western highlands of Kenya. The potential value of inorganic fertilizer in such areas should not be discounted simply because farmers face cash constraints. Such constraints can be addressed through fertilizer credit programs, as has occurred in Ethiopia, which are effective where fertilizer use is profitable. The problem then becomes the potential for successful adoption of fertilizer and improved seeds to cause a collapse in output prices as a result of poorly developed infrastructure, markets, storage, and marketing credit systems, as occurred in high-potential maize-producing areas of Ethiopia in 2001 and 2002.

Development of market infrastructure and institutions, such as roads, transportation and storage facilities, grades and standards, a market information system, and marketing credit (e.g., through a warehouse receipts system) is critical to help avoid such price collapses (Gabre-Madhin and Amha 2003) and can help to make use of fertilizer and other inputs more profitable in general. Local purchasing of grains for food aid and emergency reserve needs can also help to prevent dramatic declines in prices that undermine farmers', consumers', and traders' confidence in the market, though care should be exercised to avoid the opposite problem of causing sharp price rises that contribute to food insecurity. Beyond this, promoting development of an intensive livestock industry (e.g., poultry, pigs, beef fattening, dairy) in areas close to urban markets can stimulate the demand for maize and other feed grains from outlying areas having comparative advantage to supply this demand, providing a source of longer-term growth as well as helping to dampen price variability because of the higher elasticity of demand for feed supplies than for food supplies.

Improvements in markets for coffee are also needed in high-agricultural-potential areas. Although East African producers have limited ability to change world market prices, they can focus on earning higher returns for their coffee by investing in quality improvement and promoting coffee production for high-value specialty markets (e.g., for organic coffee, shade-grown coffee, fair trade coffee, appellation zones) (You and Bolwig 2003). Much of the coffee produced in East Africa is grown using organic methods and under shade conditions; thus, qualifying for certification should be feasible, though it is costly and subject to numerous requirements. Development of cooperatives can help to meet the requirements and reduce transaction costs per farmer of compliance. For example, the Kawacom Organic Coffee Project in Uganda has organized 14,000 farmers in farmer groups and is exporting about 1,000 tons of organic coffee annually (Parrott and van Elzakker 2003), and in Ethiopia there are about 23,000 farmers involved in organic coffee production through 35 cooperatives (Parrott and Kalibwani 2005). Organizations in several East African countries (Uganda, Kenya, and Tanzania) are pursuing development of accredited certification bodies and standards, which will help to reduce the costs of certification in the future (EPOPA 2004).

Although there is potential for increased value from specialty coffees, this potential should not be oversold, as the market for these coffees is thin, and many countries are trying to exploit these opportunities, so the price advantages of producing these are likely to be bid down as more producers enter these markets. Improvements in the technology and marketing systems of more standard coffee varieties should also be pursued and may benefit more coffee producers in the East African highlands. Among the more promising options include development and dissemination of disease-resistant and higher-yielding varieties, improved regulation of coffee quality, investments in improved infrastructure and transportation, development of institutions to reduce traders' risk, such as a forward auction (Schluter 2003), and establishment of a warehouse receipts system (being considered in Ethiopia) to facilitate provision of marketing credit (Ehui and Pender 2003). The market potential may be greater for *arabica* (produced in highland areas of Ethiopia, Kenya, and Uganda) than for *robusta* coffee (most common in Uganda at lower elevations) because of heavy competition from low-cost *robusta* production from Brazil and Vietnam (You and Bolwig 2003).

Improvements in food production are likely complementary to increasing coffee or other high-value cash crop production. In densely populated remote areas such as in much of southwestern Ethiopia, small and declining farm sizes and high transportation costs may cause farmers to reduce production of coffee in order to produce sufficient food for subsistence (Technical Committee on Agroforestry in Ethiopia 1990; Westlake 1998). Increasing productivity of food crops may therefore help farmers save land for cash crop production, whereas cash crop production enables farmers to be able to afford to purchase inputs for intensive food crop production. Such complementarities between cash and food crop production should be recognized by technical assistance programs.

