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Climate Change and Management of Cool Season Grain Legume Crops

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Preface

Dry pea (*Pisum sativum*), chickpea (*Cicer arietinum*), broad bean (*Vicia faba*), lentil (*Lens culinaris*), lupins (*Lupinus* spp.) grass pea (*Lathyrus sativus*) and common vetch (*Vicia sativa*) are the major cool season grain legume crops which grow on all continents except Antarctica in more than 100 countries. These cool season grain legume crops are ancient crops of modern times and their cultivation dates back to the pre-historic time. Due to their high nutritional value and cultivation under poor environments mainly in dry ecologies, they are an integral part of daily dietary system of millions of people around the world. These cool season legume crops dominate international markets as their trading is more than US $1,200 million annually. Due to their eco-friendly nature, low cost in production, pre-dominance in national and international trade etc. these ancient crops have been accepted as the crops of modern management.

Climate change predictions over this century are for warmer (at least 1–2°C) and drier conditions, with increased extreme weather events and increased CO_2 levels, in the regions where the principal temperate grain legumes of chickpea, lentil, faba bean and pea are mainly grown. The most important global debate of this century is on climate change. It is predicted that by 2050 there will be significant impacts including rising temperature, increasing drought due to higher evaporation and changing rainfall distribution, and increased levels of CO_2 due to greenhouse and agriculture gas emissions. Thus it is predicted that present levels of agricultural production and field crops productivity under different ecologies and regions will be affected in a big way.

The predictions about present production levels of cool season grain legume crops are that their productivity will decrease in the mid-latitudes or increase in the high latitudes regionally. People, especially in developing countries, having mostly vegetarian dietary system will face a big problem of availability of these legumes by 2050. Considering such disturbances it is important to develop efficient agronomic production system, to introduce widely adopted resistant high yielding cultivars and utilization of diverse genetic sources in the improvement of new varieties for wider ecologies and regions. This book provides a comprehensive review of current production constraints, achievements, future agronomic management and production technologies to sustain the production, utilization, international marketing, and crop improvements around the world. The chapters each written by subject matter specialists help scientists, teachers, students, extension workers, farmers, consumers, administrators, traders and NGO's in increasing their understanding of the cool season grain legume crops.

This book on climate change and management of cool season grain legume crops comprises 21 chapters. The importance and challenges of common factors and their impact on legume crops has been explained in Chapters 1, 2, 3, 4, 5, and 6. Chapter 1 present the challenges of climate change on production, Chapter 2 crop modelling to climate change, Chapter 3 ecological adaptation, Chapter 4 physiological responses to stress environments, Chapter 5 international trade around the world and Chapter 6 impact of climate change on legume diseases. The importance and role of various production technologies and agronomic approaches has been highlighted in Chapters 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17. Chapter 8 explains the agronomical approaches to stress environments, Chapter 9 major nutrient use by legume crops under stress environments. On the other hand, Chapter 10 explains the management of drought and salinity under changing climate. Likewise, Chapter 11 provides light on nutrients use efficiency and Chapter 12 explains the water use efficiency of crops under stress environments. Chapter 13 highlights the root development system to warming climates and Chapter 14 explains the importance of weed management in legume crops. The role of biological nitrogen fixation under warming climates has been explained in Chapter 15 and agrochemicals in Chapter 16. The importance of integrated crop production and management technologies under warming climates has been highlighted in Chapter 17. The role of legume cultivars, significance of molecular techniques, challenges to biodiversity and strategies to combat the impact of climatic changes around the world has been described in Chapters 18, 19, 20, and 21.

Internationally, the interdisciplinary and multifactor global modern system of team work has been recognized for scientific excellence and the legume production system is no exception. Therefore, most chapters have involved collaboration of 2–3 or more diverse international authors from Europe, Australia, Asian region, African region etc. Thus the book represents a truly global perspective consistent with the nature of climate change and its impact on legume crops production system around the world. This book offers the latest reviews of cool season grain legume crops production and management technologies and publications as well as presenting new findings direct from leading researchers for use by researchers, technologists, professionals, economists, students, traders, legume growers, consumers and policy makers. We are certain you will find it both a timely, interesting and a valuable addition to the literature on extraordinary legume crops.

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About the Editors

David McNeil started his career in agricultural science in 1971 as a trainee crop physiologist with the NSW Department of Agriculture followed by Ph.D. on lupin physiology at the University of Western Australia. Since then he has swung between Departments of Agriculture and Universities with a strong involvement in research, development and extension for pulse and grain legume crops, new and novel crops, crop growth modelling as well as molecular, microbial and other forms of biotechnology use. A key area of effort has been to expand scientific understanding of new crops (particularly pulses) and the climates in which they grow and develop new productive, viable and sustainable industries around these new crops. He has published over 100 scientific papers as well as a similar number of extension publications. Professor McNeil's research publications have covered a wide range; including crop/plant agronomy/physiology, growth modelling, effects of climate change, molecular mapping, Genetic Modification, mutation and traditional breeding, rhizobiology, bacteriophage use and bio control, market testing and consumer evaluation. David McNeil's work with legumes has included a period with NifTAL in Hawaii promoting N fixation world wide, including consulting for the UNEP program on N fixation. He has also developed super nodulation in soybeans as well as lead major Australian breeding and agronomy programs for a range of temperate pulses including lentils, peas and chickpeas. Professor McNeil was also joint leader of the project establishing FACE (Free Air CO_2 Enrichment) trials for cropping in Australia. Professor McNeil's career has included acting as researcher, lecturer, program manager and extension expert based at locations in the USA, New Zealand and Australia, usually with goals spanning both developing and developed country agricultural systems. Professor McNeil has researched legume and other crops at the Boyce Thompson Institute at Cornell, the University of Hawaii, the Australian National University, the WA Department of Agriculture, Lincoln University in New Zealand, the Victorian Department of Primary Industries, with the University of Melbourne in the Joint Centre for Crop Innovation. Presently he occupies the Chair of Agricultural Sciences in the School of Agricultural Science at the University of Tasmania. This school incorporates the Tasmanian Institute of Agricultural Sciences (Professor McNeil is Director) and as such is the predominant source of research in Tasmania for horticulture, dairy, vegetable, cropping and food safety. Professor McNeil's commitment to linking research and industry development with the latest biotechnological advances continues with a strong interest in retaining pulses and other high value specialist crops as a major component of a total cropping system. A major involvement is also with the Climate Futures project in Tasmania that is conducting fine scale mapping of potential future climates for Tasmania and evaluating future cropping potential. His interest in other areas of plant physiology, breeding and agronomic research continue including attempts to use biotechnological approaches in pulse breeding. Thus from his present position Professor McNeil continues his interest in combining detailed science with industry development of pulse, horticultural and other new crops in the Tasmanian, Australian and global environment.

Sharanagouda A. Patil an eminent researcher, educationist and administrator of international repute, with 40 years of service to the nation, particularly in the predominantly rainfed state of Karnataka. He completed his B.Sc. Agri. and M.Sc. Agri. from University of Agricultural Sciences, Bangalore, Karnataka, India and then Ph.D. in Genetics and Plant Breeding at Indian Agricultural research Institute, New Delhi, India. Have served on various senior positions like Plant Breeder (Oilseeds), Director of Instructions (Agri), Director of Research, Vice Chancellor, UAS Dharwad, and Director of the premier national institute in agriculture Viz. Indian Agricultural Research Institute, New Delhi. Made significant contribution by breeding 16 varieties and hybrids of crops like Cotton, Groundnut, Castor, Niger and Sunflower that are normally grown in the rainfed areas. These varieties and hybrids are still popular among the farmers and earning millions of rupees as revenue every year. Honored with more than a dozen prestigious awards at state, national and international levels, for contribution made in agricultural development.

Robert Redden has over 35 years of professional experience in agriculture. He completed a B.Sc. (AgSc) and M.Sc. (AgSc) with University of Adelaide in Australia, then a Ph.D. in plant breeding at Cornell University USA. Initially he was a post-doctoral fellow in wheat breeding at CIMMYT in Mexico, then a wheat specialist in Nigeria with IITA, and a cowpea breeder with the same organisation in Nigeria. This was followed with breeding of Phaseolus beans in Queensland Australia, and then curation of the temperate legume and oilseed collections in the Australian Temperate Field Crops Collection at Horsham in Victoria, Australia. While based in Australia, Robert also was involved in international projects in Columbia with CIAT, and in Japan and China. He has over 50 refereed articles on topics of plant breeding, plant pathology, entomology, agronomy, physiology, food science, biometry, genetic resources, and molecular biology. His conference proceedings number over 40, plus over 30 reports, over 30 international newsletter articles and over 20 extension publications. He has also contributed 8 book chapters and was co-editor of a major book. He has supervised 8 graduate students. In plant breeding Robert has released 10 Phaseolus bean varieties, and recommended 1 wheat variety. Robert has also been an examiner for various theses, and a reviewer for numerous refereed journal publications. His experience includes tropical and temperate crops, and wheat, grain legumes and oilseed crops, over a wide variety of climates and production systems.

Shyam S. Yadav is a programme leader of cereal and legume crops improvement programme at Regional Research Centre, Sir Alkan Tololo Research Center, National Agriculture Research Institute, Bubia, Lae, Papua New Guinea. Earlier he was working as Principal Legume Breeder at Division of Genetics, Indian Agricultural Research Institute, New Delhi, India. He received his B.Sc. degree in agricultural sciences from University of Agra, UP, India, M.Sc. degree in Plant Breeding from university of Meerut, UP, India before completing his Ph.D. in Genetics and Plant Breeding from the Indian Agricultural Research Institute, New Delhi, India in 1986. During his Ph.D. research programme he worked on the genetics and physiological basis for plant architecture of chickpea. He started his scientific journey as assistant breeder in January 1969 at the Division of Genetics, Indian Agriculture Research Institute, (IARI), New Delhi, India. Since then he has worked on various breeding positions in India and abroad till September 2009. As Principal Legume Breeder at IARI, he used different breeding options/approaches for genetic enhancement, varietal development, germplasm evaluation and maintenance and participatory breeding etc. More than 20 high yielding, widely adapted multiple resistant desi and kabuli chickpea varieties were released for commercial cultivation in different agro-ecologies under his leadership. He has also developed excellent germplasm lines are being utilised in many countries by legume breeders. Along with this, he worked on the development of integrated crop production and management technologies and its disseminations and popularization in farmer's fields. Professional collaborations were also developed under his leadership with international organizations like ACIAR, Australia, USDA, ICRISAT, ICARDA etc. during this period. He has published more than 140 research papers in national and international journals and written 15 book chapters for international books. In March 2007, a book on chickpea breeding and management was published by CABI, UK for which Yadav was senior editor. Another book on Lentil: An Ancient Crop of Modern Times was published by Springer, Dordrecht, The Netherlands in September 2007 for which Yadav was also senior editor.

Chapter 1
Climate Change, a Challenge for Cool Season Grain Legume Crop Production

Mitchell Andrews and Simon Hodge

1.1 Introduction

Dry pea (*Pisum sativum*), chickpea (*Cicer arietinum*), broad bean (*Vicia faba*), lentil (*Lens culinaris*), lupins (*Lupinus* spp.), grass pea (*Lathyrus sativus*) and common vetch (*Vicia sativa*) are the major cool season grain legume crops produced world wide (FAOSTAT, 2009). All are C_3 plants and all form associations with specific soil bacteria (rhizobia) to produce root nodules that can convert atmospheric nitrogen into amino acids (Andrews et al., 2009). This ability to fix atmospheric nitrogen gives cool season grain legumes an advantage over most non-legume crops in low soil nitrogen environments.

Dry pea, chickpea, broad bean and lentil are the four major cool season grain legume crops produced for human consumption. They are grown on all continents except Antartica and FAOSTAT (2009) lists one hundred and nine countries that produced at least one of these crops over the period 2001–2007. This is likely to be an underestimate as some countries with low production are not listed on the data base (Knights et al., 2007). Lupin species (e.g. *Lupinus albus*, white lupin and *Lupinus luteus*, yellow lupin) and vetches, in particular, common vetch, are important for animal feed. From 2001 to 2007, approximately 70% of total world production of lupin was grown in Australia (FAOSTAT, 2009). The Russian Federation was the main producer of vetch from 2001 to 2007 accounting for 40% of total world production. The Ukraine, Spain, Turkey, Mexico and Ethiopia each contributed 7–12% of total world production of vetch over this period. Grass pea is used for human and animal food in countries of the Mediterranean basin but its use is limited by the presence of the neurotoxin (oxalyldiaminopropionic acid) responsible for lathyrism in its seed.

Andrews et al. (2010) consider recent trends (2001–2007) in total world production and global pattern of production of dry pea, chickpea, broad bean and lentil and

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international trade in these crops from 2001 to 2006 highlighting the main export and import countries/regions. It is shown that a substantial proportion of the population of the Indian sub-continent depends on grain legumes as a major protein source in their diet and in relation to this, India, Pakistan and Bangladesh are major producers of dry pea, chickpea and lentil. Indeed, India is by far the largest producer of cool season grain legume crops worldwide, with a total production of chickpea, lentil and dry pea at close to 7 million tonnes (mt) annum^{-1} over 8.7 m hectares of land. The area sown in dry pea, lentil and chickpea in Pakistan and Bangladesh over the period 2001–2007 was 1.1 and 0.18 m hectares respectively (FAOSTAT, 2009). Other important areas of production highlighted by Andrews et al (2010) were Canada (dry pea and lentil) and China (mainly dry pea and broad bean), at just over 3 mt annum^{-1}, France (primarily dry pea but also broad bean) at $\sim$ 1.7 mt annum^{-1}, Russia (mainly dry pea) and Turkey (chickpea and lentil) at $\sim$ 1.1 mt annum^{-1}, Ethiopia ($\sim$ 0.5 mt annum^{-1} broad bean) and the USA ($\sim$ 0.45 mt annum^{-1} dry pea).

In relation to trade, an important feature of the data was that production of dry pea, chickpea and lentil does not meet demand in the Indian subcontinent and there is substantial import of these crops from developed countries, in particular, Canada, France, US, Australia and Turkey who export the bulk of the crop they produce.

In developed countries, cool season grain legume crops are generally minor crops grown in rotation with cereals on large farms (Yadav et al., 2007a, b). Here they have a strategic role in the food and feed economy as a high protein source and in nitrogen fixation inputs into the soil for subsequent cereal and oil seed crops. They also act as a break crop to facilitate control of weeds, pests and diseases that build up under predominantly cereal cropping. In developing countries, with either partially or wholly subsistence farming, both high rainfall and irrigated agriculture is on much smaller farms where small scale mechanization, contracted mechanical operations and animal and human labour are major features (Yadav et al., 2007a, b). Generally grain production from cereals is more reliable, and more responsive than legumes to crop inputs of water, fertilizers and weed control. This is in part because cereals have benefited to a greater extent from modern plant breeding for input-responsive varieties (Mantri et al., 2010). Also, dry matter and carbon gain per unit plant nitrogen or per unit time are generally greater for cereals than for nitrogen fixing legumes. This difference can at least in part be related to the greater specific growth rate of cereals (Andrews et al., 2009). The net result is that regions of high productivity in developing countries, either with irrigation or with medium-high rainfall, have higher economic returns with cereals than with legumes, and cereals are almost exclusively preferred by small scale farmers. Thus grain legume agriculture tends to be concentrated in marginal areas of low rainfall without irrigation, or as a dry season rotation crop after cereals grown in the rainy (monsoon) season. Under these conditions yields are low (Andrews et al., 2010). For example, the average yield of lentil in India from 2001 to 2007 was 0.70 kg hectare^{-1}. This compared with 1.14 and 1.24 kg hectare^{-1} in Canada and Turkey respectively over the same period (FAOSTAT, 2009; Andrews et al., 2010). Similarly, for dry pea, average yield from 2001 to 2007 was 1.06, 1.94 and 4.31 kg hectare^{-1} in India, Canada and France respectively.

1.1.1 Climate Change

Between 1906 and 2005, the average surface temperature of earth increased progressively, by approximately 0.7°C, with the greater part of this increase occurring over the later 50 years (IPCC, 2007a, b). The temperature increase occurred over the globe but was greater on land than in oceans and greatest at higher northern latitudes and least over the Southern (Antarctic) Ocean and parts of the North Atlantic Ocean. Linked to this, the global average sea level rose 10–20 cm in the twentieth century and at a rate of 3.1 mm year^{-1} from 1993 to 2003 due to thermal expansion and melting of polar ice sheets, glaciers and ice caps (IPCC, 2007a, b). Also, from 1900 to 2005, rainfall increased in eastern parts of North and South America, Northern Europe and Northern and Central Asia but decreased in the Mediterranean region, parts of Southern Asia, the Sahel and Southern Africa. In addition, the frequency of extreme weather and climate events, in particular, heat waves, storms and floods due to heavy precipitations and extreme high sea levels increased over most land areas (Meehl et al., 2000; IPCC, 2007a, b).

There is considerable evidence that the primary cause of increased global average temperature from 1956 to 2005 was the increase in anthropogenic greenhouse gas concentrations (IPCC, 2007a, b). Greenhouse gases absorb a proportion of the heat leaving the earth's surface and re-emit it downward, causing the lower atmosphere and hence global temperature, to increase. Carbon dioxide produced in fossil fuel use (and to a lesser extent land change use such as deforestation; Fearnside and Laurance, 2004) is the major anthropogenic gas, but methane (primarily due to fossil fuel use and agricultural practices), nitrous oxide (primarily due to agricultural practices) and chlorofluorocarbons (use in refrigeration systems, fire suppression systems and manufacturing processes) are also important (IPCC, 2007a, b).

Global atmospheric CO_2 concentration increased from around 280 ppm in the late eighteenth century to 379 ppm in 2005 (IPCC, 2007a). All countries contribute to global CO_2 emissions but China, the United States (US) and the European Union (EU, twenty seven countries) are responsible for around fifty per cent of global CO_2 emissions (Netherlands Environmental Assessment Agency, 2009). In 2008, China was the world's largest emitter of CO_2, with the US and the EU second and third respectively. This is in part related to the large population in these regions. On a per capita basis, CO_2 emissions are much lower in China than in the US, the EU or several other countries such as Australia which have substantially lower total CO_2 emissions.

In response to increasing greenhouse gas production worldwide, the Kyoto Protocol, an international agreement linked to the United Nations Framework Convention on Climate Change, was adopted in 1997 and entered into force in

2005 (United Nations Framework Convention on Climate Change, 2009). Under the Kyoto Protocol, most industrialized countries agreed to *collectively* reduce their emissions of greenhouse gases (CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by 5.2% compared to 1990 emissions. Under treaty obligations, some countries, for example the US and Canada, were set reduction targets, other countries such as New Zealand and Russia had emissions capped at 1990 levels while other countries such as Australia and Iceland were allowed to increase their CO_2 emissions. Several countries have met their targets set under the Kyoto Protocol, however, as of 2009, collective global targets in relation to CO_2 emissions were not being met. The annual atmospheric CO_2 concentration growth rate was 1.9 ppm year^{-1} from 1995 to 2008 (IPCC, 2007a; Earth System Research Laboratory, 2009).

The IPCC have estimated that if the concentration of greenhouse gases had stayed constant at 2000 levels, an increase in global average temperature of around 0.1°C per decade would occur from 2010 to 2030 (IPCC, 2007a, b). However, with the current reliance on fossil fuel use in global energy production and current climate change mitigation policies and practices, greenhouse gas emissions are likely to increase over the next twenty years and as a result, average global temperature is predicted to increase by around 0.4°C from 2010 to 2030 (IPCC, 2007a, b). Changes in average global temperature after 2030 are more difficult to predict and depend on a range of factors, in particular, the amount of greenhouse gas emissions and the proportion of CO_2 produced that is sequestered in ocean and terrestrial sinks (Andrews and Watson, 2010). Using a range of scenarios, the IPCC (IPCC, 2007a, b) predict a minimum increase in average global temperature of 1.1°C over the twenty-first century although this could be as great as 6.4°C. As occurred from 1900 to 2005, warming is predicted to be greater over land than in oceans and greatest at higher northern latitudes and least over the Southern Ocean and parts of the North Atlantic Ocean. Also, sea levels are predicted to rise by 0.18–0.59 m (depending on model used) due to further thermal expansion and melting of polar ice sheets, glaciers and ice caps.

Linked to the increase in global average air temperature and continuing the other climate trends observed from 1956 to 2005, IPCC (2007a, b) concluded that it is very likely that precipitation will increase at high latitudes but decrease in most subtropical regions. Annual river run off and water availability are predicted to increase at high latitudes and in some tropical wet areas but decrease in some dry regions in the mid-latitudes and tropics and water resources in many semi-arid areas are predicted to decrease. In addition, the frequency of hot extremes, heat waves and heavy precipitation are likely to increase further over all land areas. Also, it is very likely that tropical cyclone intensity will increase and that there will be a poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation and temperature patterns. Areas highlighted as being particularly vulnerable to extreme weather/climate events are the Asian and African mega deltas, due to their large populations and high exposure to sea level rise, storm surges and river flooding, and small islands where there is high exposure of population and infrastructure to extreme weather/climate events.