Woodlots can be highly profitable in densely populated higher-potential areas and can help to reduce pressure on natural forests and depletion of soils caused by burning of dung and crop residues, as is common in Ethiopia. Provision of nurseries and technical assistance helps to promote these. Policies that undermine woodlot development, such as excessive regulation of community woodlots and prohibition of tree planting in arable areas, as exist in the Tigray region of Ethiopia, should be reconsidered.

Areas with Lower Agricultural Potential

In lower-potential areas, as in the highlands of eastern Amhara and Tigray in Ethiopia, the comparative advantage is not in coffee production, and in most cases also not in intensive cereal production using high levels of inputs. We have seen that the profitability of inputs such as fertilizer and improved seeds is low in these areas, and as a result, agricultural extension and credit promoting them have had limited influence. Investments in some soil and water conservation practices and use of some land management practices such as reduced tillage and use of manure and compost have shown more promise as a result of low organic matter and soil moisture–holding capacity of the soils of these areas. Targeted use of costly inputs such as fertilizer and improved seeds in combination with soil and water conservation or water-harvesting measures to ensure adequate soil moisture to enhance the effectiveness of such inputs is likely to be more effective than blanket use of inputs. Agricultural technical assistance programs are likely to be more effective if they take such potential synergies into account.

Livestock are very important in the livelihood strategies of most households in the lower-rainfall highlands, as in much of the higher-rainfall highlands. Cattle (both oxen and other cattle) contribute to higher value of crop production, both directly through use of ox traction and indirectly through increased availability of manure. However, the potential to increase incomes through cattle ownership appears to be greater for cows than for oxen in parts of northern Ethiopia, consistent with the promising effects of reduced tillage found in this environment. Opportunities to promote a shift away from dependence on oxen where reduced tillage is profitable should be explored, as this can enable increased emphasis on more profitable livestock, provide better opportunities to female-headed households and oxen-poor households, and reduce degradation of grazing lands (Chapter 12). Other livestock (e.g., small ruminants and poultry) can also yield relatively high returns in this environment, though livestock are a risky asset in drought-prone areas because they are susceptible to substantial losses during drought years as a result of feed shortages and price collapses resulting from herd liquidation. Thus, efforts to develop rural financial institutions, providing farmers remunerative and less risky savings alternatives to holding livestock as a store of wealth, could be helpful.

Efforts to improve water, feed, and fodder availability and quality are needed to achieve the potential contribution of livestock in such environments. Investments in small-scale irrigation and water harvesting, as are being promoted in drought-prone areas of Ethiopia, can have benefits for livestock as well as for crop production (Sileshi, Tegegne, and Tsadik 2003), though most emphasis has been on crop production. Improved management of communal grazing lands is also needed. Although many communities in northern Ethiopia are protecting some of their grazing lands (Chapter 10), there is little investment in planting fodder trees, shrubs, or grasses in most such areas. Without investments in increased biomass productivity of such areas, the productivity of livestock will continue to be limited by the productivity of the natural vegetation growing in communal areas and the limited availability of crop residues. Availability of appropriate technical assistance, credit, and health facilities oriented toward improved livestock production can also be very helpful, as suggested by the positive effects of some NGO programs on livestock development in the Amhara region (Chapter 6). Continued efforts to provide vaccination and animal health services are also needed.

Improved management of communal lands can also contribute to increased income from forestry and related activities, such as beekeeping. Tree planting is one of the most potentially profitable investments available to communities in these less-favored environments and can contribute to increased agricultural production and improved land management by reducing the need to burn dung and crop residues for fuel, enabling more of these materials to be recycled to the soil (Jagger and Pender 2003). However, the effectiveness of collective action to manage community woodlots in northern Ethiopia has been undermined by a regulatory approach that has limited communities' sense of empowerment to harvest poles and other materials from the woodlots. Devolution of real authority over community woodlots to local communities, groups, or households is needed to achieve their potential (Jagger, Pender, and Gebremedhin 2005). There is also potential to promote tree planting through allocation of degraded communal lands for private tree-planting activities, as is being promoted in Tigray and Amhara. Such efforts have shown promise of achieving higher survival rates of trees and higher economic returns with less intensive labor input than on community woodlots, though it is still too early to be sure of their effects (Jagger, Pender, and Gebremedhin 2005). Even on these privately managed woodlots, most households still require permission to be able to harvest poles, which may undermine their incentive and ability to manage these woodlots profitably.

Beyond relaxing such regulations, governments should also reconsider other policies that restrict tree planting, such as the provisions of Tigray's 1997 land policy proclamation banning planting of eucalyptus trees or prickly pear cactus on cultivable land. The economic returns to tree planting can be much higher than the returns to crop production, tree planting can increase a household's food security by providing a source of income in a drought or other calamity, it frees labor that may be used more profitably in off-farm activities or other pursuits, and the environmental effects (though often hotly debated) are not clearly negative relative to annual crop production (Getahun 2003; Jagger and Pender 2003). Where there is serious concern about the effect of eucalyptus or other trees in arable lands on neighboring farmers or water sources (e.g., negative effects on availability of water, nutrients, or sunlight), local communities may find better ways to address this concern than an outright ban, such as by regulating tree planting to be a minimum distance from neighbors' fields or water sources. Continued promotion of tree planting through technical assistance and provision of nurseries is also important.

Investments in irrigation are also needed where this is feasible and profitable, especially in drought-prone environments. We have seen that small-scale irrigation can have large positive effects on production in such environments (Chapter 9), but this is not always the case (Chapter 5). Careful study is needed to better understand the extent to which small-scale irrigation is succeeding or failing in these contexts and the main factors contributing to success or failure. Policies and investments to address the problems discussed earlier, such as inefficient traditional irrigation practices, lack of trained manpower to design irrigation structures, lack of coordination between organizations promoting irrigation development and those responsible for maintenance of irrigation structures and watershed conservation, and the need for technical assistance, credit, infrastructure, and institutions to facilitate production and marketing of higher-value irrigated crops could be very helpful in attempts to ensure that irrigation investments achieve their full potential. The problems limiting the effectiveness of microdams and other small-scale irrigation investments, and the negative health effects of these investments, should raise a cautionary flag concerning efforts to rapidly promote other water-harvesting approaches such as the small ponds for supplementary irrigation that are now being widely promoted in Ethiopia. There is a need to assess the problems and constraints that may lead to worse than anticipated results of these investments before they are adopted on a massive scale. Targeting such investments to areas where the benefits are substantial and the health and other risks are low (e.g., higher elevations), or making these investments in combination with other investments in necessary health measures (e.g., mosquito nets), may be a more effective approach.

Regardless of what is done to promote improved agricultural production in less-favored areas of the East African highlands, these areas are likely to remain food-deficit areas and dependent to a significant degree on off-farm income for the foreseeable future. Food-for-work programs account for a substantial share of household income in drought-prone areas such as Tigray and eastern Amhara (Pender 2004), acting as employment guarantee schemes and an important means of preventing droughts from causing major famines. Efforts to promote development of the nonfarm economy in these regions will continue to be important, for example, through public investments in infrastructure, education and vocational training, and attraction of private investment in industry. Until such efforts have succeeded in bringing much broader development of the nonfarm economy, employment guarantee schemes through food-for-work or other mechanisms will continue to be needed as a safety net in these areas to prevent famines and the downward spiral of asset liquidation, declining production, increasing poverty, and land degradation that such famines can trigger (Amare 2003). However, this should be done in a way that minimizes disincentives to pursue productive alternative livelihood strategies or make productive investments.