1.2 Effect of Climate Change on Cool Season Grain Legume Production

Crop growth is greatly dependent on climate as plant physiological processes respond directly to changes in air and soil temperature, solar radiation, moisture availability and wind speed (Monteith, 1981; McKenzie and Andrews, 2010). Climate can also influence the incidence of weeds, pests and diseases which can affect crop growth and yield (Oleson and Bindi, 2002; Aggarwal et al., 2004; McKenzie and Andrews, 2010). Thus, if climate change is substantial in crop growing regions, it could greatly affect growth and yield of crops grown there.

Parry et al. (2004; 2005) and IPCC (2007a, b) assessed the effects of projected climate change from 2010 to 2060 on crop/food production and risk of hunger in different regions of the world: different climate change scenarios developed by the IPCC were considered. Generally, the scenarios predicted yield increases in developed countries at mid and high-mid-latitudes but yield decreases in developing countries in the tropics and sub-tropics with the risk of hunger particularly high in Southern Asia and Africa. The increased risk of hunger with climate change in Southern Asia and Africa would add to the existing and increasing hunger problems in these areas due to the high number of poor people and an expanding population (Parry et al., 2004; 2005; see also Aggarwal et al., 2004). Aggarwal et al. (2004) argued that assuming a medium growth scenario, the population of South Asia will increase by 700 million people from 2005 to 2035 (see also United Nations Population Division, 2009) and that the demand for grain legumes will increase by 30% between 2010 and 2030.

In relation to cool season grain legumes in the major areas of production highlighted above, climate change would be expected to result in increased yields in North America and Northern Europe but decreased yields in Ethiopia, Southern Asia and possibly Australia (Australian Government Bureau of Meteorology, 2009) and Turkey (Oleson and Bindi, 2002; Yano et al., 2007). Also, large areas of agricultural land in Bangladesh and China are vulnerable to a substantial rise in sea level (IPCC, 1996). However, Parry et al. (2004; 2005) and IPCC (2007a, b) emphasized that there will be exceptions to the generalisations. For example, yields are projected to increase in areas subjected to increased monsoon intensity or where more northward penetration of monsoons leads to increases in available moisture. They also emphasized that the effectiveness of adaptation strategies to counter the negative effects of climate change is difficult to predict. Possible adaptation strategies highlighted that are relevant to cool season grain legume production include crop relocation, changes in sowing date, use of more stress tolerant genotypes, genetic adjustment of crops to increase their tolerance of stress, increased nutrient and plant protection inputs and intercropping with other crops to lower the risk of total crop failure under adverse conditions. Genetic adjustment of cool season grain legume crops should also include consideration of the rhizobial symbiont (Andrews et al., 2009).

1.3 Effect of Elevated CO_2 on Cool Season Grain Legume Crops

A major uncertainty in relation to the prediction of climate change effects on crop growth is the effect increased atmospheric CO_2 concentration will have on crop growth under agricultural conditions (Parry et al., 2004; 2005; IPCC, 2007a, b; Ainsworth et al., 2008a, b). Carbon dioxide is a substrate in the process of photosynthesis and there are reports for many C_3 plants under controlled environment or glasshouse conditions that a doubling of atmospheric CO_2 concentration will stimulate photosynthesis and lead to increased growth/yield and, in legumes, to increased nitrogen fixation (Stulen et al., 1998; Poorter and Nagel, 2000). There are also several reports that this CO_2 effect can be obtained under water stress conditions. Indeed, there is evidence that water use efficiency can be greater under high CO_2 as transpiration is reduced as a result of reduced stomatal conductance (Eamus, 1991; Kimball et al., 2002; Fleisher et al., 2008). However, due to a lack of appropriate experimentation, it is not certain how increased atmospheric CO_2 will affect crop growth under agricultural conditions where other environmental factors may interact with the CO_2 effect (Ainsworth et al., 2008a, b; Challinor and Wheeler, 2008). It seems likely that the maximum benefit of increased CO_2 will only occur if there is adequate nitrogen available to support the increased growth (Hungate et al., 2003; Van Groenigen et al., 2006; Wieser et al., 2008). Cool season grain legumes differ from cereals and most other non-legume crops in that they are capable of nitrogen fixation, which for a range of species has been shown to be stimulated by increased atmospheric CO_2 concentration under controlled environment, glasshouse and small scale field experiments (Zanetti et al., 1996; Rabah Nasser et al., 2008a, b; Soussana and Lüscher, (2007). Thus cool season grain legume crops in comparison with non-legume crops may be less affected by adverse climate change.

1.4 Conclusions

There is now unequivocal evidence that global climate is changing and that these changes are closely correlated with the increase in anthropogenic greenhouse gas concentrations, in particular, carbon dioxide produced in fossil fuel use. There is strong evidence that the average global temperature will increase by around 0.4°C from 2010 to 2030 and at least a further 0.7°C over the rest of the twenty-first century. Linked to this, sea levels are predicted to rise by 0.18–0.59 m over this period due to thermal expansion and melting of polar ice sheets, glaciers and ice caps. It is highly probable that precipitation and water availability will increase at high latitudes and in some tropical wet areas. It is equally probable that precipitation will decrease in most subtropical regions and water resources will decrease in some dry regions and many semi arid areas in the mid-latitudes and tropics. In addition, the frequency of extreme weather/climate events, in particular, hot extremes, heat waves and heavy precipitation will increase over all land areas: the Asian and African mega deltas are particularly vulnerable to extreme weather/climate events.

The effects of climate change on crop/food production and the risk of hunger in different regions of the world under different climate change scenarios developed by the IPCC have been assessed. Generally, the scenarios predict yield increases in developed countries at mid and high-mid-latitudes but yield decreases in developing countries in the tropics and sub-tropics. In relation to the major areas of production of cool season grain legume crops, these predictions indicate increased yields in North America and Northern Europe but decreased yields in Ethiopia and Southern Asia. However, the extent of negative effects of climate change on grain legume production in some regions will be dependent on the effectiveness of adaptation strategies put in place to counter them. A major uncertainty in relation to the prediction of climate change effects on crop growth is the effect increased atmospheric CO_2 concentration will have on crop growth under agricultural conditions. It seems likely that the maximum benefit of increased CO_2 will only occur if there is adequate nitrogen available to support the increased growth. Cool season grain legume crops are capable of nitrogen fixation and because of this may be less affected by adverse climate change than non-legume crops.

This book assesses the sustainability and potential of cool season grain legume crops at regional and global levels in relation to the agricultural challenges presented by climate change in conjunction with a continuing rise in world population. This rise in world population will result in a need to increase food production, despite urban growth reducing available arable land and water supply for irrigation. These losses will be especially significant because many cities are located on fertile soils and next to rivers for water supply. The question is whether cool season grain legume crops can maintain their current role, or even assume greater prominence, for direct supply of food and for sustainability of predominantly cereal farming systems under future climate and socio-economic conditions.

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Chapter 2
Modelling Climate Change Effects on Legume Crops: Lenmod, a Case Study

Bruce A. McKenzie and Mitchell Andrews

2.1 Introduction

Plant growth is greatly dependent on weather conditions, with physiological processes responding to changes in air and soil temperature, solar radiation, moisture availability and wind speed (Monteith, 1981). The effects of individual climatic elements on crop growth during distinct phases of plant development can be quantified allowing the calibration of mechanistic numerical models of crop growth. Such models give greater understanding of how different climatic factors interact to determine crop yield and have several uses including the prediction of where previously untested crops might be grown and of how changes in climate in specific regions could affect crop growth and yield there (Milford et al., 1995; Andrews et al., 2001; Wang et al., 2002). A benefit of such models is that they can predict crop growth and yield with considerable confidence without prolonged and costly experimentation.

Probably the most widely used crop growth models are the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) crop models (IBSNAT, 1989). These are mechanistic models based on equations which relate crop growth and development to the major climatic drivers of plant growth and development listed above. The IBSNAT models such as CERES wheat (Ritchie and Otter, 1985) have been widely validated and Parry et al. (2005) used this set of models for a review on the effects of climate change on global food supply. The APSIM (Agricultural Production Systems sIMulator) suite of models is also commonly used. This is actually a modelling framework which has the ability to integrate a range of sub models. This versatile structure can simulate growth of more than 20 crops (Wang et al., 2002). It is also capable of analyzing whole farm systems and providing advice to growers on crop and pasture rotations (McCown et al., 1996). The Food and Agriculture Organisation of the United Nations (FAO)

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has developed a very simple water driven model called Aqua-crop (Steduto et al., 2009). This model is based on transpiration, thermal time and canopy cover and is simple enough that it should be valuable as a decision support tool in developing countries.

In New Zealand (NZ), a range of models has been developed to provide decision support to arable cropping farmers. The Wheat calculator, which is a version of the Sirius model developed by Jamieson et al. (1998) is used by wheat (*Triticum aestivum*) growers throughout Canterbury and accurately predicts biomass accumulation, grain yield, leaf area index (LAI), nitrogen utilization and irrigation requirements. Similar models have also been developed for maize (*Zea mays*) (Reid et al., 1999), asparagus (*Asparagus officinalis*), carrot (*Daucus carota, sativus*) and potato (*Solanum tuberosum*) (http//www.crop.cri.nz/home/products-services/crop-production/crop-mgmt.php, site accessed June 2009).

In this chapter we focus on lentil (*Lens culinaris*), one of the four major cool season grain legume crops produced for human consumption. Firstly, we describe the development of LENMOD, a lentil crop growth model, in Canterbury, NZ. Secondly, we give details of a case study of validation of the model in the United Kingdom (UK) and its use to predict crop growth and seed yield of spring and autumn sown lentils in eight sites along a transect from NW Scotland to SE England chosen to encompass important environmental gradients in the UK. Finally, we use LENMOD to predict the likely effects of increased temperature and increased soil moisture deficits (the two most likely long-term effects of climate change in Canterbury, NZ; Ministry for the Environment, 2001) on lentil growth and yield in Canterbury, NZ.

2.2 LENMOD

LENMOD was developed and calibrated in experiments carried out on a silt loam soil at Lincoln, Canterbury, New Zealand (43.38°S, 172.30°E, 11 m above sea level) using cv. Titore, a small seeded, red variety of lentil (McKenzie and Hill, 1989; McKenzie et al., 1994). The experiments utilized spring, summer, autumn and winter sowing dates and a range of irrigation treatments over different years. The model requires the input of daily values of maximum and minimum air temperature, solar radiation, precipitation, potential evapo-transpiration and day length and assumes that there is no water stress at the time of sowing, soil fertility is non-limiting and the crop is free of weeds and disease throughout all stages of growth. A flow chart outlining the lentil growth modeling process is shown in Fig. 2.1.

All developmental stages in LENMOD except emergence to flowering depend on accumulated thermal time (TT). Sowing to emergence, flowering to physiological maturity and physiological maturity to harvest date require 115, 546 and 270°C days above the critical temperature respectively. Emergence to flowering is dependent upon accumulated photothermal time and requires 278°C days (photothermal) above the critical temperature. The critical temperature below which growth and

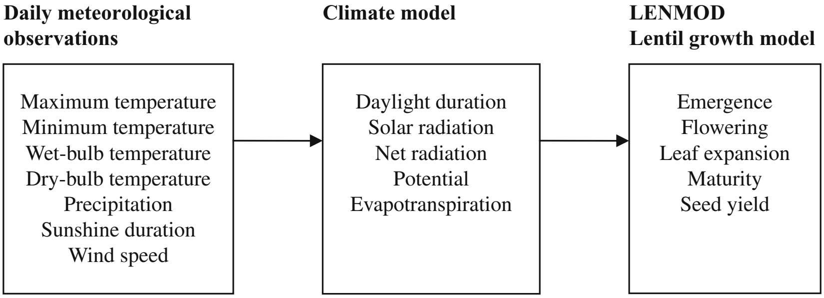

Fig. 2.1 Flowchart showing the lentil crop growth modelling process

development stop is 2°C up to flowering and 6°C after flowering. The equations for relative daily leaf growth (RDLG), LAI and crop growth rate (CGR) are:

(1) $\mathrm{RDLG} = -0.0174 + 0.00829 \times \text{daily TT}$
(2) $\mathrm{LAI} = \text{previous LAI} \times \mathrm{RDLG} + \text{previous LAI}$
(3) $\mathrm{CGR} = 0.5 \times \mathrm{IR} \times \text{fraction IR intercepted} \times \mathrm{RUE} \times \text{drought factor}$

In Equation (2), LAI is not allowed to exceed seven. In Equation (3), IR equals incident radiation and the drought factor is a "switch" that turns off growth when the limiting deficit is passed. Radiation use efficiency (RUE) is set at 1.7 g DM MJ^{-1} of intercepted radiation. The equation for the fraction of IR intercepted is:

(4) $\text{Fraction IR intercepted} = 1.0 - \exp(-k \times \mathrm{LAI})$

where –k is the extinction coefficient which is usually set at 0.32. The limiting soil moisture deficit is calculated from the relationship between relative yield and maximum potential soil moisture deficit (Penman, 1948). When all plant available soil water is depleted, the drought factor becomes zero and thus the CGR becomes zero. After achieving maximum LAI, LAI declines to zero as a parabolic function of TT, based on 650°C days as follows:

(5) $\mathrm{LAI} = \text{previous LAI} - \text{max LAI} \times [(\text{accumulated TT}/2.5) \times \text{daily TT} \times \text{leaf killer} \times (2/650^2)]$

Leaf killer is dependent on soil moisture. If the soil moisture goes above the limiting deficit, leaf killer is five, but if it is below the limiting deficit, then leaf killer is one. Soil moisture deficit is based on Penman's potential evapotranspiration. Total dry matter (TDM) is calculated from daily crop growth rate and the model assumes a stable harvest index of 40% for the calculation of seed yield.

2.3 LENMOD Case Study 1: The UK

2.3.1 Validation of the Model

Crop growth models can be used to predict where previously untested crops might be grown (Milford et al., 1995; Andrews et al., 2001; Wang et al., 2002). LENMOD was used to assess the potential of lentil as a grain legume crop in the UK (Andrews et al., 2001; Joyce et al., 2001). Firstly, the model was validated on one site (Durham 54.77°N, 1.58°W, 40 m above sea level; Fig. 2.2) over different studies. In the main study, predicted and actual time to flowering and seed yield were determined for five spring sowing dates in 1999 (Table 2.1).

The simulations were also run with two levels (150 and 250 mm) of plant available water (PAW). In LENMOD, soil moisture deficit is a trigger for turning off growth when the soil moisture deficit passes a critical deficit (0.5 × PAW). This example considers a soil with a PAW of 150 mm as an average soil and a soil of PAW = 250 mm as a heavy soil.

For the four sowing dates from 21 April to 12 May 1999, predicted flowering date was within 3 days of actual flowering date (Table 2.1). For the final sowing date (26 May), predicted flowering date was 3–7 days later than actual flowering date. For all sowing dates, predicted seed yields were within 9% of actual seed yields which ranged from 1.40 to 1.65 t ha^{-1}. It was concluded that use of LENMOD in Durham is valid.

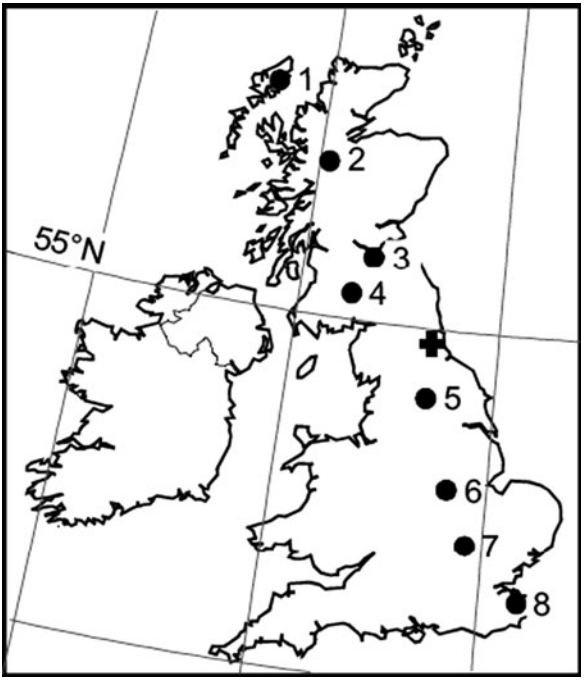

Fig. 2.2 The location of the eight sites within the UK for which meteorological data were used to predict lentil crop growth utilizing LENMOD. From north to south the sites are *1* (Stornoway, 58.22°N 6.32°W), *2* (Fort Augustus, 57.13°N 4.68°W), *3* (Turnhouse, 55.95°N 3.35°W), *4* (Eskdalemuir, 55.32°N 3.20°W), *5* (Bramham, 53.87°N 1.15°W), *6* (Sutton Bonington, 52.83°N 1.12°W), *7* (Woburn, 52.02°N 0.58°W) and *8* (East Malling, 51.28°N 0.45°E). The location of Durham where field experiments were carried out is indicated by a cross

Table 2.1 Actual and predicted flowering date and seed yield of lentil cv Titore for five sowing dates at Durham in 1999

	Flowering date		Seed yield (t ha^{-1})	
Sowing date	Actual	Predicted	Actual	Predicted
21 April	24 June–28 June	26 June	1.65	1.55
28 April	29 June–1 July	30 June	1.58	1.47
5 May	2 July–5 July	4 July	1.55	1.46
12 May	6 July–10 July	9 July	1.40	1.47
26 May	11 July–15 July	18 July	1.62	1.48
SE (10df)			0.109	

Taken from Andrews et al. (2001).

2.3.2 Prediction of Crop Growth

After validation of LENMOD at Durham, the model was used to predict maximum crop growth rate (CGR), flowering date, maximum LAI, radiation intercepted, total dry matter (TDM) produced, harvest date and seed yield for spring and autumn sown lentil over the period 1987–1995 for eight sites selected from the UK Meteorological Office network of climate stations along a transect from NW Scotland to SE England (Fig. 2.2; Andrews et al., 2001). This transects spans 7 degrees of latitude, corresponding to a difference in day length of approximately 1.5 h in mid-summer and is likely to capture the major spatial variability of mean temperature, rainfall and sunshine intensity throughout the year in the UK. Solar radiation and potential evapotranspiration are also likely to vary systematically over the length of the transect.

Mean climatic conditions during the period 1987–1995 varied systematically between the eight sites used to model lentil yields. Mean air temperature during the growing season (May to September) increased with decreasing latitude, from 11.6°C at Stornoway to 15.4°C at East Malling (Table 2.2). Elevation above sea level exerts a secondary influence on temperature, illustrated by the anomalous cold conditions at Eskdalemuir (11.6°C) which is the highest site at 242 m above sea level. Mean solar radiation and potential evapotranspiration also tended to increase with decreasing latitude (Joyce et al., 2001). Mean May to September precipitation totals ranged from 543 mm at Eskdalemuir to 235 mm at the most southerly sites.

Predicted data for three sites, Fort Augustus (57.13°N, 4.68°W, 40 m above sea level), Eskdalemuir (55.32°N, 3.20°W, 242 m) and East Malling (51.28°N, 0.45°E, 40 m) are presented to highlight how different climatic conditions would be expected to interact to determine crop growth and yield. In general, over the period 1987–1995, monthly mean daily solar radiation increased in the order Fort Augustus < Eskdalemuir < East Malling but monthly mean daily air temperature during the growing season (May to September) increased in the order Eskdalemuir (11.6°C) < Fort Augustus (12.6°C) < East Malling (15.4°C) (Table 2.2; Joyce et al.,

Table 2.2 Monthly mean air temperature (°C) for the period 1987–1995 for eight sites in the UK for which meteorological data were used to predict lentil crop growth

Site	May	June	July	August	September	Average
Stornoway	9.2	11.2	13.3	13.1	11.1	11.6
Fort Augustus	10.1	12.5	14.8	14.0	11.4	12.6
Turnhouse	10.3	13.0	15.0	14.9	12.1	13.1
Eskdalemuir	9.1	11.6	13.8	13.1	10.4	11.6
Bramham	10.9	13.5	16.1	15.9	13.0	13.9
Sutton Bonington	11.5	14.1	16.9	16.5	13.6	14.5
Woburn	11.6	14.0	16.9	16.7	13.7	14.6
East Malling	12.4	14.8	17.7	17.7	14.4	15.4

Taken from Joyce et al. (2001).

2001). Temperatures were lowest at Eskdalemuir because of its greater elevation. Monthly rainfall was generally greater for Fort Augustus and Eskdalemuir than for East Malling. In comparison with mean monthly rainfall, mean monthly potential evapotranspiration was generally less variable across the sites. During May and June for Eskdalemuir, from May to July for Fort Augustus and from April to August for East Malling, mean monthly potential evapotranspiration was substantially greater than mean monthly rainfall.