Policy and Program Lessons

A primary lesson of the studies in this book is the critical importance of identifying and promoting profitable income strategies and land management practices in different biophysical and socioeconomic contexts. This lesson appears obvious but needs to be emphasized because technical assistance and credit programs sometimes attempt to promote activities and technologies that are not profitable in many contexts. The ineffectiveness of agricultural extension and credit focusing on promoting fertilizer and improved seeds in drought-prone areas of northern Ethiopia is a clear example, but there are many others highlighted in the case studies of this book.

Profitability depends not only on the price of outputs and purchased inputs but also on the opportunity costs of nonpurchased inputs such as land and family labor. Despite impressive effects of many organic technologies on crop yields in many settings, these technologies often entail high land or labor costs that make the technologies unattractive to farmers, as argued by Delve and Ramisch in Chapter 13. Such costs must be taken into account in efforts to promote technologies. Identification of what domains and for what types of households such costs and constraints are likely to be prohibitive can help in targeting technical assistance efforts. For example, improved fallow technologies are not likely to be widely adopted in very densely populated areas, except in niches such as along field boundaries or on degraded plots; and highly labor-intensive technologies are less likely to be adopted by extremely labor-constrained households, such as female-headed households and HIV-affected households.

Technical assistance programs are more likely to be successful in identifying and promoting profitable technologies if they take a farmer-centered, demand-led approach and provide farmers with a broad menu of options rather than a very narrow package of technologies. Top-down, target-driven approaches to technical assistance are likely to fail, as shown in this book and in numerous other studies. Farmers need information about the potential profitability of alternative livelihood and land management options in different contexts, and not just blanket recommendations to maximize yield or minimize soil erosion, which are unlikely to be their primary objectives. Farmers also need information about postharvest and marketing technologies, prices and marketing options, especially for newer commodities with which they are less familiar.

The profitability of land management practices can be increased in several ways. Where high-value crops are agronomically and economically feasible, the return to applying labor and other inputs intensively is generally higher for such crops. Thus, promotion of cash crops, where feasible, together with suitable land management practices can help to promote more profitable and sustainable land management. Development of improved technologies, such as drought-tolerant or more fertilizer-responsive crop varieties can also help increase the profitability and reduce the risks associated with fertilizer or other inputs. Continued applied research and dissemination of improved land management options, such as agroforestry, improved forages, and other promising technologies for specific recommendation domains, are also needed. Investments in infrastructure and market institutions can help to increase the profitability and reduce the market risk of producing high-value crops as well as other commodities. However, it is important to have realistic expectations about how much can be accomplished by such investments and where they will have the most near-term influence. Where such investments can enable expansion of what is already a highly profitable enterprise, such as dairy production in periurban areas, they will likely yield high returns in the near term. By contrast, investments in road building in remote areas will likely not have major effects on agricultural production or household incomes in the near term. Being a two-hour walk to the nearest all-weather road or town instead of three hours likely makes little difference in terms of farmers' current livelihood or land management options. Nevertheless, construction of roads and other infrastructure is an important step toward longer-term rural development, and its importance should not be discounted even if it does not show immediate effects. Such investments are part of the long-term development process.

Development of farmer organizations, such as cooperatives, can be very helpful where there are potentially profitable commodities for such organizations to promote, by reducing transactions costs in acquiring inputs or marketing outputs, and providing access to credit and technical assistance. However, as with most interventions, such organizations are not a panacea, and we have seen examples where these are not associated with higher production or incomes. Further research is needed to identify what circumstances favor the success of such organizations, but certainly the profitability of the commodities that they deal with is one of the primary factors.

In addition to expected profitability, risk is also, of course, important to farmers in the East African highlands. For farmers in high-potential areas, weather risk is often less important than market risk, and addressing this requires development of market infrastructure and institutions, as discussed previously. Problems of pest and diseases are also a major concern, especially (but not only) in humid environments, and investments in appropriate infrastructure, collective action, research, inputs, and technical assistance are critical to addressing these concerns (e.g., vaccination campaigns, tsetse eradication efforts, human and animal health facilities, development of disease- and pest-resistant varieties, training in integrated pest management).