For the May sowing with 150 or 250 mm PAW, predicted mean values for maximum CGR, maximum LAI, radiation intercepted, TDM and seed yield increased with site in the order Fort Augustus < Eskdalemuir < East Malling (Table 2.3). These

Table 2.3 Predicted mean values for maximum crop growth rate (CGR), flowering date, maximum leaf area index (LAI), radiation intercepted, total dry matter (TDM) produced and seed yield for lentil cv Titore with spring (1 May) and autumn (1 October) sowings at three sites in the UK over the period 1987–1995

	Fort Augustus			Eskdalemuir			East Malling		
	1 May[1]	1 May[2]	1 Oct[1]	1 May[1]	1 May[2]	1 Oct[1]	1 May[1]	1 May[2]	1 Oct[1]
Max CGR ($kg\ ha^{-1}\ d^{-1}$)	93	93	117	100	117	71	162	186	213
Flowering date	3 July	3 July	7 June	9 July	9 July	14 June	28 June	28 June	20 May
Maximum LAI	2.18	2.18	2.66	2.23	2.23	1.08	3.94	3.94	7.35
Radiation intercepted ($MJ\ m^{-2}$)	208	210	262	246	247	166	317	363	704
TDM ($t\ ha^{-1}$)	2.50	2.64	2.96	3.22	3.60	2.42	3.08	4.75	6.94
Seed yield ($t\ ha^{-1}$)	1.00	1.10	1.18	1.29	1.44	0.97	1.23	1.90	2.78

[1] 150 mm plant available water.
[2] 250 mm plant available water.
Taken from Andrews et al. (2001).

effects were related to differences in average air temperature and radiation interception. An increase from 150 to 250 mm PAW with the May 1 sowing had only small effects on growth and yield at Fort Augustus and Eskdalemuir (Table 2.3). However, for East Malling where potential evapotranspiration was substantially greater than mean monthly rainfall for the longest period, this increase in PAW caused 54% increases in TDM and seed yield.

A switch in sowing date from 1 May 250 mm PAW to 1 October gave small increases in crop growth and yield at Fort Augustus, substantial increases in crop growth and yield at East Malling but substantial decreases in crop growth and yield at Eskdalemuir. The positive effects of autumn sowing at East Malling were due, in part, to greater leaf area duration (LAI × time) and hence greater radiation interception. Also, autumn sowing reduced the period of time the crop was exposed to water stress due to its earlier maturation. The negative effects of autumn sowing at Eskdalemuir were due to low temperatures over-winter and in spring which restricted leaf development and hence reduced radiation interception. At all sites, flowering date was unaffected by an increase from 150 mm to 250 mm PAW with the May sowing but was earlier with the October sowing due to photothermal effects.

For a 1 May sowing at 150 mm PAW, seed yield was similar at Eskdalemuir and East Malling but for the 1 October sowing, seed yield was three times greater at East Malling. In the case of East Malling, predicted yields for autumn sowing (2.78 t ha^{-1}) are exceptional but not unrealistic as yields of around 2.8 and 2.5 t ha^{-1} were obtained for autumn-sown lentil at Reading in S England over different years (Crook et al., 1999). Andrews et al. (2001) concluded that lentil has considerable potential as a grain legume crop in the UK but acknowledged that further tests are required at more northerly and southerly sites in the UK.

2.4 LENMOD Case Study 2: Climate Change in NZ

2.4.1 Predictions of NZ Climate

The New Zealand government has suggested that the most likely long term effects of climate change in the South Island of New Zealand are an increase in temperature of about 3°C and a reduction in rainfall of 5–10% which is likely to increase drought conditions during summer (Ministry for the Environment, 2001). In relation to this, LENMOD was used to predict lentil yields in Canterbury, New Zealand under four climatic scenarios. These were: (1) control; (2) dry environment simulated by reducing PAW from 150 mm in the control to 135 mm. This is equivalent to a 10% reduction in soil water availability to the crop; (3) a hot climate simulated by adding 3°C to daily minimum and maximum temperatures and (4) a combination of both dry and hot conditions. In addition the crop was virtually sown on either 1 June or 1 October. These dates are appropriate for winter sowings and late spring sowings respectively and provide significant variation in yields (McKenzie and Hill, 1990). Simulations were run over five contrasting years from 2004 to 2008. For analysis of variance, years were used as replicates.

2.4.2 Sowing Date Effects on Yield

Yield results are presented in Table 2.4. As expected, winter sown lentils produced more grain and TDM than did spring sown lentils. This is supported by a survey of results of lentil trials at Lincoln averaged over four seasons for winter sowing and six seasons for spring sowings. Winter sowings yielded 2.21 t grain ha^{-1} while spring sowings yielded 1.61 t grain ha^{-1} (McKenzie, 1987; McKenzie et al., 1986; McKenzie et al., 1989; Ayaz et al., 2004). Only in wet seasons when disease potential is high do spring sowings usually out-yield winter sowings (McKenzie, 1987). This scenario is not possible to model with LENMOD as it contains no disease sub-routines.

Winter sowings yield more than the spring sowings in most years due to increased LAI and increased intercepted solar radiation. As shown in Tables 2.4 and 2.5,

Table 2.4 Simulated yields of lentil and possible explanatory variables generated by LENMOD for crops sown in June and October in 2004–2008 in Canterbury NZ under four climatic scenarios

	Grain yield (t ha^{-1})	Total dry matter (t ha^{-1})	Maximum LAI	Intercepted PAR (MJ m^{-2})	Effective Penman ET (mm)
Sow date					
June	2.50	6.25	7.22	655	438
October	2.06	5.13	4.63	482	283
Significance	**	**	**	**	**
SED	0.118	0.29	0.098	36.3	16.03
Climate					
Control	2.19	5.44	5.53	550	382
Dry	2.01	5.04	5.53	530	385
Hot	2.55	6.38	3.36	631	338
Hot and dry	2.36	5.90	6.30	563	335
Significance	*	*	**	NS	NS
SED	0.167	0.412	0.138		

* Significantly different $P < 0.05$
** Significantly different $P < 0.01$

Table 2.5 Correlations between simulated total dry matter yield and a range of possible explanatory variables (see Table 2.4)

	Intercepted PAR	Maximum LAI	Maximum growth rate	Growth duration	Effective Penman PET
Total dry matter	0.76	0.35	0.62	0.30	0.37

the simulated winter sowings intercepted 36% more radiation than did the spring sowings and intercepted radiation had the highest correlation with total dry matter production.

2.4.3 Climate Scenario Effects on Yield

The four different climate scenarios, in comparison with sowing date, had a much smaller effect on both grain yield and total dry matter production (Table 2.4). The highest yields were produced under the hot climate scenario (2.55 t ha^{-1}) which was 16% greater than the 2.19 t ha^{-1} achieved in the control simulations. This is not too surprising when one considers long term temperatures in Canterbury. Mean daily maximum temperature in January (the hottest month) is 21.3°C (Broadfields meteorological station, Canterbury, NZ), while mean daily temperature in January is a modest 16.4°C. The maximum predicted increase in temperature in Canterbury of 3°C is clearly likely to result in improved lentil yields. This is primarily due to increased LAI as temperature is an important factor affecting leaf expansion (Dennett et al., 1978; Andrews et al., 1989). The greater LAI tends to result in greater interception of photosynthetically active radiation (PAR). While intercepted PAR was not significantly increased in these simulations, the highest value obtained was in the hot scenario.

The dry scenario did not result in significant decreases in either seed or TDM yield when compared with the control. This is mostly due to two factors. Firstly, a 10% decrease in plant available water is a small change and secondly the soil which was used for these simulations is a deep cropping soil which contains a total PAW of 150 mm m^{-1} of soil (McKenzie and Hill, 1990). This soil has a critical limiting deficit of about 130 mm for lentils and hence irrigation does not usually result in yield responses in Canterbury (McKenzie, 1987). These results clearly indicate that climate change in Canterbury is unlikely to be detrimental to lentil yields. Indeed, it is likely to result in increased yields of cool season grain legumes.

The situation in other grain legume growing areas could be different. The IPCC (1996) report suggests that global warming over this century will be 1–4.5°C. Cline (2007) presents figures that state long term annual temperatures in NZ will rise from 10.2 to 12.7°C; in NW India, they will rise from 23.6 to 27.5°C and in central Canada from –0.5 to 5.4°C. Precipitation in the three regions is expected to increase 5, 21 and 16% per day respectively. Increased temperatures in NW India are likely to result in decreased yields. However, work in India by Dinar et al. (1998) suggests that while warming in India has the potential to reduce yields by 8–12%, increased CO_2 levels could offset this reduction. Their sensitivity analyses suggested that increased precipitation may actually give a small increase in net revenue. In Canada, the increased temperatures are likely to result in increased yields. However, Cutforth et al. (1999) suggested that increased temperatures in SW Saskatchewan are likely to result in a reduction in precipitation and this is likely to result in increased frequency of droughts. This has the potential to negatively impact on cool season grain legume yields in this prairie province.

2.5 Conclusions

Crop growth and yield is dependent upon weather conditions and soil factors. Computer simulation models can accurately predict growth and yield of a range of crops. LENMOD, a computer simulation model of lentil growth development and yield developed in NZ was used to determine potential yield of lentils at a wide range of sites in the UK. The model was first validated at Durham, UK. Using a range of sowing dates, time to flowering was predicted within 3–7 days and predicted yields were always within 9% of actual yields. The model suggested that SE England has the greatest potential for growing lentils with yields of up to 2.8 t ha^{-1}.

In NZ, LENMOD was used to study the potential effects of climate change on lentil growth and yield. The New Zealand government has suggested that the most likely long term effects of climate change will be a temperature increase of about 3°C and a reduction in rainfall of between 5 and 10%. When past climate records were altered using these parameters, the highest yields were obtained in the warm climate scenario (2.55 t seed ha^{-1}) which was 16% higher than the 2.19 t ha^{-1} produced in the control simulations. The 10% reduction in soil moisture had no significant effect on either seed yield or total dry matter production. These effects can be explained by the moderate maritime climate of New Zealand, and even though Canterbury is sub-humid, rainfall is still approximately 600 mm $year^{-1}$ and evenly spread. Average daily temperature in January, the warmest month, is 16.4°C and increasing this by 3°C provides close to ideal temperatures for lentils. This warming will increase leaf expansion rates and result in greater LAI and usually greater radiation interception.

The situation in other countries could be different. In NW India, increased temperatures are likely to reduce lentil yields, although elevated CO_2 could offset this reduction and an increase in rainfall could even result in a small increase in yield.

In SW Saskatchewan, Canada, increased temperatures are likely to increase yields unless rainfall decreases to a point that increases the frequency of drought.

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Chapter 3
Ecology and Adaptation of Legumes Crops

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3.1 Introduction

It is recognized that agricultural practices determine the level of food production and, to a great extent, the state of the global environment (Tilman et al., 2002). In this context, after the "Green Revolution", recognized for the adoption of new varieties with a higher yield potential and crop performance than that rendered by conventional varieties, it is clear that the new varieties were not developed to withstand low inputs unimproved environments. The technological packages developed during the "Green Revolution" were clearly fertilizer input-specific with a high rate of economic return, which was an initial decision to stimulate the public acceptance of the new technology. Without the use of synthetic fertilizers, world food production could not have increased at the rate it did and more natural ecosystems would have been converted to agriculture. Between 1960 and 1995, global use of N fertilizer increased sevenfold, and P use increased 3.5-fold; both are expected to increase another threefold by 2050 unless there is a substantial increase in fertilizer efficiency (Tilman, D. et al., 2001; Cassman and Pingali, 1995). After decades from the beginning of the "Green Revolution", it is clear that fertilizer use and legume crops have almost doubled total annual nitrogen inputs to global terrestrial ecosystems (Vitousek and Matson, 1993; Galloway et al., 1994). The Green Revolution then failed to place enough emphasis on the sustainability of its increased productivity, as production became dependable on the application of fertilizers (though it must be remembered that the initial focus was to avert the imminent prospect of mass starvation in many countries) (Welch and Graham, 2000). Indeed, it is essential that the plant breeders expose its genetic material to strong pressures of selection (Jennings, 1974), which is the case of low fertility soils, among others; in this sense, improved varieties of legumes adapted to nutrient deficiency have the potential to improve food security for the poorest farmers (Snapp and Silim, 2002). On the contrary, the scheme that was drawn by the "Green Revolution",

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obviously reduces the possibilities to recognize the tolerant segregates, that often by chance, by insufficient sampling or other reasons are not taken into account. As Yield expression is a combination of genotype and environment, it is difficult to select successfully for improved yield in only a low yielding low input environment. However, evidence is needed to assert that selection across both, low and high input environments, selected against yielding ability in low input environments. On the other hand, while no one knows for certain what changes will have to be made, we can be sure that when conventional energy resources, required for fertilizers industries and mechanization, become scarce and expensive, the impact of such industries and the way of life on agriculture will be significant (Pimentel et al., 1973). The intensification of the use of resources, especially in the wheat-rice system, resulted in resource degradation, mainly related to soil and water quality, as occurred in the Indian and Pakistan Punjab. The Indian Punjab was hurt by a steep decline in the water table, while rising water levels in the wheat-cotton zone led to severe water logging; on the other hand, data from the Pakistan Punjab also confirm a serious problem of water logging and salinity, due in part to deterioration in the quality of tube-well water. Additionally, if the water supply has now declined, this indicates lack of water replenishment which will become worse with climate change (Murgai et al., 2001). After five decades of planned economic development, large numbers of people in the Developing World still lack the basic means of subsistence, due to insufficient technical and economical support and to a lack of appropriate training and capacitating programs, among other factors; as Yapa (1993) pointed out, seeds themselves have been the material embodiment of a nexus of interacting relations between social, political and ecological aspects of society. Anyway, the efforts of the "Green Revolution" rendered different responses in countries and regions; in this sense, both China and India benefited from the Green Revolution, but improvements in the Chinese agricultural sector were also aided by more fundamental institutional reforms. China achieved its gains through both substantial increases in capital per worker and rates of total factor productivity growth more than double those for India (Bosworth and Collins, 2008).

Now it is recognized that the essential plan to achieve a sustainable change in the agriculture should include an integral vision of the agricultural sector, capable to consider the balance among the diverse factors of the production: opportune and adequate prices, credit or financing, availability of supplies and inputs, transportation, techniques of conservation and storage, maintenance of the soil fertility, and in the case of the arid and semiarid zones, attention to long-term water supply and to drainage/soil salinity. After all, agricultural development requires re-investment in all aspects of infrastructure in rural areas, not just the performance of plans and strategies for export of produce. Despite recent achievements in conventional plant breeding and genomics, the rate of increase of crop yields is declining and thus there is a need for a second green revolution, considering that, in the first "Green Revolution", the initial gains over unimproved varieties were easier to achieve, but further gains require more extensive, larger and scientifically informed breeding programs (Wollenweber et al., 2005). In order to reach a sustainable agriculture, under an optimized management of inputs, it is required to find and develop tolerance to an extensive set of factors that limit the production, as diseases, pests, frosts, high temperatures, drought, low fertility and salinity, excesses of humidity, poor drainage, and water deficit, among the most important. As a necessary improvement, the centralized global approach to germplasm improvement that was so successful in the past is today being enhanced by enforcing the incorporation of decentralized local breeding methods designed to better incorporate the perspective of end users into the varietal development process (Morris and Bellon, 2004).

3.2 Benefits of Legume Based-Agriculture System

The economic and environmental costs of the heavy use of chemical N fertilizers in agriculture are a global concern. In this context, biological nitrogen (N_2) fixation is an important aspect of sustainable and environmentally friendly food production and long-term crop productivity (van Kessel and Hartley, 2000). Sustainability considerations mandate that alternatives to N fertilizers must be urgently sought. Biological nitrogen fixation (BNF), a microbiological process which converts atmospheric nitrogen into a plant-usable form, offers this alternative (Bohlool et al., 1992). Legumes are noteworthy for their ability to fix atmospheric nitrogen, an accomplishment attributable to a symbiotic relationship with rhizobia found in root nodules of these plants. The symbiotic relationship between legumes and their resident nitrogen-fixing bacteria (rhizobia) begins when the plant senses the bacteria and develops a specialized nodule to house them (Udvardi and Scheible, 2005). The ability to form this symbiosis reduces fertilizer costs for farmers and gardeners who grow legumes, and means that legumes can be used in a crop rotation to replenish soil that has been depleted of nitrogen. Legume seed and foliage has comparatively higher protein content than non-legume material, probably due to the additional nitrogen that legumes receive through nitrogen-fixation symbiosis. This high protein content makes them desirable crops in agriculture. Benefits arising from breeding of legumes for N_2-fixation and rhizobial strain selection have the potential to increase inputs of fixed N, for alleviating the environmental stresses, and for promoting changes in farming systems to include more legumes (Giller and Cadisch, 1995).

Legume seed, although rich in protein (Duranti and Gius, 1997), tends to be relatively expensive, and a high seeding rate of 40–100 Kg per ha may be required for larger-seeded legume cover crops. If a legume cover crop is incorporated as a green manure, and the resultant nutrients reduce requirement for fertilizer or manure application, then the net benefits in soil quality improvement and nutrient supply may alleviate the cost of N fertilizers. One of the most inexpensive legume cover crops is soybean, either a grain soybean that is incorporated while still vegetative or a forage soybean that remains vegetative longer and produces much larger amount of residues for use as a green manure. Presently underutilized crop and pasture legumes could still emerge (Graham and Vance, 2003). Ladizinsky and Smartt (2000) address opportunities for improving the dry matter production, hence increasing the volume of green manure, via further adaptation and domestication.

3.3 Ecology and Management of Legume Crops

Most legumes are adapted to a wide range of well-drained soils. In its native range, some of them are often found on highly eroded soils of volcanic origin with pH 4.5–6.2, but is also found on sands, heavy clays and slightly alkaline, calcareous limestone soils. Anyway, adaptation to soil type ranges widely among crop legumes, acidic for lupin angustifolius, alkaline for chickpea and for lentil. A work in Peru suggests that *Gliricidia sepium* (Jacq.) Kunth ex Walp. is suitable for acid and low-fertility soils. However, in Indonesia, there was poor survival of *G. sepium* plants on soils with a high Al saturation; in Australia, this legume tree is thought to be suitable for low-calcium soils, although it does not grow well on wet or waterlogged soils. Legume species can be used as a crop associated with other species. In a study carried out in Nicaragua, the common bean (*Phaseolus vulgaris* L. Cultivar Rev-81) was intercropped with coffee (*Coffea arabica* L. Cultivar Catuaí), during two years. The yield of common bean was higher in the first year (710 kg/ha) than in the second year (406 kg/ha) (Blanco et al., 1995); this was due because common bean is poor in N fixation, and hence N fertilizer is often applied. Yield commonly is higher in the first year based on residual soil fertility, but run down in year 2.

About the ecology of herbaceous perennial legumes, there are doubts about its adaptation to acid soils and to climates where summer rainfall is low and ambient temperatures are high. There is also a need to diversify the species available to reduce the likelihood of invasion by exotic diseases and insects. Several genera are likely to be of value in this respect, although few will be as widely adapted as lucerne. Perennial legumes are found in environments ranging from alpine to desert. Targeted collections of genera from the dry areas, especially where soils are acid, are likely to yield species of value. These may include perennial species of *Astragalus*, *Hedysarum*, *Lotus*, *Onobrychis*, *Psoralea*, and *Trifolium*. Some other genera, for example *Swainsona*, *Glycine*, and *Cullen* may also be of value. Most of these genera are adapted to alkaline soils, and the need to cope with acid soils that are often high in free aluminium is seen to limit their use (Cocks, 2001). As a multiple-purposes resource for dry zones, mezquite (*Prosopis articulata*) is a useful legume tree for soil conservation in grazing lands (Fig. 3.1). A relative, velvet mezquite (*Prosopis velutina*) is a large shrub or tree up to 30′ or higher, which holds the record for deepest root (160’); these taproots can “tap” into deep, ground water supplies that aren’t available to the “average” plant. Its seeds need to be scarified (abraded in flash flood or digestive tract for example) to germinate. Velvet Mesquite has many uses for humans, including food (its pods make a sweet flour), furniture, charcoal (“mesquite-grilled”), fabric, medicine, and it even provides the “gum” of gumdrops. The tree is also valuable to other organisms for food, shelter, and other uses. According to León de la Luz et al. (2005), the fresh woody biomass for two species of mezquite (*Prosopis articulata* and *P. palmeri*) is currently used as raw material to make commercial charcoal in Sierra de la Giganta, Baja California Sur, Mexico.

In Australia, Lefroy et al. (1992) studying browse plants, found that of the cultivated species two have achieved any degree of commercial acceptance (*Leucaena*

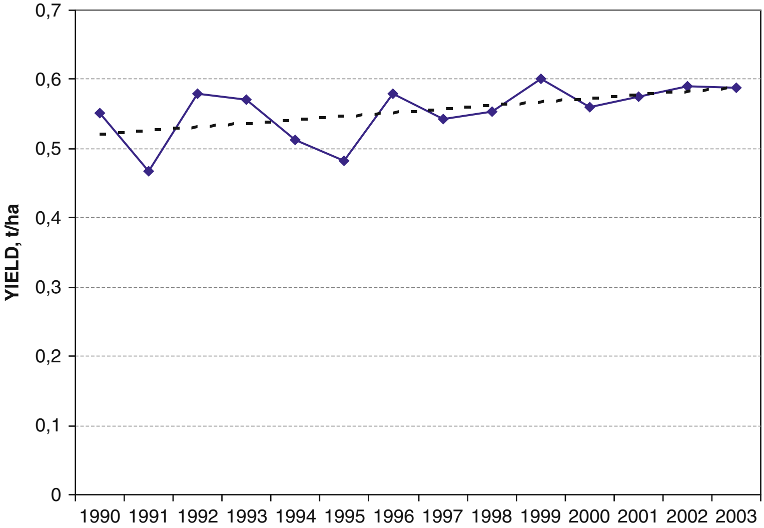

Fig. 3.1 Yield of common bean (*Phaseolus vulgaris* L.) in southern México, from 1990 to 2003

leucocephala and *Chamaecytisus palmensis*), and indicated that these are of sufficiently high forage value to be used as the sole source of feed during seasonal periods of nutritional shortage. Both are also leguminous shrubs that establish readily from seed. They suggested that a limitation in their use is the reliance on stands of single species which leaves the grazing systems vulnerable to disease and insects. In this context, grazing systems so far developed for high production and persistence of cultivated species involve short periods of intense grazing followed by long periods of recovery.

3.4 Aspects of Soil and Plant Nutrition Under Warming Climates and Temperate Zones

Because of beneficial association with Rhizobia, the main deficient mineral status in legumes relate to other elemental interactions, rather than N. In a study carried out in México, it was found that cowpea plants growing in desert calcareous soils took up lower amounts of N, P, and K than those considered as optimum in previous reports. Through principal component analyses, six interactions strongly indicated for cowpea different relations in foliar elemental composition: positive for Ca-Mg, and negative for N-Ca, N-Mg, Ca-P, Mg-P, and K-P. Furthermore, two interactions were also identified using simple correlations, negative N-P and positive K-Ca. In that study, the foliar compositional nutrient diagnosis (CND) for five nutrients in a high-yield subpopulation yielding at least 1.88 t ha^{-1} of cowpea indicated that the optimum ranges of the main nutrient concentrations (g kg-1) were, N: 26.2+2.4, P: 2.57+0.68, K: 22.9+9.2, Ca: 21.7+3.2 and Mg: 4.01+0.7 (García-Hernández et al., 2005).

In dry and low fertility soils, soil amendment with green manure, mainly from legume crops, is an ecological option with long term beneficial effects. In an agroecological research in semiarid Northwest Mexico, *Dolichos Lab-lab purpureus* was applied as green manure in two conditions (with incorporation or without incorporation). In soil samples obtained at 0–30 cm depth, average increments in OM (0.12%), in K (12.64 mg·kg^{-1}) and on microbial activity (36.6%) were found at the second sampling, as compared to the first sampling, before the incorporation of green manure. Plots with manure incorporation showed increases in OM (0.17%), K (12.46 mg·kg^{-1}) and soil respiration rate (48.3%), as compared to plots without incorporation, showing significant increments of mineralized carbon, macronutrients (N, P and K) and OM after green manure incorporation (Beltrán-Morales et al., 2006). The growing concern about the sustainability of tropical agricultural systems stands in striking contrast to a world-wide decline in the use of soil-improving legumes. It is timely to assess the future role that soil-improving legumes may play in cropping systems. Only a few legume species are currently used as green manures in lowland rice. *Sesbania cannabina* is the most widely used pre-rice green manure for rice in the humid tropics of Africa and Asia. *Astragalus sinicus* is the prototype post-rice green manure species for the cool tropics. Stem-nodulating *S. rostrata* has been most prominent in recent research (Becker et al., 1995).

In temperate and cool season-prevailing zones, besides increasing N availability through atmospheric nitrogen fixation, temperate legumes can help bridge a gap between winter and summer pastures. In these zones, optimum growth and availability of temperate legumes occur during spring, a time in which the quality of winter small-grain pastures is declining and common grasses are yet unavailable. The benefits of legumes in temperate zones are vast and diverse; according to Rogers et al. (1997), several species or lines showed potential as salt-tolerant germplasm including *Trifolium tomentosum*, 2 lines of *T. squamosum* and *T. alexandrinum* cvv. Mescani and Wardan, which were all more salt tolerant than *T. subterraneum*. Two lines of *Lotus tenuis* and 1 line of *L. corniculatus* were also relatively salt tolerant. Some of this material had never been previously assessed under saline conditions. Further selection and field evaluation (including selection for increased productivity and salt tolerance over a range of growth stages) is required for the material that has shown potential in order to fully assess its performance under saline soil conditions, especially under climate change.

3.5 Constraints of Legumes Production: The Case of Common Bean (*Phaseolus vulgaris* L.)

Despite evident advances in the productivity of different crop species, mainly cereals and forages, unfortunately, improvement in legume crop yields has not kept pace with those of cereals; Jeuffroy and Ney (1997) note that wheat (*Triticum aestivum*)

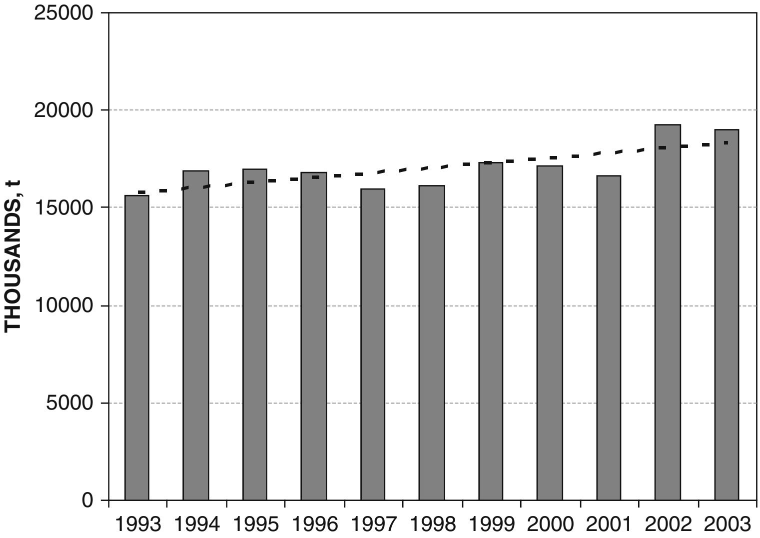

Fig. 3.2 World production of common bean (*Phaseolus vulgaris* L.), from 1993 to 2003

yields in France increased 120 kg ha^{-1} year^{-1} between 1981 and 1996, but those for pea increased only 75 kg ha^{-1} year^{-1} over the same period. In Fig. 3.2 the tendency for the world production of common bean is shown; global increases of 252,600 t per year were estimated for all over the world, but yet insufficient to satisfy a growing demand, because of the expanding population.

3.6 Actual and Potential Possibilities for Legume Crops Breeding Based on Ecological Traits

Legume-based agriculture under unfavorable conditions requires specific studies; in this context, Murillo-Amador et al. (2001) concluded for cowpea genotypes that selection and classification for salt tolerance can be successfully undertaken at early seedling stages.

As regards to the research of options for the development of a selection or breeding program oriented to drought, according to Kelly et al. (1998), strategies employed by dry bean breeders to improve yield include early generation testing, ideotype breeding, selection for physiological efficiency, and selection based on genotypic performance and combining ability across gene pools of Phaseolus vulgaris. Ideotype breeding has been successfully deployed to improve yield in navy, pinto and great northern seed types. The ideotype method is based on an ideal plant architecture to which breeders target their selection. Breeding for physiological efficiency is important in combining increased biomass, high growth rates and efficient partitioning. Breeders must work within specific constraints for growth habit, maturity, seed quality, and disease resistance.

Legume crops selection or breeding program using biochemical traits. It is well known that the abscisic acid (ABA), a plant growth-regulator, is involved in the stomata closing in the stress responses, and there is evidences that differences in the stomata response to stress are at least partially determined by genetic differences in the ABA biosynthesis. For example, a variety of sorghum-milo Serere 39, with a high capacity of accumulation of ABA, showed a significantly greater sensitivity to water stress that two other varieties with low accumulation of ABA (Henson et al., 1981). On the other hand, the analysis of transgresive segregation in crosses between lines with high and low accumulation of ABA suggested the participation of more than one gene. Other biochemical substances, among them some osmolites, cations, plant-regulators, protein compounds and low molecular weight metabolites, also can be useful in the evaluation and selection of tolerant plants to stress (water, saline, thermal). Examples are proline, the concentration and activity of the peroxidase enzyme in mezquite leaves (García-Carreño et al., 1992; García-Carreño and Troyo-Diéguez, 1991), citokinines, the accumulation of K^+, and others. (For temperate zones)

It can be concluded, therefore, that the stomata-character based breeding directed to diminish the losses of water can have greater possibilities of success, in those cases where breeders can modify the total time of stomata closing, but not where small quantitative, non significant, changes in the conductance occur. In this context, it is possible to make emphasis, that the modifications of a culture in relation to the area to foliar, including those resultants of the changes in the duration of the time of culture, they are possibly more important for the water use in all the service life that the changes in the stomata conductance.

For drought tolerance, it is difficult to determine the optimal balance between the factors involved in water conservation (low stomata conductance "SC") and those required to maximize production (high SC). This balance depends, in a complex way, on the agricultural situation and on the particular climate in each case (particularly on the probability of precipitations). Although frequently it is argued that the stomata apparatus which closes as a respond to stress would be ideal in many cases, some researchers have found that a relatively insensible stomata apparatus can be preferable since it would allow a continuous assimilation during drought (Henzell et al., 1976). Despite the prevailing difficulties and the controversy that prevails in the science of plant ecophysiology, possibilities exist for breeders to manipulate stomatal and related traits associated with the soil-plant-atmosphere continuum. Such breeding will depend on further understanding about the role of stomata in the adaptation of plants to environment.

The use of mutants and variant genetic lines with different stomata characters constitutes a technique valuable to elucidate the physiological role of stomata. As Kramer (1988) stated, the field aspects, and its implicit variability, must receive a greater attention, and the differences found between the laboratory and field must be analyzed methodically, in order to avoid erroneous conclusions. On the other hand, it is well established that the destructive methods and the use of sensors which modify climatic variables may lead to biased data (Passioura, 1988).

3.7 The Role of Legumes to Provide Soil N Through N Fixation

Intensive high-yield agriculture is dependent on addition of fertilizers, especially the industrially produced NH4 and NO3. In some regions of the world, crop production is still constrained by too little application of fertilizers (Pinstrup-Andersen and Pandya-Lorch, 1996). The goal of sustainable agriculture is to maximize the net benefits that society receives from agricultural production of food and fibre and from ecosystem services. This will require increased crop yields, increased efficiency of nitrogen, phosphorus and water use, ecologically based management practices, judicious use of pesticides and antibiotics, and major changes in some livestock production practices. Advances in the fundamental understanding of agroecology, biogeochemistry and biotechnology that are linked directly to breeding programmes can contribute greatly to sustainability (DeVries and Toenniessen, 2001). Pingali and Rosegrant (1998) point out that nitrogen fertilizers have been widely subsidized in Asia, and that at least some of the problems of providing adequate soil nutrient supplies in agro ecosystems as rice and rice-wheat production units would be eased by elimination of these subsidies.

Without a doubt, because of well known benefits obtaines from Rhizobia, the increase of legume-associated agro ecosystems will continue contributing to maintain soil fertility and reducing environmental impacts derived from extensive use of industrial fertilizers.

3.8 Current Perspectives for Drought Tolerance Research in Arid Zones

The requirements for strategies useful to alleviate the deficiencies of an insufficient agricultural production could be based on a multidisciplinary global approach. This contrasts with uncoordinated and numerous independent detailed tests in laboratory and field requested by plant ecologists and physiologists. The proposal is for integration of scientists and technicians with different academic backgrounds, dedicated to a common global goal, including the collection and evaluation of seeds, native and introduced, and the promotion of thorough integrative evaluation research. Under such a scheme, environments with different levles of abiotic stresses, including low fertility and salinity, must be used, and also those sites with different levels of available nutrients, and different qualities of available water, with integration of the objectives drawn up from both individual and from group levels. We reiterate that the practice of agriculture of high technology can put in risk the quality of the environment (soil, natural vegetation, surface waters, ground water), specially under the effects of climate change, and also we make emphasis in the troubled possible scenario related to the water scarce availability, under climatic change tendencies, mainly in arid and semi-arid zones, which can worsen in the near future.

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Chapter 4
Physiological Responses of Grain Legumes to Stress Environments

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Availability of water for agriculture is being challenged increasingly because of a growing demand for water from other sectors such as industry, urban use, and for social and environmental purposes. The increase in demand for blue water (surface and sub soil) in future would perhaps be met at the cost of irrigation available to agriculture. Water is essential to plant growth as it provides the medium within which most cellular functions takes place. Water is also required as a unit of exchange for acquisition of CO_2 by plants. Water stress may conceivably arise either from an insufficient or from an excessive water activity in the plant's environment. In the case of terrestrial plants in nature, the former occurs as a result of a water deficit or drought and therefore is called a water deficit stress (shortened to water stress) or drought stress. Many physiological characteristics are correlated with the water potential of mesophyll tissue but the correlations are species specific. There is a general hierarchy of sensitivities among general physiological activities. Most sensitive are cell expansion, cell wall synthesis, protochlorophyll formation, and nitrate reduction. Generally turgor pressure is still accepted as the best indicator of water stress in plants. The specific mechanism by which turgor regulates physiological function probably relates to cell walls and membranes. Since cell expansion is dependent on cell pressure and the cell wall yield threshold, there can be no cell expansion without turgor pressure greater than the yield threshold for cell expansion. Studies with algal systems have indicated that slight changes in turgor pressure decrease membrane permeability to water and ions. Cell membrane structure and spatial arrangement of enzyme, transport channels, cellulose synthesis rosettes, and receptor proteins may be dependent on turgor pressure. Thus, when turgor pressure decreases, the spatial relationships of these proteins change, and membrane function is disrupted.

Due to the wide variation in ambient temperature among environments where plants reside and the poikilothermic nature of plants, it is logical to expect a wide range of metabolic, morphological and anatomical adaptations to thermal

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conditions. One of the most important aspects of tissue energy balance is energy absorbed from radiation impinging on the tissue surface. Radiation comes to the leaf surface from the series of different sources. Direct and diffused solar radiation sum to produce total radiation impinging on a leaf from the sky. Diffused radiation from the sky is that which is scattered by particles or clouds in the atmosphere. Temperature can influence economic yield through each of the components, with variation in relative magnitude of effect on them. In most of the situations, the main effect is likely to be on cumulative radiation incident and proportion intercepted, through crop ontogeny and rate of leaf area development. There is relatively little information available for the food legumes about the effect of temperature. Clearly extremes of temperature which reduce the reproductive sink through gametogenesis can substantially reduce harvest index. To date, most of the efforts have been made in improving adaptation to cooler temperatures. But, opportunities for genetic improvement in relation to temperature responses remain largely unexploited. In most cases, little is known about the complexity of genetic control of differential responses. Genetic advances may be further hindered by the lack of correlation between sensitivities at different stages and between different processes.

4.1 Introduction

Food legumes are still relatively minor crops despite their role as a source of protein in the diet of predominantly vegetarian populace and their importance as components of animal feed and a major source of biological nitrogen fixation in a cropping system. An important explanation of the apparent low status of food legumes, despite their tropical and subtropical adaptation is the tendencies to underestimate the role of these crops in farming systems. They are often grown as a secondary crop in arid and semi-arid regions under poor edaphic and receding soil moisture conditions. Most food legumes have a long history of domestication almost as long as cereals, and during this time they have been subjected to conscious and unconscious selections for better adaptation to environmental condition as well as better seed yield. Larger seed size, lack of germination inhibitors, non-shattering pods and freedom from toxic compounds are all retrospective evidence of modification by man (Zohary and Hopf, 1973). Despite this, yields of food legumes fall well short of the yields obtained for the major cereals like wheat, maize, rice, sorghum *etc.* Although, simple dry matter comparisons under estimate the dietary contribution of legumes by 25–30%, because of their high caloric contents of protein, it is of interest to explore the reason(s) for the apparent differences in the genetic yield potentials of these two important crop families.

Pulses belong to the *Leguminosae* family. Mostly cultivated grain legumes are the following (Table 4.1)

Pulse crops can be categorized into cool-season (dry peas lentil, lupins and chickpea) and warm- season (common bean, soybean, pigeonpea, mungbean, urd beans, cowpea) crops based primarily on their ability to emerge in cool season conditions and on frost tolerance (Miller et al., 2002). Minimum temperature for seed

Table 4.1 List of major cultivated grain legumes with their botanical names

Mungbean (green gram)	*Vigna radiata* (L) Wilczek
Urdbean (black gram)	*Vigna mungo* (L) Hepper
Pigeonpea (red gram)	*Cajaus cajan* (L) Millsp.
Chickpea (gram)	*Cicer arietinum* L.
Lentil	*Lens culinaris* Medik.
Lathyrus (grass pea)	*Lathyrus sativus* L.
Bean (rajmash)	*Phaseolus vulgaris* L.
Field pea	*Pisum sativum* L.
Cowpea	*Vigna unguiculata* (L) Walp.
Mothbean	*Vigna aconitifolia* (Jacq.) Marechal
Horsegram	*Macrotyloma uniforum* (Lam.) Verdc
Ricebean	*Vigna umbellate* (Thumb) Ohwi and Ohashi
Lupins	*Lupinus albus* L.
Faba beans	*Vicia faba* L.

germination and crop growth differ amongst pulse crops, with soybean having a base temperature near 10°C (Raper and Kramer, 1987) compared to base temperature near 0°C for chickpea, dry beans and lentil (Summerfield et al., 1989; Roberts et al., 1988; Ney and Turc, 1993). Consequently soybeans typically require a relative later seeding date, mid May to early June to reduce the risk of frost injury (N Hemisphere). Chickpea, dry beans and lentil tolerate a moderate degree of frost, 2 to –18°C, depending upon the cultivars, degree of acclimation and plant growth stage (Wery et al., 1993; Welbaun et al., 1997; Srinivasan et al., 1998). On the Canadian Prairie, daytime temperature for best growth of chickpea range from 21 to about 30°C, whereas temperature range for best growth of field pea is 13–23°C (Hnatowich, 2000; Soltani et al., 2006; Wang et al., 2006). Temperatures exceeding 30–32°C limits yield of chickpea by hastening maturity and/or decreasing seeds/plant and seed weight (Harris, 1979; Wang et al., 2006). Chickpea will tolerate higher temperatures than field pea during flowering; temperature >27°C will often decrease flower numbers and flowering duration (Hnatowich, 2000; Hawthorne et al., 2003). Lentil has poor tolerance for higher temperatures, especially at flowering and pod set (Erskine et al., 1994).

Abiotic stresses adversely affect growth and productivity and trigger a series of morphological, physiological, biochemical and molecular changes in plants. Drought, temperature extremes and saline soils are the most common abiotic stresses that plants encounter. Globally, approximately 22% of the agricultural land is saline (FAO, 2004), and areas under drought are already expanding and this is expected to increase further (Burke et al., 2006). Often crops are exposed to multiple stresses, and the manner in which a plant senses and responds to different environmental factors appears to be overlapping.

Till to date most of the breeding programmes for improved yield of grain legumes rely on empirical selection for superior seed yield and quality across a wide range of target environments. Unfortunately, the inheritance of seed yield is very low, which is indicative that the observed variation attributed to genetic effects (G) is relatively small in comparison to variations observed due to environmental effects (E) and that different genotypes respond differentially, depending on environment (G × E) (Blum, 1998). The G × E term of the phenotypic model combines all the specific genotypic responses to varying environmental conditions into a single parameter that plant breeders have tried to interpret and exploit (Turner et al., 2003).

The factors which underline the yield gaps are numerous and complex. They relate to inherent differences in crop architecture and developmental pattern. For cereals these differences allow intercepting more light and remaining insensitive to day length. These changes in light responses sustain a much higher concentration of inflorescence and grain per unit of land area in cereals than legumes. Genetic manipulation is only one aspect of crop improvement and may not be most appropriate means for resolution of the primary limits of productivity for adaptation. For those cases, where the differences in plant performance relate to mainly one specific limitation, such as disease, the strategy of crop improvement is relatively clear. More commonly, however, agricultural environments impose quite complex challenges with many factors bearing simultaneously limiting and there may be a range of responses by different genotypes to these changes. In these situations, relative differences among genotypes become important. The nature of the differences and of the appropriate resolution strategies become less clear and the objective of providing alternative strategies for crop improvement becomes more complex. Climate is the major factor of the environment conditioning the regional and seasonal adaptation and yield of the crop plant. Improvement in climatic adaptation is fundamental to the process of crop improvement in broader sense viz., the manipulation of both genotypes and environments to respectively maximize genetic potential and minimize environmental constraints to the expression of the potential. The key climatic factors influencing the food legumes are insolation, temperature, day length and water availability.