In drought-prone environments, weather risk is usually the primary concern. Coping with risk is of necessity a constant preoccupation of poor households in these environments. Livelihood and commodity diversification is one common strategy that households pursue to address risk as well as for other reasons (e.g., to more fully utilize labor and other household resources or to exploit economies of scope among different activities) (Barrett, Reardon, and Webb 2001). Education, technical assistance, and credit programs should recognize the importance and potential of the variety of income strategies that households may pursue, facilitating options and not focusing too narrowly on a particular commodity or set of land management technologies.

Irrigation, other water-harvesting technologies, and soil and water conservation measures can help to reduce risk and increase profitability of agricultural production, especially in drought-prone environments. However, such efforts must be carefully designed and implemented (especially if done on a large scale) to address the technical, institutional, and market problems such as have been discussed in the context of Tigray (but which are likely not limited to Tigray). This need appears to be at odds sometimes with the desires of policymakers and program managers, who may feel pressure to rapidly scale up such efforts and achieve broad consequences. In some cases, the availability of food aid or other assistance or the goal of providing employment may contribute to the desire to implement public works projects rapidly and on a large scale, even if production or conservation objectives may not be adequately served (Bantirgu 2003). Because irrigation and water-harvesting projects can have substantial negative health and environmental effects as well as being costly to implement and maintain, it is advisable for policymakers and development agencies to resist such pressures and take a more careful approach to ensure that such negative effects can be minimized, while the economic and social benefits of such projects are maximized.

Education can contribute substantially to households' livelihood options and to household income, although these occur only in the long-term. In some cases, this will also contribute to improved land management. However, this will not always be the case, as more educated households are sometimes less prone to adopt labor-intensive land management practices. This is not an argument not to invest in education, but it suggests that the potential trade-offs of improved education for land management should be recognized and addressed. For example, incorporating teaching about the principles of sustainable land management into educational curricula could help to improve farmers' capacity to innovate and adapt technologies to their particular circumstances.

Even when profitable and risk-reducing technologies are available, they may not be adopted by households because of the constraints that they face. For example, fertilizer and improved seed use are often constrained by farmers' lack of access to cash and credit, even where they would be profitable. Improved fallows are constrained because of farmers' lack of land. Application of organic materials is often limited by scarcity and competing uses for these materials and by labor constraints. Knowledge constraints may also limit adoption of many natural resource management technologies (e.g., integrated pest management, integrated soil fertility management) that require adequate understanding of local conditions and the principles underlying the technologies to adapt them to local conditions. Many of these constraints may be binding for smallholders in the East African highlands; thus, an integrated approach that accounts for and addresses multiple constraints is needed.

Special attention is needed to address the constraints of women farmers. As we have seen, in some places they are disadvantaged by cultural norms. They often face much tighter labor constraints than male farmers and male-headed households, and women are sometimes inhibited from making decisions about land investments and land management practices while their husbands are away, as seen in western Kenya. Addressing these problems requires special attention in agricultural research, technical assistance, education, training, and credit programs to provide livelihood and land management options that are suitable to the circumstances of women farmers. Households affected by HIV/AIDS and other diseases also require special consideration, particularly when labor-intensive methods are being promoted.

Land tenure policies and traditions also sometimes discriminate against women farmers. For example, households that move away from their village in northern Ethiopia for more than two years lose access to their land; this restriction may be very limiting to a widow who is not able to farm productively but is prevented from moving to town where she may have better employment opportunities. Addressing such problems requires changes in social attitudes as well as policies.