In general, crops face a number of abiotic stresses during their ontogeny viz., excessive and/or low soil water stress, soil salinity stress, high as well as low temperature stress. It has been well documented that crop yields would be greater in many cropping regions if more water were available. Before examining different physiological processes as affected by various stresses, let us first examine, in brief, the generalized view of these stresses on the various physiological processes in plants. It has been stressed that the adaptability and productivity of cool season food legumes (chickpea, faba beans, lentil and pea) are limited by major abiotic stresses including drought, heat, frost, chilling, water logging, salinity and mineral toxicity (Stoddard et al., 2006).

4.2 Excessive Water (Flooding) Stress

Ecosystems that normally are affected by flooding, called *wetlands*, are diverse in species composition and ecosystem function (Maltby and Turner, 1983). Plants found in wetland systems are often more diverse than the wetland systems themselves. Prolonged saturation of wetland sediments or upland soil in which plants grow has a significant impact on both abiotic and biotic attributes of the rhizosphere. The population of soil microorganisms shift in composition and abundance, resulting subsequently in changes to soil solution chemistry due to differential metabolism of the new soil flora. These changes affect root growth and therefore, plant performance.

Water logging occurs when water enters the soil faster than it can drain away under gravity. Intensive and large-scale irrigation of farmland can also increase the incidence of water logging of the soil. A third contributory factor can be a change of land use. For example, conversion of meadow land to arable farming. The most important detrimental characteristic of the flooded ecosystem for plants is the resulting reduced oxygen partial pressure in the root zone. This is important because (1) roots are particularly sensitive to anaerobic conditions, and (2) anaerobic conditions support a unique microbial community compared with aerobic conditions, and this can severely affect the nutrient relations of the soil (Nilsen and Orcutt, 1996).

The most immediate effect of anaerobic soil conditions on plants is a reduction in aerobic respiration in roots. The switch to anaerobic conditions in soil around roots, upon extended flooding, causes root cells to switch to anaerobic respiration, which is much less efficient than aerobic respiration. The particular end product of anaerobic respiration is partly dependent on pH. At a pH above neutrality, lactate fermentation is dominant, and as pH decreases (due partially to lactate fermentation), ethanol fermentation is induced. Rapid drop in cytosolic pH, called *acidosis,* is thought to be one of the main reasons why cells die in response to flood. In flood-tolerant plants the pH drop may be counteracted by an alkalization process. The formation of α-aminobutyric acid, the accumulation of amides, and possibly the accumulation of arginine may be part of the alkalization process of wetland roots during anaerobic conditions (Crawford et al., 1994).

In *Phaseolus vulgaris*, a plant that is sensitive to hypoxia, a 20 h absence of oxygen resulted in an accumulation of pyruvate, ethanol and lactate (Chirkova et al., 1974). Flooding increases the alcohol dehydrogenase activity of clover roots as much as 30 times (Francis et al., 1974), indicative of anaerobic respiration, and therefore, of possible injury. In the cotyledons of pea and beans, submerged for 24 h in aerated or “nitrogenated” water, the aerobic dehydrogenase (malate dehydrogenase) decreased slightly in activity, while the activity of the two anaerobic dehydrogenases, lactate dehydrogenase and alcohol dehydrogenase, increased, the lactate dehydrogenase by many times more than the alcohol dehydrogenase (Schramn and Mazurowa, 1975). The lactate dehydrogenase is an indication of flooding injury in seeds, as is alcohol dehydrogenase in roots.

Catalase and peroxides of water-grown rice coleoptiles were maintained at lower levels than in air-grown seedlings (Paul and Mukherji, 1977). According to Burrows and Carr (1969), the severe chlorosis in the lowest leaves of flooded sunflower plants may be due to a reduction in import of cytokinins from the flooded roots. In the case of barley root (De Witt, 1969) polysaccharides synthesis was reduced indicating a disturbance in phosphorus metabolism (Anikiev et al., 1973). Low soil temperature and low oxygen levels interact to retard shoot development in wheat plants, pointing to a dependence of shoot development on root metabolism (Sojka et al., 1975).

Excessive water can limit yields of food legumes in several ways. The most common is reduction in nitrogen fixation, chlorosis and reduction in crop growth. There is variation amongst food legume species in tolerance to temporary water logging, e.g., mungbean, pigeonpea, grass pea and moth bean are particularly sensitive to water logging conditions while other food legume species are more tolerant to water logging condition.

Pigeonpea is susceptible to water logging with the effect that many areas of high rainfall and/or impermeable soil are not suitable for pigeonpea production. One apparent cause of physiological damage is ethylene produced by soil micro flora. Short term or intermittent water logging affects biological nitrogen fixation and can lead to severe nitrogen deficiency (Thompson et al., 1981). Genotypic differences in physiological tolerance of water logging have been reported (Chauhan, 1987).

4.3 Soil Water Deficit Stress

Availability of water for agriculture is being challenged increasingly because of growing demand for water from other sectors such as industry, urban use, and for social and environmental purposes. The increase in demand for blue water (surface and sub soil) in future would perhaps be met at the cost of irrigation available to agriculture (Saxena and O'Toole, 2002). Water is essential to plant growth as it provides the medium within which most cellular functions takes place. Water is also required as a unit of exchange for acquisition of CO_2 by plants. Water stress may conceivably arise either from an insufficient or from an excessive water activity in the plant's environment. In case of terrestrial plant in nature, the former occurs as a result of a water deficit or drought and therefore is called a water deficit stress (shortened to water stress) or drought stress. Drought is a meteorological term, and is commonly defined as a *period without significant rainfall* (Turner, 1979).

The linkage between water availability and deleterious influences on physiological processes is easy to document. However, the specific aspects of tissue water relation that cause the deleterious impact are enigmatic. Many physiological characteristics are correlated with the water potential of mesophyll tissue. However, the correlations are species specific. Thus one species may have severely reduced photosynthesis at tissue water potential of –2.0 MPa (e.g., soybean), while that of another species (such as *Larrea tridentate*, Creosote bush) is not affected. This phenomenon was presented and investigated in the 1970s (Hsiao, 1973; Hsiao et al., 1976). There is a general hierarchy of sensitivities among general physiological activities. Most sensitive are cell expansion, cell wall synthesis, protochlorophyll formation, and nitrate reduction.

Genotypic differences for various morpho-physiological traits in lupins under the low rainfall environments of the Mediterranean climatic regions has been studied for consecutive years in Western Australia and it has been shown that fast rates of seed development were highly and significantly correlated with high yield in seasons in which the intensity of the development of terminal drought was average but not under extreme conditions of terminal drought. It was also shown that dry matter transfer from stem to seeds was insignificant and not related to seed yield, suggesting that it is not a useful characteristic in screening for high yield under terminal drought (Palta et al., 2007). Genotypic variations in rooting behavior across environments were demonstrated in chickpea genotypes (Ali et al., 2005) and it has been advocated that the ability of a plant to change its root distribution to exploit deeper stored soil water may be an important mechanism to avoid drought stress (Benjamin and Nelson, 2006). Yield and yield components of twenty lentil (*Lens culinaris* L.) genotypes were compared in Iran during 2004. It was observed that there were significant genotypic differences between traits in lentil genotypes. The seed yield per plant was sensitive to drought stress but 100-seed weight was more tolerant and stable trait in drought conditions (Salehi et al., 2008).

The water relations characteristic that is most associated with cell growth and other sensitive physiological processes is the change in water potential rather than the absolute value of tissue water potential. Frequently, a decrease in cell water potential of only 0.1 MPa can cause a decrease in cell enlargement rate and the result is reduced cell size in shoots and roots. Amongst the various components of water potential, turgor potential (Ψ_t) decreases most rapidly with any change in tissue water potential. Thus, Ψ_t was identified as the best indicator of water stress (Hanson and Hitz, 1982). Many studies have shown the correlation between turgor potential and physiological function, but few studies have tried to evaluate the mechanism by which turgor potential is regulating physiological function. Turgor pressure is not always associated with changes in physiological function induced by water limitation. Turgor pressure of corn tissues at different developmental stages responded differently to water limitation (Boyer, 1970). When the elongation rate of differentiating cells was inhibited by withholding water, cell expansion decreased along with a decrease in $\Delta\Psi_t$ of differentiated cells. Yet there was no change in turgor pressure of non-differentiated (juvenile tissues). Thus, as the water limitation occurred, cell size decreased and turgor pressure remained constant in differentiating cells (Boyer, 1970) (Table 4.2).

Table 4.2 Effect of various levels of water potential on different physiological processes

Process $\Delta\Psi$ (MPa)
————————————————0————————0.5————1.0————1.5————
-2.0——————2.5
Cell growth ————————————- —————-
Cell wall synthesis —————————- —————
Protein synthesis ————————— ———
Protochlorophyll formation ——— ———-
Nitrate reductase ———————— ———
Stomatal closure ———————— ——————- —————-
Some xerophytes ————
CO2 assimilation —————————- ——————- ———
Some xerophytes ————
Stem hydraulic conductance —— ——————
Proline accumulation ——————- ————————-
Sugar accumulation ——————— ———————

Table 4.2 lists relative sensitivities for major physiological functions to water limitations. Water limitation is defined as the changes in tissue water potential. $\Delta\Psi_{,}$ the changes in tissue water potential from some initial to some final state. This index does not concern the absolute value of tissue Ψ (Redrawn and modified from Hsiao, 1973).

How much turgor pressure is required for optimal physiological processes? This is a hard question to answer because turgor pressure varies between 1.0 and 0.5 MPa amongst species during normal water availability conditions. Turgor potential may decrease from these values at dawn to approximately zero at mid day in many species. Furthermore, some species normally have turgor pressure close to zero over most of the day light hours during the entire growing season (Nilsen et al., 1984) without any indication of physiological dysfunction. Under these conditions cell expansion and growth occur at night when turgor pressure is maximum.

Generally (although there is some disagreement amongst scientists) turgor pressure is still accepted as the best indicator of water stress in plants. The specific mechanism by which turgor regulates physiological function probably relate to cell walls and membranes. Since cell expansion is dependent on cell pressure and the cell wall yield threshold, there can be no cell expansion without turgor pressure greater than the yield threshold for cell expansion. Cell wall synthesis is highly related to cell expansion; therefore, it is reasonable to expect these two functions to be most sensitive to reduction in turgor pressure. After a cell has matured, no more cell expansion will occur, yet cell physiology remains sensitive to turgor pressure. Studies with algal systems have indicated that slight changes in turgor pressure decrease membrane permeability to water and ions (Zimmerman and Steudle, 1975). Cell membrane structure and spatial arrangement of enzyme, transport channels, cellulose synthesis rosettes, and receptor proteins may be dependent on turgor pressure. Thus, when turgor pressure decreases, the spatial relationships of these proteins change, and membrane function is disrupted (Hsiao, 1973).

A reduction in mesophyll water potential (with or without a reduction in turgor pressure) can affect the physiology of cells in several ways.

- Reduced water potential reduces the chemical activity of water and thereby modifies the structure of water in the cell.
- A lower chemical activity of water can cause a change in the structure of the sheath of hydration around proteins and thereby reduces their efficacy.
- The relationship among intracellular membranes of chloroplast, nucleus, mitochondria, endoplasmic reticulam, tonoplast, plasmalemma and others will change because the cellular position of these membranes will change.
- A loss of turgor may cause a change in the spatial position of transport channels and membrane enzymes and decrease membrane thickness.
- A change in cell pressure and the resultant cell wall shrinkage may constrict the entrance to plasmodesmata.
- The concentration of molecules in specific regions may change due to the loss of water in some sub cellular locations.

When water limitation is large enough to increase tissue water deficit, there will be a reduction in turgor pressure. Since cell expansion is dependent on the cell Ψ_t, developing cells will expand less and cell size will be smaller under these conditions. The turgor potential of expanding cells remains constant during decreasing water potential even though severe reduction in cell expansion may occur (Boyer, 1970; Barlow, 1986). Therefore, the impact of reduced turgor is transmitted from mature cells to developing cells. The critical water potential of cell expansion is different among species and within plants (e.g., corn roots and leaves have different critical water potentials). For example, changes in water potentials of –0.2 to –0.4 MPa (Boyer, 1970) cause cessation of leaf expansion in sunflower, while the threshold for corn leaf expansion is a change of –0.7 MPa and that of soybean is change of –1.2 MPa (Acevedo et al., 1979).

The initial effect of water limitation on photosynthesis is usually stomatal closure. Stomata may close because of a root signal (Davies and Zhang, 1991), probably abscisic acid, or low turgor pressure of the guard cells (Collatz et al., 1991). Stomata also close in response to increased vapour pressure gradient between leaf and air, although this may not be associated with a change in water potential (Turner et al., 1984). Non-stomatal inhibition of photosynthesis (due to photo-inhibition or other mechanisms) normally accounts for a larger proportion of photosynthetic inhibition as water potential becomes lower (Ögren and Öquist, 1985). However, during the initial phase of water limitation, stomatal closure and non-stomatal inhibition occur concurrently. In fact, there is evidence in several species that non-stomatal inhibition may occur first, causing a temporary increase in C_i, which causes stomata to close (Briggs et al., 1986). The mechanism by which water limitation directly inhibits the photo-synthesis apparatus is controversial. Some like Björkman and Powles (1984) believe that non-stomatal impact is due to photo-inhibition, while others (Ögren and Öquist, 1985) believe that RuBP carboxylase is inactivated leading to nonstomatal photoinhibition of photosynthesis. Reduced turgor may increase the permeability of the outer chloroplast envelop, resulting in a change in chloroplast pH and ion concentrations. The change in ion concentrations and pH can affect secondarily the activity of RuBP carboxylase. Some studies have pointed out that photosynthetic enzymes are relatively immune to the deleterious effects of water stress (Björkman et al., 1980; Mayoral et al., 1981), while others indicates direct impact on photosynthetic enzymes (O'Toole et al., 1976). Degradation of chlorophyll increases, and the concentration of the chlorophyll (in particular *a/b* binding protein complex) decrease during water stress. Therefore, light harvesting and electron transport associated with photosystem II is preferentially decreased (compared to that of photosystem I) by water deficit stress (Björkman et al., 1981).

As water limitation progresses, photosynthesis decreases before respiration decreases; consequently, the ratio between photosynthesis and respiration decreases. The decrease in ratio of photosynthesis to respiration, and the potential increase in both photo-respiration and dark respiration during water stress causes the plant to starve. However, it is more likely that the plant will suffer greater damage to the shoot system from metabolic effects of water limitation other than carbohydrate deprivation (Nilsen and Orcutt, 1996). Carbohydrate translocation also decreases during water limitation during the day, but may increase relative to well-watered plants at night (Bunce, 1982). The decrease in sugar translocation is not due to specific effects on the phloem loading process. In fact, phloem loading is relatively resistant to water limitation (Sung and Krieg, 1979). The cause of reduced photosynthate translocation is the change in source-sink relationships during water stress. Low CO_2 assimilation by leaves and increased respiration in mesophyll cells of leaves decreases the gradient of sucrose between source leaves and the photosynthates sinks. The reduced gradient from source to sink causes a reduction in carbohydrate flow in the phloem.

However, in another study involving six species of grain legumes viz., lupins, chickpea, faba beans, field pea, grass pea and lentil in southern Australia it was shown that the effects of water deficits on the growth, yield, water relations and gas exchange are remarkably similar in all six species of grain legumes. There was little correlation between net photosynthetic rates per unit leaf area and water relation characteristics and it was concluded that yield under drought conditions is strongly correlated with early vigour and early pod set which enables the plants to escape drought (Leport et al., 2003).

Nitrate and ammonia assimilation decrease during water limitation stress. The flow of nitrogen from roots to leaves becomes slower and higher concentrations of nitrate and ammonia build up in water stressed roots than in the roots of well watered plants (Nilsen and Muller, 1981a&b). Water limitation is associated with an increase in protein hydrolysis and a decrease in protein synthesis. In addition, a decrease in polyribosomes abundance is correlated with the decreased protein synthesis. Coincident with the decrease in total protein there is an increase in free amino acids. Much of the amino acid accumulation is due to the reduction in protein synthesis, but in some cases biosynthesis of particular non-protein amino acids is stimulated, e.g., betain, proline. (Kavi Kishor et al., 2005).

Osmotic potential is based on the concentration of solutes in water. Plant's intracellular water contain large quantities of solutes, creating an osmotic potential at the turgor loss point as low as –5.0 MPa (twice that of sea water) in some cases (Meinzer et al., 1986). There are four main classes of osmotically active solutes that can significantly affect tissue osmotic potential, ions, carbohydrates, non-protein amino acids and organic acids. Two of the four classes, non protein amino acids and carbohydrates, are compatible with protoplasm. The other two can reach high concentrations only in the vacuoles. The energy requirement (respiratory cost) of adjusting osmotic concentration with various constituents is different. The use of nonprotein amino acids such as betaine (*N,N,N-trimethyl glycine*) and proline for adjusting osmotic potential is relatively expensive compared to other osmotic moieties.

Accumulation of proline upon dehydration due to water deficit or increasing osmotic pressure has been recorded in bacteria (Measures, 1975), algae (Brown and Hellebust, 1978), crustaceans (Vincent-Marique and Gilles, 1970; Fyhn, 1976) and higher plants (e.g., Palfi et al., 1973). Indeed it has been suggested (Measures, 1975) that proline accumulation is a primitive response of living organisms to increasing osmotic pressure in the environment, which, until the evolution of homeo-osmotic mechanism in higher animals, was widespread throughout the biological world. Many other investigations have reported an accumulation of proline as a result of water stress (Stewart et al., 1966). Only proline was reported as accumulated by water stressed barley (Savitskaya, 1967). In wheat (Vlasyuk et al., 1968) Proline was accompanied by asparagines (Slukhai and Opanasenko, 1974). The content of free proline in plants with an appropriate supply of water is usually very low (0.2–0.69 mg/g dry matter). It rapidly rises to 40–50 mg/g dry matter during slow dehydration of tissues (Palfi et al., 1973). In water stressed sunflower, several amino acids increased initially, and proline accumulated only in severe stress (Lawlor and Fock, 1974). An osmotic stress (0.7 M manitol) led to an accumulation of large amounts of proline in isolated tobacco protoplast (Premecz et al., 1978). Some studies have indicated that an increase in ribonuclease occurs during water limitation. There is little evidence that mRNA translation is affected (Shah and Loomis, 1965); thus the cytosolic mRNA pool most probably decreases due to an increase in cytosolic ribonuclease activity (Todd, 1972).

When drought was induced in chickpea cultivars accumulation of proline was evaluated along with separation of stress responsive proteins by PAGE. A PCR based RAPD technique was also employed to detect polymorphism in genomic DNA with eight random primers. A higher magnitude of proline accumulation was observed in the leaves of stressed plants of tolerant cultivars. In addition, with tolerant cultivars an additional protein band of $\sim$17.78 kD size was observed under water stress conditions along with other protein bands of $\sim$16.21, 36.30, 46.77 and 85.11 kD (Ahire et al., 2005).

Now coming to grain legumes, it has been documented that soil texture influences the adaptation of pigeonpea principally through effects on aeration, water holding capacity and soil strength. Aeration can become limiting in wet soils, and waterlogging is more likely to be a problem in clay than in sandy soils. However, high clay soil is widely used for pigeonpea production because of the need for adequate water storage for dry land crops. Pigeonpea is intermediate among crop legumes in its susceptibility to mechanical impedance caused by high soil strength. Compaction of both Vertisol and Oxisol by agricultural traffic restricted root growth and as a consequence shoot growth and seed yield when soil conditions are dry. However, when irrigation was applied soil strength in the compaction layer was reduced sufficiently to enable root growth (Table 4.3).

The main effect of water stress can be viewed as follows:

1. A decreased cumulative radiation interception (Hughes and Keatinge, 1983; Lawn, 1982a&b; Muchow, 1985d).
2. A reduction in the efficiency of utilization of intercepted radiation through reduction in carbon exchange rate (Cortes and Sinclair, 1986) associated with reduced stomatal conductance.
3. A reduction in partitioning efficiency (Korte et al., 1983b).

The relative effect of water deficit on each of the above depends in large part on timing in relation to ontogenic development of crop duration and intensity.