Land tenure issues have implications beyond the effects on female farmers, especially regarding the means of acquiring land. In Ethiopia, where land sales are prohibited, alternative means of land transfer can have important effects on land management and productivity. We have seen that government land redistribution can increase farming intensity and productivity in the near term but may also undermine productivity in the long term by reducing tenure security. Land lease markets in many areas appear to function relatively efficiently, though this is not always the case, as seen in Tigray. This may be a result of government regulation of land lease markets in Tigray (Pender and Gebremedhin 2004) and argues for avoiding such restrictions.

We do not see significant productivity advantages of freehold tenure over customary or other tenure systems in Uganda, consistent with findings of other studies from Kenya and elsewhere in Sub-Saharan Africa. Thus, there is little argument for broad-based land titling efforts, although there may still be advantages of land titling in some socioeconomic contexts (e.g., in periurban areas where the demand for land titles to facilitate sales and access to credit may be high). This is consistent with the general theme of this book that such interventions should be targeted to the development domains where they can yield high returns.

Population pressure was found in several studies to contribute to intensification of agriculture, as argued by Boserup (1965) and her followers. However, rural population pressure is associated with land degradation in some studies, and we have seen that population pressure and small farm sizes inhibit adoption of some improved land management practices, such as improved fallows. Reducing population pressure in densely populated highland areas thus may help to improve some aspects of land management and reduce land degradation. However, it is clear that population pressure is not the most important factor contributing to land degradation in the East African highlands, as demonstrated by the favorable land management outcomes in the densely populated highlands of central Kenya.

Research Implications

A great deal has been learned from the research studies included in this book. Still, these studies have not been able to cover all of the important research issues related to achieving improved livelihoods and sustainable land management in the East African highlands; many important information gaps remain to be investigated.

Despite the primary importance of profitability of livelihood and land management options, there is still a dearth of information about this. The studies in this book have shed light on the profitability of some options in some circumstances, but much more needs to be known in order to develop effective targeted interventions. There is little systematic and reliable information collected on a regular basis about the profitability of different crop, livestock, or forestry activities in the different domains of the highlands or the profitability of land management practices linked to these different livelihood activities. Beyond estimating private profitability, information on the social profitability of alternative activities in different domains is also needed, taking into account externalities, market price distortions, nonmarketed inputs and outputs, and other factors.

The social profitability of alternative public programs and investments also needs to be better understood, to help guide development investors and governments as to where the highest returns can be expected. For example, there is limited information on the social costs and benefits of investments in small-scale irrigation and other water-harvesting measures, as mentioned previously. The returns, costs, risks, and social and environmental effects of other public investments, such as investments in infrastructure, education, agricultural research and extension, and others are also not well quantified. Several of the chapters in this book provide a solid basis to build on in addressing this information need, but more research is needed to estimate the costs, risks, and social and environmental effects.

To better assess such effects, more long-term research with panel data sets and dynamic models is needed to better understand the dynamic relationships between policy and program interventions; among local institutions and endowments of physical, human, natural, financial, and social capital; between community and household responses in terms of collective action, livelihood strategies, and land management practices; among changes in production, income, land degradation, and other outcomes; and the feedback effects of these responses and outcomes on interventions, local institutions and endowments, and future responses. It is difficult to know the extent to which communities and households are trapped in a downward spiral, stagnation, a virtuous upward spiral, or another kind of dynamic development path, or what the most effective interventions will be to promote sustainable development, without better understanding of the dynamic situations that are occurring and the key causal factors and feedback relationships that are driving them.

For example, some communities may be falling deeper into poverty and depleting all of their endowments as a result of a lack of sufficiently profitable investment opportunities for any type of capital. Unless profitable investments of some kind can be identified, a sustainable development solution may not be possible without promoting large-scale emigration out of such areas. In other cases, communities and households may be depleting their natural capital but investing in other forms of capital that are yielding higher returns (Pender 1998). Such a development path may be sustainable as long as households are aware of the depletion of natural capital and will eventually address it adequately as the returns to investing in natural capital increase relative to the returns to investing in other types of capital (Pender 1998). Alternatively, they may not be sufficiently aware of the depletion, may not have adequate incentive or ability to address it because of externalities or other market failures (e.g., absence of credit, land tenure insecurity), or may be crossing a threshold into a poverty-degradation trap in which the costs are too high or the marginal returns too low to maintain or restore the natural capital stock (Pender 1998; Barrett et al. 2002).