Table 4.3 Effects of soil compaction on soil bulk density (g/cm^3) and shoot dry matter (g/m^2) at 40 days after sowing of pigeonpea on two clay soils

		Shoot dry matter			Shoot dry matter		
Compaction treatment	Bulk density (g/m^3)	1984 (dry)	1988 (wet)	Bulk density (g/m^3)	1987 (wet)	1988 (wet)	1987 (rain excl.)
Deep ripped	1.01	90	142	1.01	275	286	110
Moderate compaction	1.17	73	169	1.37	295	313	116
Severe compaction	1.28	44	147	1.45	304	268	69
C.D. at 5%	0.04	14	NS	0.06	NS	NS	NS

Pigeonpea has a deep and extensive root system and can endure periods of water deficit through relatively higher levels of tolerance to desiccation and osmotic adjustment. Compared to other crops (Flower and Ludlow 1987), stomatal conductance in pigeonpea is relatively insensitive to saturation deficit, i.e., stomata of well-watered plants remained open when evaporative demand is high (Muchow, 1985c; De Veries, 1986). As a water deficit develops, both leaf water potential and stomatal conductance decline gradually, permitting continued photosynthesis. Reports are there for lower and higher abilities of pigeonpea to reduce the radiation load through leaf shedding or through leaf orientation (Muchow 1985a, b; De Veries 1986). Presence of drought tolerance and polycarpic flowering habit enable pigeonpea to survive long water deficit periods, but it will yield poorly or not at all if drought stress during the reproductive growth period is severe and persistent (Sinha 1981; Troedson, 1987). The main effects of water deficit on pigeonpea productivity can be summarized in terms of consequences for the efficiencies of interception (E_i) and conversion (E_c) of PAR to biomass and partitioning of biomass to seed (Lawn and Williams, 1986). Water deficit can influence E_i through the following ways:

1. Relative reduction in leaf area index due to a slower rate of leaf initiation and/or faster rate of leaf senescence.
2. Decrease in *k* due to paraheliotropic leaf movement and leaf rolling.

The relative effects of water deficit on pigeonpea crop depend mainly on timing relative to crop ontogeny, duration and intensity. Where water deficit develops gradually after sowing; the reduction in E_i may be greater than E_c (Muchow 1985b). Where water deficit develops rapidly, the effects on E_c may be comparable with or exceed those on E_i. In addition to water deficit effects constraining the carbon economy of the crop, symbiotic nitrogen fixation is sensitive to water deficit (De Veries, 1986) and nitrogen accumulation can be reduced under drought conditions (Chapman and Muchow, 1985). Two related mechanisms contributing to strong tolerance of tissue water deficit are high levels of osmotic adjustment and a low critical or lethal relative water content (RWC) of leaves (Flower and Ludlow, 1986;

Sinclair and Ludlow, 1986). Lopez et al. (1996) reported that genotypic differences in drought resistance were probably due to differences in leaf area maintenance during and in the recovery of dry weight and pod production following water stress periods.

A study was conducted to evaluate the contribution of osmotic adjustment to growth and productivity of extra short duration pigeonpea during soil moisture deficits. Osmotic adjustment in leaves increased with the depletion of soil moisture and reached close to 0.5 MPa at physiological maturity. Genotypic variation in osmotic adjustment (ranging from 0.1 to 0.5 MPa) was significant. Genotypic variation in leaf relative water content was correlated with OA (r^2=0.66*, n=6). Leaf osmotic adjustment was correlated with the amount of stem sucrose mobilized (r^2=0.67*; n=6). The relationship between osmotic adjustment and leaf area duration was significant (r^2=0.94**; n=5). Genotypic variation in leaf relative water content was correlated with crop growth rate (r^2=0.74*; n=6) and radiation-use efficiency (r^2=0.84**; n=6) under moisture deficits. Below 30 cm depth, 60–80% of the plant extractable soil water was not utilized at physiological maturity in the drought treatment. It was concluded that osmotic adjustment could influence radiation-use efficiency and crop growth rate of extra short duration pigeonpea indirectly by increasing leaf relative water content during soil moisture deficits (Subbarao et al., 2000b). In another study conducted by Subbarao et al. (2000a) using two automated rain shelters, 26 extra short duration pigeonpea genotypes were grown with irrigation throughout the growth period or with water stress from flowering until maturity. Mean leaf osmotic potential at full turgor (PSIs100) 60–92 days after sowing under water stress correlated significantly with the mean osmotic adjustment and contributed 72% of the genotypic variation in osmotic adjustment. Significant genotypic variation was observed in the initiation, duration and degree of osmotic adjustment. Genotypic differences in total dry matter production under water stress were positively associated with osmotic adjustment at 72 days after sowing. There was a significant positive relationship between osmotic adjustment at 72 days after sowing and seed yield under water stress. However, osmotic adjustment towards the end of the pod filling phase, i.e., at 92 days after sowing, had a significant negative relationship with seed yield under water stress. Genotypic differences in seed yield under water stress were best explained using stepwise multiple regressions to account for differences in osmotic adjustment at 72, 82 and 92 days after sowing. The degree of osmotic adjustment at 72 and 82 days after sowing contributed positively to the seed yield, whereas osmotic adjustment at 92 days after sowing contributed negatively to this relationship.

As previously indicated nitrogen fixation is extremely sensitive to water deficit (Pankhurst and Sprent, 1975; Weisz et al., 1985). In large part, it is due to the effects on oxygen permeability and indirectly through carbon supply for nodule development and activity. The consequences are a substantial reduction in nitrogen accumulation under water stress conditions (Chapman and Muchow, 1985).

Osmotic adjustment has been shown to maintain stomatal conductance and photosynthesis at low water potential (Ludlow, 1980, 1987), delay leaf senescence and death (Flower and Ludlow, 1986, 1987), reduce flower abortion (Morgan and

Table 4.4 Variation in osmotic adjustment observed in few grain legume species

Species	Organ	Range in osmotic adjustment	References
Pigeonpea	Leaf	0.3–1.0	Muchow (1985c) and Lopez et al. (1987)
Greengram (Vigna radiata)	Leaf	0.2–0.4	Muchow (1985c) and Zhao et al. (1985)
Vigna ungliculata	Leaf	0.1–0.5	Muchow (1985c) and Sinclair and Ludlow (1986)
Cowpea	Leaf	0.0–0.4	Muchow (1985c); Sinclair and Ludlow (1986) and Lopez et al. (1987)
Chickpea	Leaf	0.6	Morgan et al. (1991)
Pea	Leaf	0.4	Turner et al. (1996) and Leport et al. (2003)
	Root	0.3–0.8	Greacen and Oh (1972)
Lentil	Leaf	0.6	Turner et al. (1996) and Leport et al. (2003)
Lathyrus sativus	Leaf	0.1	Turner et al. (1996) and Leport et al. (2003)

Adopted from Subbarao et al. (1995).

King, 1984) and improve root growth and water extraction (Morgan and Condon, 1986). The capacity for osmotic adjustment varies among grain legume species. Relative to cereals, the degree of osmotic adjustment in grain legumes is modest except in pigeonpea, lentil and chickpea (Table 4.4, Turner et al., 2003). The degree of osmotic adjustment has been shown to be correlated to seed yield in chickpea (Morgan et al., 1991). Osmotic adjustment has not been found to delay the decrease in photosynthesis in grain legumes (Leport et al., 1998), but has been observed to delay leaf senescence and increase remobilization of reserves in some grain legumes (Flower and Ludlow, 1986, 1987; Leport et al., 2003). Variation in osmotic adjustment among chickpea cultivars has been observed when exposed to terminal drought. Some studies suggest that this benefits yield while others suggest it does not benefit yield in water limited environments (Turner et al., 2007; Souri et al., 2006).

Food legumes are generally more sensitive to water stress during their reproductive phase of growth when pod numbers are being determined (Korte et al., 1983a). Beyond that time the possibilities for compensation are much reduced being limited to seeds per pod and/or seed size (Korte et al., 1983b). In cowpea, mungbean and urdbean, less determinate genotypes produce new flushes of flowers and pods when water stress applied during the reproductive phase is released (Lawn, 1982a).

The water use efficiency for grain production in chickpea of 16 kg/ha/mm is approaching that of wheat (20 kg/ha/mm), a well adopted crop in South Australia. Water use efficiencies of chickpea in Australia may be improved by selecting genotypes with more rapid biomass accumulation, especially in Mediterranean-type environments where low winter temperature limits growth (Loss et al., 1998). In these environments, 60% of the water used by chickpea crop can be lost through soil evaporation (Siddique and Sedgley, 1987) and rapid canopy cover of the soil surface may reduce this. There is considerable genetic variation for early growth and biomass at maturity in chickpea. Nine inbred lines of faba beans were tested under adequate water supply and limited water conditions. The genotypes showed substantial variation in shoot dry matter, water use efficiency, stomatal conductance, leaf temperature, transpiration efficiency, carbon isotope discrimination, relative water content and osmotic potential, determined at pre-flowering vegetative stage. It was stated that moisture deficits decreased water usage and consequently shoot dry matter production (Habib ur Rahman et al., 2007).

Selecting for increased osmo-regulation (Morgan et al., 1991) and greater re-translocation of biomass from stem and leaves to seeds under a terminal drought scenario (Leport et al., 1998) are also strategies to enhance the adaptation of chickpea to water limited environment. Patel et al. (2000) subjected determinate and indeterminate types of pigeonpea genotypes to three seeding dates. Genotypes sown on the earliest date attained the highest leaf area index, absorbed the largest amount of photosynthetically active radiation and produced the highest total dry matter. The differences in biomass and seed yield among sowing dates were largely ascribed to totals of photosynthetically active radiation absorbed and dry matter produced, especially during the reproductive phase. The high leaf area index persistence and photosynthetically active radiation interception, coinciding with the podding phase, appeared to be mainly responsible for the increased yield in early sowings. Radiation use efficiency decreased as sowing was delayed, but neither had much effect on dry matter accumulation in various phases nor on final yield. Although the extinction coefficient was not influenced by sowing dates, it was inversely related to leaf area index in both cultivars. Between the cultivars, the differences in biomass reflected the differences in photosynthetically active radiation absorbed and dry matter accumulation, depending upon leaf area development and growth duration. The determinate genotypes had higher seed yields and harvest indices than indeterminate genotypes due to more of the dry matter produced being partitioned into pods during the reproductive phase on account of their determinate growth habit. Early sowings of determinate cultivars could maximize both vegetative and reproductive growth, capture more light and produce more seed yields under rain fed conditions.

Singh and Singh (2000) reported from a field trial with determinate and indeterminate types. They showed the total number of flowers shed/plant was greater in indeterminate than determinate types. Maximum production and shedding of flowers were observed on the 7th and 4th branch in indeterminate and determinate types, respectively. The intensity of flower shedding was greatest within 24 h of anthesis and decreased subsequently with flower age. Flower shedding was greater during the night in both cultivars. In terms of periodicity the two cultivars behaved similarly for flower production and shedding. The production and shedding of flowers was correlated with environmental factors.

Increased induction of "determinateness" or degree of synchrony of flowering and pod setting may increase the vulnerability of food legumes to intermittent deficits during reproductive growth. In soybean it has been shown that the relative effects of water deficit during reproductive growth are greater in determinates than indeterminate genotypes (Villalobos-Rodriguez and Shibles, 1985). However, synchronous podding may be of benefit in case of terminal water stress.

Excessive water can limit yields of food legumes in several ways. The most common is reduction in nitrogen fixation, chlorosis and reduction in crop growth. There is variation amongst food legume species in tolerance to temporary water logging e.g., mungbean, pigeonpea, grass pea and moth bean are particularly sensitive to water logging conditions while other food legume species are more tolerant of water logging conditions. Pigeonpea is susceptible to water logging with the effect that many areas of high rainfall and/or impermeable soil are not suitable for pigeonpea production. One apparent cause of physiological damage is ethylene produced by soil micro flora. Short term or intermittent water logging affects biological nitrogen fixation and can lead to severe nitrogen deficiency (Thompson et al., 1981). Genotypic differences in physiological tolerance of water logging have been reported (Chauhan, 1987).

The intensively managed pigeonpea systems that involve short-duration pigeonpea have a higher water requirement because they are grown at high density (Meherotra et al., 1977; Singh et al., 1983). Meherotra et al. (1977) estimated water use by T 21 to be in the range of 55–60 cm. Bhan and Khan (1979) recorded significant responses to one or two supplementary irrigations on a sandy loam soil, and they reported that a single irrigation applied at pod-filling stage gave a better result than application on the basis of cumulative pan evaporation demand of 80 or 120 mm (Table 4.5). Under arid conditions, water applied at early vegetative stage reduced yield by 14%, whereas when applied at branching stage it increased yield by 34% (Makhan and Gupta, 1984). Saxena and Yadav (1976) on the other hand reported no response to applied irrigation. Chauhan et al. (1987) did not observe any significant response to applied irrigation on an Alfisol in a normal (about 700 mm) rainfall year. These studies indicate that injudicious use of water may not help the pigeonpea crop sown in the rainy season; rather it may harm the crop. Responses to irrigation are generally more consistent in pigeonpea sown in the post rainy season as the crop then has to rely on stored moisture in the soil profile. At the International Crop Research Institute for Semi Arid Tropic (ICRISAT)

Table 4.5 Effect of irrigation on yield (t/ha) of pigeonpea during rainy season

Stages of irrigation	Yield (t/ha)
Control	1.28
Flower initiation	1.30
Peak flowering	1.22
Pod filling	2.14
Flower initiation and pod filling	2.43
Irrigation after 80 mm CPE	2.27
Irrigation after 120 CPE	2.36
CD at 5%	0.49

Source: Bhan and Khan (1979).

Centre, application of 2–3 irrigations about 1 month after sowing increased seed yield by about 150–160% over a non irrigated control (Rao et al., 1983). In a similar environment on clayey soil where the soil moisture holding capacity was high, the increase in yield due to irrigation was relatively small, 14–19%, (Reddy et al., 1984). Bhowmik et al. (1983) on an alluvial soil recorded a significant increase in seed yield of pigeonpea with two irrigations but found that three irrigations had a negative effect.

Another constraint imposed by excessive water in some species, e.g., mungbean and cowpea is the damage caused to ripening pods by exposure to humid and wet conditions. Finally, exposure to humid and wet condition can favor rank growth and pre disposition of plants or pods to a host of foliar and pod diseases.

Constraints imposed by water deficit can be overcome by agronomic practices and/or by genetic manipulation for better water use efficiency (WUE). Normally biomass production is a linear function of water use (Lawn, 1982b). However, food legumes with C_3 metabolism have lower WUE are inferior producers under conditions of high temperature and radiation and low moisture (Huber and Shankhla, 1976). Despite evidence of genotypic variations within C_3 plants for photosynthetic efficiency, the potential for genetic improvement of production by raising photosynthetic capacity appears to be small (Lawn and Williams, 1986). Producers and scientists have attempted to escalate genetic exploitation of environments, e.g., by exploitation of chance introductions, planned introduction of new cultivars and species, limited local breeding for specific aspect(s) of adaptation culminating in National Breeding Programmes. Significant National and/or International collections exist for many major food legumes and the diversity they contain is exploited by National Programme Scientists. Progress in tissue and haploid culture in somatic hybridization in other organisms suggests that genetic engineering may have future applications in plant breeding. However, there has been only limited progress in food legumes (Mehta and Ram, 1980; Sinha et al., 1983; Kumar et al., 1984). In view of the complexities in environmental adaptation in crops, these approaches have limited relevance to adaptive traits. Munoz Perea et al. (2007) advocated that in dry bean landraces and cultivars with high WUE should be used to reduce dependence on irrigation water and to develop drought-resistant cultivars to maximize yield and WUE.

4.4 High Temperature Stress

Plants are poikilotherms (except for a few rare exception), thus temperature in their tissues are reflective of their thermal environments. Due to the wide variation in ambient temperature among environments where plants reside and the poikilothermic nature of plants, it is logical to expect a wide range of metabolic, morphological and anatomical adaptations to thermal conditions. Some tissues will have a temperature that is very close to air temperature at all times ($\Delta T = 0$).

Heat stress often is defined as where temperatures are hot enough for sufficient time that they cause *irreversible* damage to plant function or development. In addition, high temperatures can increase the rate of reproductive development, which shortens the time for photosynthesis to contribute to fruit or seed production. The extent to which heat stress occurs in specific climatic zones is a complex issue. Plants can be damaged in different ways by either high day or high night temperatures and by either high air or high soil temperatures. Also, crop species and cultivars differ in their sensitivity to high temperatures. Cool-season annual species are more sensitive to hot weather than warm-season annuals (Hall, 2001). Heat stress due to increased temperature is an agricultural problem in many areas in the world. Transitory or constantly high temperatures cause an array of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield. The adverse effects of heat stress can be mitigated by developing crop plants with improved thermo tolerance using various genetic approaches. Heat stress affects plant growth throughout its ontogeny, though heat-threshold level varies considerably at different developmental stages. For instance, during seed germination, high temperature may slow down or totally inhibit germination, depending on plant species and the intensity of the stress. At later stages, high temperature may adversely affect photosynthesis, respiration, water relations and membrane stability, and also modulate levels of hormones and primary and secondary metabolites. Furthermore, throughout plant ontogeny, enhanced expression of a variety of heat shock proteins, other stress-related proteins, and production of reactive oxygen species (ROS) constitute major plant responses to heat stress. In order to cope with heat stress, plants implement various mechanisms, including maintenance of membrane stability, scavenging of ROS, production of antioxidants, accumulation and adjustment of compatible solutes, induction of mitogen-activated protein kinase (MAPK) and calcium-dependent protein kinase (CDPK) cascades, and, most importantly, chaperone signaling and transcriptional activation. All these mechanisms, which are regulated at the molecular level, enable plants to thrive under heat stress (Wahid et al., 2007).

One of the most important aspects of tissue energy balance is energy absorbed from radiation impinging on the tissue surface. Radiation comes to the leaf surface from the series of different sources. Direct and diffused solar radiation sum to produce total radiation impinging on a leaf from the sky. Diffused radiation from the sky is that which is scattered by particles or clouds in the atmosphere. Reflected radiation (a portion of diffused radiation) is solar radiation that hits surfaces (soil, trunks, branches, leaves etc.) near leaves and is reflected towards leaves. Reflected radiation will increase radiation absorbed by leaves and can account for 10–30% of the total radiation impinging on a leaf surface. The fraction of shortwave radiation (not infra red radiation) reflected from surfaces is termed as the albedo. The albedo of ground surfaces can vary from about 0.60 for snow to 0.10 for peat soils (Rosenberg et al., 1983). The higher the albedo, the higher the significance of reflected radiation to energy absorbed by leaves. Reflectance of the surroundings is further modified by the angle of incidence between the radiation source and the reflective surface.

The smaller the angle of incidence, the greater the reflectance. The total amount of absorbed radiation can be calculated as:

$$\text{absorbed radiation} = a(\Phi^{\text{direct}} + \Phi^{\text{diffuse}}) + ar(\Phi^{\text{direct}} + \Phi^{\text{diffuse}}) \text{ or } = a(1 + r)^{\Phi}$$

where a is the absorption, which is the fraction of total radiant energy flux (Φ) absorbed by the leaf, Φ^{direct} the direct solar radiant energy flux, Φ^{diffuse} the total diffuse radiant energy flux, r the fraction of Φ reflected from the surroundings onto the leaf surface, and Φ the total of diffuse and direct radiance flux.

The characteristic of plant leaves that has the greater impact on absorption of solar and reflected radiance is leaf absorption (a) leaf absorption varies with the wavelength of light impinging on the surface. For example, in the visible wave bands (400–700 nm) the value of a is often between 0.8 and 0.9. Absorption of near–infrared radiation (800–1,500 nm) is relatively low (0.1), but absorption of longer–wave radiation (1,500–3,000 nm) is also approximately 0.9. In as much as leaf absorption has a dramatic effect on radiation absorption, energy balance, and photosynthesis, the ability of plants to adjust their absorption by morphological or behavioral mechanism will have a great effect on tissue temperature and metabolism.

The greatest danger of heat injury occurs when the soil is exposed to insolation, reaching temperature as high as 55–75°C (Lundegårdh, 1949). It has been reported that if the leaf temperature is 5°C above the atmospheric temperature, this is equivalent to a steepening of the gradient by a 30% lowering of the atmospheric R.H. (relative humidity). In other words, if the external atmospheric R.H. is 70%, the 5°C rise in leaf temperature would double the gradient and, therefore, the evaporation rate, aside from the increase due to the increased molecular velocity at the higher temperature. A 10°C rise would have a proportionally even greater effect than the expected doubling of the temperature gradient. In addition to this direct effect of temperature on evaporation, it may further increase transpiration by maintaining the stomata open due to increased root temperature (Gur et al., 1972). The danger of drought injury under such conditions is obviously great, even without a deficiency in soil moisture. It is not surprising, therefore, that prolonged high temperature stress often result in injury due to desiccation, for instance, in the case of turf grass (Krans and Johnson, 1974).