It matters a great deal for the appropriate policy or program response which situation householders are in. If there is sufficient awareness and no major market failure, the problem is likely to take care of itself as the relative returns to investment in different types of capital adjust (Pender 1998). If there is insufficient awareness of the degradation problem, educational and technical assistance approaches may be sufficient to solve it. If the problem is caused by market failures or a degradation trap, more intervention will be necessary to address these causes. Without more information to diagnose what kind of dynamic situations communities and households are facing, it will be difficult to prescribe effective remedies.

Even before such dynamic information becomes available, however, it would be very useful to identify areas and household types for whom profitable livelihoods and land management practices are feasible but are not being pursued. Where such untapped potentials exist, it is useful to investigate the reasons why and identify the extent to which policies, public investments, and programs could facilitate fulfillment of these potentials. The research in this book has identified some examples of such potentials, such as production of high-value commodities in high-potential areas close to urban markets and tree-planting activities in many other areas. The research has also provided some insights into the reasons why such potentials are not being more widely exploited; these include the lack of development of cooperatives in Ethiopia and Uganda, in part because of politicization and poor performance of these in the past, and overregulation of tree-planting activities in northern Ethiopia. Further case study research into these and other promising livelihood and land management options could yield valuable insights.

More historical case study research investigating the dynamics of changes in income strategies, land use, land management, land degradation, productivity, and welfare outcomes, such as the influential case study of Machakos by Tiffen, Mortimore, and Gichuki (1994), would also be valuable. Such long-term historical studies can yield a wealth of insights into the processes of land degradation or improvement and into key driving forces and responses that are not possible to achieve using only cross-sectional surveys of the type emphasized by many of the studies in this book. However, the conclusions of such a well-focused case study can easily be overgeneralized. Similar studies are needed in different development domains and different historical, political, and social contexts to draw more robust and generalizable conclusions about the dynamics of land degradation, causes, and responses in the East African highlands. A combination of quantitative survey and qualitative case study research methods, building on the strengths and addressing the weaknesses of each approach, is more likely to produce clear and robust conclusions than reliance on any single approach.

The scale of interventions and their effects also need to be better understood and have been addressed only in a limited fashion in this book. Interventions that are able to increase production and household income when pursued on a small scale may lead to quite different effects when implemented on a large scale. The negative effects of rapid adoption of improved maize varieties and fertilizer on maize prices in high-potential areas of Ethiopia have been cited, but other examples of such scale-dependent effects could be found. Research tracing effects across scales is needed, from assessing influences of policy and program interventions on adoption decisions at the plot and household scale and their implications for local natural resource conditions to the effects on prices and other outcomes at the community, national, and regional scales. The feedback effects occurring between these scales must be better understood and accounted for in planning interventions if the benefits of such interventions are to be maximized and unintended negative effects are to be minimized. The use of bioeconomic models at household, community, and higher scales are likely to be essential for an understanding of these effects.

Notes

1. However, substantial efforts were made in the chapters to base the empirical specification on sound theoretical models and to control for threats to causal interpretation such as nonrandom selection of cases, omitted variables, and endogenous explanatory variables. Thus, although causality cannot be proven, the studies have addressed many of the usual reasons why the relationships between explanatory and dependent variables may fail to be causal ones.

2. Interestingly, Deininger et al. (2003) also found that past land redistributions were associated with more tree-planting investments. They argued that this may be because tree planting increases tenure security, but it may simply have been the result of young households planting trees around newly constructed houses on land acquired through redistribution, as trees are commonly planted around the homestead in Ethiopia.

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