In the case of 25 species of plants, the temperature maximum for assimilation (36–48°C) was from 3 to 12° below the heat-killing temperature (44–55°C; Pisek et al., 1968). Similarly, when measured by the beginning of rapid loss of ions, heat killing may require 11°C higher temperature than that at which photosynthesis is destroyed (Berry et al., 1975). Starvation, however, occurs before this high temperature limit (the T_{max}) for photosynthesis is reached. This is because of the higher temperature optimum for respiration than for photosynthesis (50 and 30°C, respectively) in potato leaves (Lundegårdh, 1949). The temperature at which respiration and photosynthesis are equally rapid is called the *temperature compensation point*. Obviously, if the plant's temperature rises above the compensation point, the plant's reserves will begin to be depleted. The deficit increases particularly rapidly in plants with an active photorespiration (C_3 plants) in addition to the normal dark respiration. The pronounced increase in rate of photorespiration at high temperature is apparently due to a higher Q_{10} for glycolate oxidase activity relative to that of catalase. As a result, there is an increased availability of H_2O_2 and a marked increase in glycolate oxidation to CO_2 by the peroxisomes of the leaves (3 times as rapid at 35°C as at 25°C; Grodzinski and Butt, 1977).

Starvation injury is not necessarily due to a net decrease in assimilation, but may be due to effects on translocation. When Japonica rice was grown at 35°C day/30°C night, the rate of ripening was more rapid than at normal growing temperature, but the inflow of assimilate into the grain ended earlier. This resulted in lower 1,000-kernel weight, although there was no deficiency in the assimilate content of the plant (Sato and Inaba, 1976). Similarly, in the case of *Agrostis palustris* grown at 40°C day/30°C night the carbohydrate content of the leaves was higher than that of plants grown at lower temperature. The growth reduction was, therefore, not due to carbohydrate starvation of the leaves (Duff and Beard, 1974). The inhibitory effect of high temperature on photosynthesis is completely reversible if not too extreme – for instance a 2-min shock at 46–51°C reduced $^{14}CO_2$ fixation in detached leaves of *Nicotiana rustica* (Ben Zioni and Itali, 1972). This decrease continued for 2½ h but recovery was complete 45 h after treatment. Similarly, 5 min at 40°C was strongly inhibitory but 24 h later the rate was restored almost to the control (Yodanov et al., 1975). Even when photosynthesis was completely inhibited by a short term heating (10–15 min), all the plants were able to renew photosynthesis after 17 h in the dark at room temperature (Egorova, 1975, 1976).

Temperature affects the rate of the metabolism involved in growth and development. In general, developmental processes (such as germination, ontogenic changes, leaf initiation and meiotic division) are more thermally sensitive than growth or photosynthesis per se and have more sharply defined optima although there are substantial differences in sensitivity amongst processes. A linear function of daily mean temperature can be used to approximate temperature responses in the field (Angus et al., 1981) (Table 4.6). This implies in effect that temperature is accumulated above a base temperature at which the process rate approaches zero and this accumulation can be expressed as degree days needed to complete the process which is a constant. The thermal constant has been termed the “thermal time” for the process (Monteith, 1977). However, not all temperature accumulations produce the same result. When lupin (*Lupinus luteus*) was grown under different day/night temperature regimes, it was found that temperature conditions, constant high temperature, or physiologically optimal thermal oscillations (24/19°C) or high-low temperature regimes, differently affected the contents of six soluble carbohydrates in maturing seeds of yellow lupin (Piotrowicz Cieslak, 2006)

In photoperiod-sensitive genotypes, the effect of temperature on different growth phases in food legumes is somewhat more complex. One of the main effects of temperature is to modulate the critical photoperiod of a genotype (Hadley et al., 1983), as photoperiod may influence base temperature in relation to pre flowering development (Roberts and Summerfield, 1987). The optimal temperature for rates for development prior to floral initiation in a range of pigeonpea genotypes is

Table 4.6 Relative sensitivity of pigeonpea to temperature during emergence. Estimated time (days) to emergence at mean temperature of 18 and 25°C for pigeonpea and other tropical grain legumes, based on experimental estimates of base temperatures (T_b), and thermal time to emergence (days degree > T_b)

Crop species	Days to emergence		Base temperature (T_b) (°C)	Thermal time (degree days >T_b)
	18°C	25°C		
Pigeonpea (Cajanus cajan)	11.2	4.8	12.8	58.2
Cowpea (Vigan unguiculata)	6.1	3.1	11.0	43.0
Green/black gram (Vigna radiata/mungo)	6.9	3.5	10.8	49.6
Bean (Phaseolus vulgaris)	7.0	3.6	10.6	52.1
Soybean (Glycine max)	8.7	3.6	9.9	70.5
Groundnut (Arachis hypogea)	16.2	6.5	13.3	46.3

Source: Angus et al. (1981).

around 20–24°C, but rates of leaf emergence are fastest in the range of 28–32°C (McPherson et al., 1985). Symbiotic nitrogen fixation (Layzell et al., 1983) and meiotic cell division are very sensitive to temperature extremes. Pollen formation is particularly sensitive both to high (Warrag and Hall, 1983) and low (Lawn and Hume, 1985) temperature stresses.

Daily mean temperature requirement for pigeonpea emergence was estimated to be 12.8°C and 50% emergence was best at 58.2° days, and the same can be accumulated in 26 days at 15°C, 8 days at 20°C or in 5 days at 25°C (Angus et al., 1981). It was reported that at least 85% germination occurred at a range of temperatures between 19 and 43°C but no germination occurred at either 7.1 or 46.5°C (de Jabran et al., 1986). Controlled environment studies have demonstrated that the growth related attributes, e.g., plant height, nodes/plant, shoot dry matter accumulation and leaf area have a linear relationship with increase in temperature within the range 16–32°C (McPherson et al., 1985; Turnbull, 1986). It has been reported that in northern India, where daily temperature is consistently between 35 and 45°C for 2 months, the high temperature does not present a serious limitation to vegetative growth of pigeonpea if water supply is adequate (Troedson et al., 1990). However, there is a report that high constant day temperature (> 35°C) increases floral abortion and decreased pod set (Turnbull, 1986). Pigeonpea crops are more likely to be limited by water than by irradiance, with the exception of extended cloudy period during the monsoon season (Versteeg and van Keulen, 1986) and intercrops that are shaded by their companion crop (Natarajan and Willey, 1980a). In addition, interception of radiation is limited by slow leaf area development, observed at seedling and in intercrops after harvest of the companion crop (Sheldrake and Narayanan, 1979). Pigeonpea is most sensitive to low irradiance during pod formation, when pod retention is strongly related to current assimilation (Thirathon et al., 1987a).

Three extra-early and three early maturing genotypes of pigeonpea were grown during April and November in Kenya at altitudes between 50 and 2,000 m and latitudes ranging from 0° to 4°S. They were grown under normal field conditions, as well as under clear polyethylene enclosures at six sites to produce warmer than ambient temperatures (Omanga et al., 1995). Mean pre-flowering temperature varied from 15.6 to 34.0°C, and photoperiod varied from 12.6 to 15.0 h. The shortest time between sowing and flowering (f) occurred at 26.5° (53–54 days), while time to flowering was longest at 17.6 or 16.1°, depending on genotype (104–118 days). Time to flowering was generally unaffected by photoperiod.

Ellis et al. (1998) studied photoperiod and temperature requirement during pre flowering in photoperiod-sensitive, late-maturing pigeonpea in Kenya. The plants were subjected to different durations after emergence from natural short days (12.6 h/day) to artificially-extended long days (15.0 h/day), and *vice versa*, under both ambient (19°C) and warmer (26°C) temperatures. All plants at 19°C flowered within 106–160 days after emergence whereas only those transferred from long days to short days flowered at 26°C. A well-defined photoperiod-insensitive pre-inductive phase (A_1) was detected after emergence; it lasted for 26 days at 19°C but increased to 49 days at 26°C. Thereafter, short days hastened and long days delayed progress to flowering until a third phase, the photoperiod-insensitive post-inductive phase (A_3) of pre-flowering development. At 19°C, A_3 was 66 days while the duration of the inductive phase in short days (IS) was 25 days and in long days (IL) it was 72 days. Plants were also moved from ambient to warmer temperatures and *vice versa* within either short days or long days at different durations after emergence. In short days all plants flowered during the investigation (250 days) whereas in long days only the plants transferred from the warmer to the ambient temperature regime flowered. During the initial stages of development plants were less sensitive to supra-optimal temperatures so that developmental progress from emergence to first flowering was the same whether plants were held at warmer or ambient temperatures during the first 35 days from emergence. Furthermore, plants transferred from the ambient to the warmer temperature in short days at any time from 49 to 77 days from emergence flowered at similar times to those kept at ambient temperature from emergence. Since $A_1 = 26$ days and $A_1 + \text{IS} = 51$ days, it is suggested that these results imply that exposure to supra-optimal temperature in short days during the latter 60% of the photoperiod-sensitive inductive phase (IS) of pre-flowering development delayed progress to flowering. In contrast, exposing plants to supra-optimal temperature during either the photoperiod-insensitive pre-inductive phase (A_1) or part of the photoperiod-insensitive post-inductive phase (A_3) or during the first 40% of the photoperiod-sensitive inductive phase did not delay progress to flowering.

Temperature can influence economic yield through each of the components, with variations in relative magnitude of effects on them. In most of the situations, the main effect is likely to be on cumulative radiation incident and proportion intercepted, through crop duration (i.e., phenological potential) and rate of leaf area development. There is relatively little information available for the food legumes about the effect of temperature on HI, although there is evidence in soybean (Seddigh and Jolliff, 1984) and *Vigna* spp. (Lawn, 1979a&b) that cool night temperatures can depress HI. Clearly extremes of temperature which reduce the reproductive sink through gametogenesis can substantially reduce HI.

To date, most of the efforts have been made in improving adaptation to cooler temperature, with some success (Voldeng et al., 1982; Holmberg, 1973). However, opportunities for genetic improvement in relation to temperature responses remain largely unexploited. In most cases, little is known about the complexity of genetic control of differential responses. Genetic advances may be further hindered by the lack of correlation between sensitivities at different stages (Hume and Jackson, 1981) and between different processes (McPherson et al., 1985).

4.5 Low Temperature (Chilling) Stress

Chilling stress is usually limited to plants native to or growing in tropical or subtropical regions of the world. The temperature range for chilling stress ranges from just above freezing to 15–20°C. Plants vary greatly in their sensitivity to chilling stress. Chilling-sensitive plants have been defined as plants that are killed or injured by temperatures above the freezing point of the tissues up to 15–20°C (Graham and Patterson, 1982). Chilling resistant plants are those able to grow at temperatures near 0°C. However, considerable variability exists amongst plants relative not only to genetic factors but to stages of development, metabolic status (dormancy or active growth), and conditions under which plants are growing before, during and after the chilling episode. Generally, plants are more sensitive under non-dormant conditions (high metabolic activity) during younger stages of development, during the day or under high-light intensities, under drought stress (although drought hardening can increase chilling tolerance) and when nutrients are limiting (particularly K, which is involved with osmotic adjustment).

Chilling stress can affect proteins both qualitatively and quantitatively. Generally, soluble proteins increase and proteins that have enzymatic functions can either be up or down regulated, depending on specific function. Following are the enzymes activity and processes that are affected by chilling stress (Table 4.7).

Generally enzymes are more liable to be affected by high temperature stress than they are to low temperature stress. However, complex enzymes possessing subunits such as P_i dikinase and phospho-fructokinase involved in the carbon fixation reactions in C_4 plants and glycolysis, respectively, are inactivated by chilling temperatures as a result of converting their tetramers from dimers. Another enzyme critical for osmotic relations in plant, K^+-mediated ATPase is affected by chilling stress. Associated with reduced activity of this protein is leakage of K^+ from cells exposed to chilling stress. It appears that this process is reversible if the stress is not prolonged or too severe (Palta and Weiss, 1993).

Structural changes in organelles have been observed with chilling stress, and it appears that differences in organelles exist relative to chilling sensitivity. Ilker et al. (1979) observed the degree of injury exhibited by tomato cotyledon organelles after different chilling periods at 5°C. It would appear from this study that the order of sensitivity is plastids > mitochondria > peroxisomes > nuclear membrane > tonoplast > plasmalemma (Table 4.8).

The effects of cold and drought stress on antioxidant responses and growth parameters in shoots and roots of lentil seedlings were investigated on 10 day old hydroponically grown seedlings subjected to drought and cold (4°C) stress for

Table 4.7 Enzymes or processes up or down-regulated in plants as a result of chilling stress

Enzymes or processes up-regulated	Enzymes or processes down-regulated
a. Phenolic synthesis	a. Carbon fixation reactions
(1) PAL (phenylalanine ammonium synthase)	(1) NADP-malate dehydrogenase (C_4 reactions, high light)
(2) CQT (hydroxycinnamoyl CoA quinate Hydroxycinnamoyl transferase)	(2) Pyruvate P_i dikinase (C_4 reactions, high light)
b. Respiratory enzymes	(3) PEP carboxylase (C_4 reactions)
(1) Glycolysis	(4) Rubisco (dark reaction)
(2) TCA cycle	(5) Fructose-1,6-bisphosphatase (dark reaction)
(3) PPP (pentose phosphate pathway)	b. Light reaction
c. Cryoprotectants	(1) NADP reductase
(1) Invertase (starch and glucose)	(2) Plastocyanin
(2) Proline	(3) CF1
(3) Putrescine	(4) Ca^{2+} ATPase
(4) Betaine	c. Respiration
d. Antioxidants	(1) NADP-malate dehydrogenase (TCA Cycle)
(1) Glutathione	(2) 3-PGAL-dehydrogenase (glycolysis)
(2) Ascorbate	(3) Phosphofructokinase (glycolysis)
e. Membrane Lipids	(4) 6-Phosphogluconate dehydrogenase (PPP)
(1) Desaturases	d. Nitrogen metabolism
(2) Acetyl-CoA carboxylase	(1) Glutamate dehydrogenase (NH_4 to α-kitoglutarate)
f. Nonenzymtic proteins	(2) Aspartic β-semialdehyde dehydrogenase (lysine and alanine)
(1) Ice nucleators	e. Starch metabolism
(2) Cryoprotective proteins	(1) Fructose-1,6-bisphosphatase
g. Invertase (decreased inhibitor activity)	(2) Starch synthase
	f. Antioxidants
	(1) SOD (superoxide dismutase loss of Zn and Cu)
	(2) Catalase
	(3) Ascorbate peroxidise

Modified from Graham and Patterson (1982).

5 days. The length and fresh weight of shoots decreased significantly under both stress conditions, contrary to the increase in these growth parameters for roots under the same conditions. The oxidative damage as generation of malondialdehyde and H_2O_2, was markedly higher in shoots under cold. Both stress conditions caused a significant increase in malondialdehyde levels in root tissues. The increase in proline levels was more pronounced under cold stress in shoots and roots. Superoxide dismutase activity was differentially altered in shoot and root tissues under drought and cold stress. The catalase activity was higher in roots under drought stress, but ascorbate peroxidase activity increased in root tissues under cold stress (Oktem et al., 2008).

Table 4.8 Dependency of chilling symptoms on time in various compartments of tomato cotyledons chilled at 5°C

Chilling time (h)	Plasma lemma	Tonoplast	Mitochon dria	Plastids	Nuclear envelop	Peroxi-somes	Micro-tubules
2	–	–	+	–	–	–	–
4	–	+	+	+	+	+	–
8	–	+	+	++	+	+	–
12	–	+	++	+++	+	+	Absent
16	+	+	+++	++++	+	++	Absent
20	+	++	+++	++++	+++	++	Assent
24	++	++	+++	++++	++++	+++	Absent

Modified from Ilker et al. (1979).
–, No injury; +, slight; ++, moderate; +++, severe; ++++, extreme.

4.6 General Stress Responses of Various Physiological Processes

4.6.1 Photosynthesis

Photosynthesis provides the basis of dry matter accumulation and plant growth. Conversion of radiant energy to crop yield and the input of other factors such as temperature and water have been well documented over the past several years (Charles-Edwards, 1982). Economic yield can be expressed as the product:

$$Y_{\mathrm{e}} = (Q) \times (i) \times (\mathrm{E_c}) \times (p)$$

Where Y_{e} = Economic Yield, Q = Cumulative radiation incident on the crop, i = Proportion intercepted by the crop, $\mathrm{E_c}$ = Conversion efficiency to total dry matter, p = Partitioning efficiency to economic yield.

An examination of the four components of the above relationship helps to illustrate the potential role of various physiological and environmental factors in contributing to variation in crop performance and thus to identify where an opportunity exists for improvement.

Dry matter accumulation is the result of balance between photosynthetic activity and respiratory loss in any autotropic plant. Some of the well known parameters used for determining plant efficiency are net assimilation rate, relative growth rate, leaf area ratio and crop growth rate. As an individual leaf of a plant grows, a part of the leaf area becomes less efficient in photosynthetic activity, while still retaining greenness as well as respiratory activity. As a consequence of this there could be a loss in net assimilation rate. However, this could be brought back into balance if the leaf declining in photosynthetic activity drops off quickly. The relative growth rate declines as a plant grows, because there is increase in non photosynthetic tissue. Some of these aspects have now been studied in pigeonpea, chickpea, cowpea and some other pulse crops. In cowpea and mungbean, it was observed that almost two thirds of the total dry matter accumulated during one third of the total life span of the plant (Sinha, 1976). Similarly, in pigeonpea and chickpea about one third to one fourth of the growth period accounted for 60–80% of the total dry matter (Sheldrake and Narayanan, 1977; Saxena and Sheldrake, 1978). It is interesting to note that a major part of the dry matter is produced after flowering starts (Haloi and Baldev, 1986).

4.6.2 Cumulative Incident Radiation

One of the main determinants of the cumulative incident radiation falling on the crop is duration of crop growth. The second main determinant of cumulative incident radiation is level of insolation, e.g., the difference in irradiance induced by changes in level of cloudiness between rainy and dry seasons, which could result in 50% higher yield potential for dry season grown crops (Versteeg and van Keulen, 1986). Levels of irradiation can present a severe constraint to growth of legumes in various cropping system, e.g., inter, alley, relay and companion cropping. Research on inter and mixed cropping systems has identified the need for the legumes to compliment the other component in terms of phenology and leaf area development to maximize interception and minimize inter-component competition (Willey et al., 1981). There has been no report on systematic efforts to improve adaptation of food legumes species to low light environments, such as under mango or orange trees where legume crops can be grown for several seasons until irradiance levels become too low.

There is evidence that such an approach may be profitable. Studies with leguminous ground cover under sorghum and sunflower have shown that *Vigna trilobata* compensates for low irradiance with higher specific leaf area and increased partitioning of dry matter into leaf area development (Leach et al., 1986). Evaluation of soybean (Catedral and Lantican, 1986) and mungbean (Lantican and Catedral, 1986) under full sun and 50% shade indicated that shading reduced soybean yield by 30% and mungbean yield by 68%. There were differences in genotypic responses in shade in both the species.

In almost all the pulses the leaves are compound, but the number of leaflets varies within the genera. The genus *Vigna* is characterized by trifoliate leaves, whereas in *Cicer, Pisum, Lens and Lathyrus* there are several leaflets. The leaf area development in most pulses is very slow. The development of leaf area in cowpea, mungbean and urdbean is relatively very slow for the first 4 weeks, after which the rate of leaf area development picks up quickly. In pigeonpea, chickpea, peas and lentil the period of slow growth could extend to 5 weeks or more. Leaf area development has been studied in different genotypes of many pulses. For example, in chickpea both leaf area index and dry matter produced is high under irrigated conditions. In cowpea, the development of leaf area, dry matter accumulation, nitrogen assimilation and yield were studied in determinate and indeterminate genotypes (Chaturvedi et al., 1980). The results showed that the indeterminate genotypes yield higher than determinate

Table 4.9 Development of leaf area in cowpea genotypes

	Leaf area cm^2/plant		
Genotypes	26 DAS	47 DAS	Leaf area cm^2/day during 26–47 days after sowing
C-2	171	300	6.1
C-16	165	452	13.66
C-17	153	215	3.00
C-19	149	520	17.85
C-20	178	559	18.14
K-11	118	348	10.95
NP-2	166	527	17.19
S-8	205	353	7.04
S-14	169	328	7.57
T-2	125	300	8.33
CD at 5%	17.5	46.5	

genotypes under dry land conditions. In another study, leaf area development was studied in 12 varieties of cowpea and it was observed that between 26 and 47 days after sowing, the rate of leaf area development varied from 3.00 to 18.14 cm^2/day (Shantakumari and Sinha, 1972).

Cultural practices also influence leaf area development in various pulses, e.g., soil type, soil temperature and water availability can have a profound effect. Narayanan and Sheldrake (1975–1976, ICRISAT report) observed that leaf area index in pigeonpea on black soil reached 8.2 as against only 6.4 on red soil. The water holding capacity of the two kinds of soils is different, black soil retaining more water than red soil. Leaf area development can also be enhanced by the application of nitrogen. Leaf area development is also influenced by the date of sowing during different seasons as shown by Saini and Das (1979) in mungbean (Table 4.9).

4.6.3 Radiation Interception

In a closed canopy, irradiance is attenuated downward with cumulative leaf area index in approximation with Bear's Law with an extinction coefficient (K) characteristic of the canopy. The main influences on K are the orientation, angle, size and dispersion of leaves and prior to canopy closure, planting geometry. However, K can be influenced by the proportion of diffused light to direct light. Thus the leaf area index necessary to effect more than 95% interception of radiation (critical leaf area index) depends partly on the level and nature of irradiance and extinction coefficient for that crop. Critical leaf area index values for the large leaved food legumes range between 3 and 3.5 depending on genotypes and planting geometry (Muchow and Charles-Edwards, 1982; Shibles and Weber, 1986), but can exceed 5.0 for small leafed pigeonpea (Rowden et al., 1981).

It has been shown that in absence of stress, increase in early leaf area index though isomeric sowing with high densities enhances total dry matter production. This calls for optimization of leaf area index through genotype x sowing date x density interaction in phenological unstable crops such as food legumes. Photosynthetic efficiency of pods relative to leaves in top podding crops such as cowpea, pigeonpea and mungbean genotypes needs to be clarified as a significant proportion of the total incident energy during pod filling can be intercepted by the flower and pods (Rowden et al., 1981). Actively growing cowpea pods can recycle much of CO_2 evolved by the respiring seeds, but are not capable of net CO_2 uptake even in full sunlight.

Biomass accumulation in pigeonpea is essentially a linear function of the amount of photosynthetically active radiation intercepted by the crop canopy, which, in turn, is a function of crop leaf area index (Hughes et al., 1981; Hughes and Keatinge, 1983). The proportion of incident energy intercepted, E_i, increases with leaf area index in accordance to Beer and Lambert's Law, i.e.,

$$E_i = 1 - e^{-k\,\mathrm{LAI}}$$

Where k is the canopy extinction coefficient and is a characteristic of the canopy. Crop influences k via the orientation, angle, size and spatial dispersion of leaves and can be variously altered by genotypic effects and water status. For smaller and lanceolate leaves, k may be as low as 0.3, e.g., in pigeonpea (Rowden et al., 1981). The critical leaf area index, i.e., leaf area index necessary for 95% interception of incident PAR ($E_i = 0.95$), is dependent upon k, and for pigeonpea it varies from 3.9 (Muchow, 1985a) to more than 6.0 (Rowden et al., 1981).

During the reproductive growth phase, floral structure and developing pods intercept an increasing proportion of incident photosynthetically active radiation. Interception of photosynthetically active radiation by reproductive structures is more in determinate genotypes with apical inflorescences. The slope of the linear relationship between biomass production and cumulative photosynthetically active radiation interception is the indication of a plant's efficiency for conversion of radiation energy to chemical energy (E_c). The factors influencing E_c are inherent photosynthetic capacity of leaves, balance between photosynthesis and respiration (including photo-respiration), and k. Values for k were reported to be 0.35 in upper and 0.84 in lower halves of the canopy (Thirathon et al., 1987b), suggesting thereby that dispersion of radiation through the canopy may be near optimal. Experimental estimation of E_c for pigeonpea varies from 0.9 (Natarajan and Willey, 1980a; b), 1.23 (Hughes and Keatinge, 1983), 1.30 (Muchow, 1985a) to as high as 1.62 (Thirathon et al., 1987b) and comparable to other C_3 species. However, Charles-Edwards (1982) suggested that if in these studies, senescent leaves are considered then E_c values for pigeonpea might be as large as 2.2 g MJ^{-1}, and thus comparable with C_4 species.

4.6.4 Efficiency of Conversion

Growth rate in the absence of stress is a linear function of the amount of radiation intercepted (Muchow and Charles-Edwards, 1982; Shibles and Weber, 1966). With the slope of the relationship providing an estimate of $E_{c.}$ physiological factors which might conceivably contribute to differences in E_c include the inherent photosynthetic capacity of leaves, the balance between photosynthesis, photorespiration, respiration and canopy extinction coefficient.

In food legumes, genotypic variation within a species for photosynthetic efficiency has been reported (Sinha, 1973; Durnhoff and Shibles, 1970). But its contribution to differences in dry matter accumulation is relatively smaller than variation in leaf area and light interception (Duncan et al., 1978). Likewise much of the large variation in initial crop growth rate amongst food legumes species can be ascribed to differences in leaf area expansion rate. In pigeonpea relative higher partitioning of dry matter into roots appears to be slower during the initial crop growth period creating higher leaf area development (Sheldrake and Narayanan, 1979). Enhanced leaf photosynthesis is often related to compensatory mechanism, such as thicker leaves but with slower leaf expansion rate (Charles-Edwards, 1982). The experience with improving growth by changing leaf size and shape (Mandle and Buss, 1981; Wien, 1982) has not been encouraging.

The total photosynthate availability in a plant depends upon the photosynthetic surface and the rate per unit area, minus respiration and photorespiration. In pulse crops, often it has been observed that they often produce a lesser amount of dry matter compared to other crop plants in the same situation. Photosynthesis In leaves is dependent upon the incoming light, CO_2 diffusion and carboxylation. In addition, occasionally differences in phosphorylation could also be responsible for variation in photosynthetic rate. This may be more related to the stage of leaf development and senescence. In pulses the following points are important in relation to photosynthesis:

1. In India the incident radiation exceeds 500 cal cm^{-2} day^{-1} in most parts of the country during the *kharif* season when pigeonpea, mungbean, urdbean, cowpea and other crops are grown. Even in the winter season, the incoming radiations exceed 450 cal cm^{-2} day^{-1} during the vegetative growth period and rises to more than 500 cal cm^{-2} day^{-1} when the crop enters the reproductive stage.
2. The factor of CO_2 is common to all the places for all the crops but is presently rising due to human activity.
3. Temperature is important, because there is considerable variation in day and night temperature in different seasons. This could have a profound effect on the photosynthetic rate and eventually dry matter production.

The main photosynthetic characteristics of the pulses are described below. The important points are, the pulses have a temperature optimum of 25–30°C and their light saturation occur around 50,000 lux (Table 4.10).

Table 4.10 Photosynthetic characteristics of grain legumes

Photosynthetic rate	Normally 20–30 mg CO_2 dm^2/h
Temperature range	Optimum between 25 and 30°C
Light saturation	5,000 f.c. or 50,000 lux
CO_2 compensation point	About 50 ppm
Photorespiration	Present
Main carboxylating enzyme	RuBP carboxylase
Kranz anatomy	Absent

In the cultivation of these crops, temperature plays a very significant role. An increase in temperature from 25 to 35°C enhances photorespiration by 100%. The net photosynthesis is dependent upon gross photosynthesis minus the rate of photorespiration. Increase in temperature leads to greater increase in photorespiration but not photosynthesis, therefore, rate of photosynthesis would be adversely affected (Sinha et al., 1988). It has been showed that under normal seeding of chickpea, some yield attributing traits showed high association with total degree-days during both pre and post flowering durations (Bhattacharya and Pandey, 1999).

The rate of photosynthesis in mungbean, cowpea and chickpea was examined at different stages of growth. In both mungbean and cowpea, the rate of photosynthesis was highest at the time of flowering and there was considerable variation among the varieties. Photosynthesis rate of 22 varieties of chickpea revealed a variation of more than three times between the minimum and maximum. Furthermore, there were clear differences in response to light intensity. However, an important observation was that the photosynthesis rate declined in post-flowering period when pod development commenced (Shantakumari and Sinha, 1972). Similar results have now been obtained by others (Bhattacharya and Singh, 1999). The rate of photosynthesis was evaluated in a range of species including mungbean, cowpea, pigeonpea and pea (Sinha, 1974; Khanna-Chopra and Sinha, 1977).

In addition, the rate of photosynthesis was examined in different varieties of chickpea, cowpea, mungbean and pigeonpea. There appeared to be significant differences in the rate of photosynthesis among the varieties of these species, at a given point of time. However, the surprising thing was that sometimes a variety which had a lower rate of photosynthesis at one stage became better than others at a later stage. Some of these results could be due to differences in developmental stages of the leaves or plants. In fact, some studies have been done using varieties at flowering while others are setting fruits. Consequently, the differences observed under such conditions are really not comparable (Tables 4.11 and 4.12).

The reduction in photosynthetic rates during the post flowering period could be due to several reasons. One of the major factors appears to be the loss of activity of RuBP carboxylase. It was observed that the activity of this enzyme started declining in cowpea soon after pod setting commenced. The same was true in chickpea. However, Bhattacharya and Singh (1999) reported that there exist genotypic differences for decline in rate of photosynthesis during post flowering

Table 4.11 Relative photosynthetic rates in cowpea cultivars

Cultivar	μ Moles CO_2 fixed/dm^2/h		
	Seedling	Pre-flowering	Pod development
C-2	12.8	5.2	6.3
C-16	14.9	5.0	3.2
C-17	14.7	9.8	8.0
C-19	21.3	22.3	3.5
C-20	21.8	10.0	7.3
K-11	22.2	17.9	8.2
NP-2	25.8	5.9	3.3
S-3	30.7	11.3	5.3
S-14	18.4	5.7	3.2
T-2	24.2	5.3	3.0

Table 4.12 Photosynthetic activity in the leaves of mungbean cultivars at different stages of growth

Cultivar	μ Moles O_2 evolved/cm^2/h		
	Seedling	Pre-flowering	Pod development
Baisakhi	91.24	84.2	39.5
S-8	101.90	98.2	48.2
PS-7	106.80	115.2	49.0
PS-8	125.50	127.7	66.3
PS-16	218.70	172.4	109.3

Table 4.13 RuBP carboxylase activity in leaves of cowpea genotypes at different stages of growth

	Enzyme activity as CPM $\times 10^4$ g fwt^{-1}		
Genotypes	Pre flowering	Flowering	Pod setting
C-2	65	61	60
C-16	84	61	59
C-17	92	60	19
C-19	95	72	40
K-11	103	69	24
T-2	68	65	44

period and there appears to be at least one genotype, *cv*. Katila, which had an unchanged photosynthetic rate during the pre as well as post flowering period (Table 4.14).

An interesting observation in cowpea was that the decrease in RuBP carboxylase activity was associated with a decrease in nitrogen in the leaves after flowering (Chaturvedi et al., 1980). This is not an unusual feature, because a similar decrease

Table 4.14 Photosynthetic rates (μ moles of $CO_2/m^2/s$) of chickpea genotypes at different crop growth stages under normal and late seeding conditions

			Days after flowering						
Flowering groups	Vegetative	Flowering	10	20	30	40	50	60	70
Normal planting									
60–65	32.9	11.4	14.6	16.2	18.6	21.1	16.5	21.3	19.1
66–70	20.8	13.6	16.7	14.5	25.8	18.4	11.1	12.2	19.2
71–75	22.0	20.9	13.0	13.6	25.7	16.2	14.6	12.0	–
76–80	23.6	20.7	14.4	8.7	21.5	17.4	18.4	10.0	–
Late planting									
50–55	18.8	17.5	17.1	14.5	15.0	18.5	–	–	–
56–60	15.2	14.2	22.3	20.3	11.0	1.8	–	–	–
61–65	14.6	14.3	18.6	26.6	12.7	12.1	–	–	–
66–70	15.9	14.9	18.0	23.3	11.9	4.5	–	–	–
71–75	23.6	22.9	18.1	19.9	10.9	–	–	–	–
CD (Dates)	0.1	0.2	0.4	0.3	0.4	0.02	–	–	–
CD (Genotypes)	0.5	0.6	0.6	0.5	0.7	0.04	–	–	–
CD (D × G)	0.8	0.9	1.2	0.9	1.1	0.08	–	–	–

in nitrogen content in leaves after anthesis occurs in cereals also, particularly wheat. Therefore, it appears that the maintenance of an adequate level of nitrogen in leaves would be an important approach to control the decline in photosynthetic rate (Table 4.13).

The relationship between rates of photosynthesis and yield is complex (Evans and Dunstone, 1970). But the relationship between photosynthetic rates and growth and yield is tenuous (Murthy and Singh, 1979), so much so that it is possible to select fescues with higher growth rates but low photosynthetic rates and *vice versa* (Wilhelm and Nelson, 1979). It has been reported that photosynthetic rates are determined to some extent by sink growth rates in relation to leaf area (Gifford and Evans, 1987). The inverse relationship between leaf area and maximum photosynthetic rates among alfalfa (Delancy and Dobrenz, 1974) and soybean (Burris et al., 1973) varieties is partly due to inverse association between specific leaf weight and leaf area. Reports from CO_2 and light enrichment studies indicated that crop yield is frequently photosynthetically limited (Gifford and Evans, 1987).

Chickpea planting is almost always delayed due to late harvest of paddy. Therefore to have chickpea genotype(s) suitable for late planting, Bhattacharya and Singh (1999) attempted to generate basic information(s) on rates of photosynthesis and allied traits during crop ontogeny in relation to yield in twenty six chickpea genotypes. To generalize the result, they divided the chickpea genotypes with respect to their days to flowering under normal and late seeding conditions. It was observed that chickpea genotypes of different durations had significant differences for rates of photosynthesis under normal and late seeding conditions.

4.6.5 Flowering Behavior

Day length is the other major climatic factor influencing the rate of ontogenic development in plants. Its effects are mostly observed by changes in the progress of plants from the vegetative to reproductive stage.

All the tropical legumes exhibit photoperiodism and all are short-day plants (Roberts and Summerfield, 1987). In those species which have been studied, most lines showed a quantitative short day flowering response, although qualitative short-day flowering does occur (Aggarwal and Poehlman, 1977; Hadley et al., 1983; Lush and Evans, 1980; McPherson et al., 1985; Turnbull et al., 1981). In most species, there also exists either day neutral or relatively day length insensitive genotypes, at least in the context of rate of development to flowering (Aggarwal and Poehlman, 1977; Ariyanayagam and Spence, 1978; ICRISAT, 1983; Inouye and Shanmugasundaram, 1984).

Rate of development after induction in food legumes is also sensitive to day length. In soybean, e.g., exposure to non inductive long days following initiation can cause reversion to the vegetative phase (Lawn and Byth, 1973; Board and Hall, 1984), in cowpea (Lush and Evans, 1980), *Vigna* spp. (Lawn, 1979a) and pigeonpea (Wallis et al., 1985) exposure to long day after floral initiation/ induction can variously extend the duration of the flowering period, reduce the flowering synchrony, pod setting and maturation and extend the post flowering period by delaying pod ripening and/or inhibiting leaf senescence or abscission.

Thus, the main effect of day length is to determine, in conjunction with temperature, the crop phenology and so the potential productivity, through crop production. The important effect in the food legume is on the synchrony of flowering, pod set and maturity and the relative partitioning of dry matter between vegetative and reproductive growth which contribute to differences in harvest index.

In several species the high correlation between days to flowering and crop duration has been exploited to develop an index where by different day length responses amongst genotypes can be classified and their likely region of adaptation indicated. This has resulted in various maturity groups among genotypes (Aggarwal and Poehlman, 1977; Sharma et al., 1981; Shibles, 1980). The differences among the genotypes are largely due to difference in critical day length while variation in the other parameters will contribute to differences in maturity.

When chickpea genotypes were subjected to early, mid and late podding water stress it was observed that time of pod set affected the yield components. Early stress affected biomass and seed yield more severely than the later stress, and in all stress treatments secondary branches were more affected than primary ones. Pod abortion was more severe in *kabuli* types than in *desi* types, but final seed size per se did appear to be a determinant of pod abortion under terminal drought conditions. It was amply demonstrated that pod abortion is one of the key traits affecting seed yield of chickpea exposed to terminal drought (Leport et al., 2006).

Direct exploitation of photoperiod effect on phenology and morphology can manipulate crop ideotype through genotype x sowing time x density interaction

(Byth et al., 1981; Schweitzer and Harper, 1985; Sheldrake and Narayanan, 1979; Wallis et al., 1985). When a short day plant is grown in relatively shorter day length than its quantitative sensitivity range, crop duration is shortened and less vegetative growth ensues. Moreover, flowering, pod set and pod maturity become more synchronous, particularly in cowpea, mungbean, urdbean and pigeonpea. Reduced biomass per plant is compensated for in part by increased plant density and an increase in harvest index.

4.6.6 Partitioning

Increases in the yield of cereal varieties over the past half century have been associated with rising values in harvest index with little increase in biomass, although originally no plant breeder purposely sought this increase (Donald and Hamblin, 1976). In Australia, the improvement in harvest index of cereals is largely associated with early flowering and a greater duration of reproductive growth (Loss and Siddique, 1994). Biomass and harvest indices in chickpea are often lower than cereals and other pulse crops in Mediterranean type environments (Thompson et al., 1981).

Harvest index (HI) depends on the relative duration of the vegetative and reproductive phases, the proportion of dry matter assimilated during the vegetative phase, and the amount of assimilate remobilization from vegetative to reproductive organs. Much of the advances in cereal yield have been from improvement in HI rather than in total crop dry matter (Donald and Hamblin, 1976). Seed yield itself can be partitioned into the number of pods per unit area (or the product of plant density and the number of pods per plant), the number of seeds per pod and mean seed weight. Of these yield components the number of seeds per pod and mean seed weight are relatively stable while seed yield is most highly correlated to the number of pods in chickpea (Siddique and Sedgley, 1985) and many other legumes.

The key physiological constraint to potential productivity is the relatively low harvest index, at least as grown in traditional production systems. Harvest index of most pigeonpeas is very low when compared with such species as soybean and groundnut and much of the genetic advance made in the latter species has been due to improvement in harvest index. It has been said that low harvest index in pigeonpea as compared to soybean is due to:

1. Relatively low nitrogen concentration in pigeonpea seeds compared to soybean seeds.
2. Negligible oil content compared to soybean. The energy concentration of pigeonpea seeds are relatively lower than that of soybean, and
3. Loss of biomass (carbon and nitrogen) through senescent leaves, petioles, and stem in pigeonpea plants would be sufficient to sustain much greater seed yield without any need for improved nitrogen and carbon productivity.

In the short term, the manipulation of photothermal sensitivity offers the most powerful tool for improving harvest index. There are several successful application exemplifying this approach (Byth et al., 1981; Wallis et al., 1981; Chauhan et al., 1987), which relies on the fact that under strong inductive photothermal conditions, time to flower is shortened, plants are less vegetative and less prone to loss of biomass through senescence of shaded leaves, branch *etc*. In a large part, although not always (Chauhan et al., 1987) reduced biomass per plant is compensated by greater harvest index and the use of dense stands. Nevertheless, the heaviest seed yields were recorded for pigeonpea from this approach (Whiteman et al., 1985).

Due to the fact that harvest index of pigeonpea is influenced by its photothermal regime; questions have been raised about its utility as a selection criteria in a breeding programme. Most obvious of these is that unless genotypes are tested under the same conditions of location/sowing date, the effect of photothermal regime will confound and probably obscure any inherent genotypic variations for the trait. Also, the sensitivity of harvest index to environmental stresses such as water deficit raises a specific problem in selection.

It has been asked whether most pulses produce enough dry matter to give yields comparable to cereals. In many instances more than 10 t/ha dry matter is produced in chickpea (Sinha, 1977, Koundal et al., 1979) and 14 t/ha in pigeonpea (Khanna-Chopra et al., 1979; Narayanan and Sheldrake, 1976). However, the fact remains that this dry matter production capacity is poorer than the cereals grown in the same season (Sinha et al., 1988).

The net assimilation rate and relative growth rate have been studied in many pulse crops (Chaturvedi et al., 1980; Sinha, 1978; Saxena and Sheldrake, 1978). The net assimilation rate during the life cycle of these crops was highest before flowering but declined afterward. However, it should be noted that there were occasional peaks in net assimilation rate. This was because of dropping of lower leaves, which did not contribute towards photosynthesis but retained respiratory activity. The relative growth rate was maximum in the initial stages of growth but continued to decline as the crop advanced in growth. These points are further brought out clearly for different stages of growth. Saini and Das (1979) have confirmed these finding in mungbean (Table 4.15).

Beside transport of recently fixed carbon and nitrogen to the developing seeds, pre flowering stored reserves of carbon and nitrogen are reported to be an important assimilate source for seed filling, particularly when plants are subjected to water deficit. Generally in pulses, 2–42% of seed dry matter has been reported to be contributed by the remobilization from vegetative tissues (Bushby and Lawn, 1992). In chickpea a decrease of dry matter in the stem, leaf and pod walls of field grown plants suggest that dry matter (carbon, nitrogen and others) is important as an alternative assimilate source to current photosynthates (Leport et al., 1999). It was estimated that one third of the pod dry matter is derived from the remobilization of dry matter from vegetative tissues in chickpea (Khanna-Chopra and Sinha, 1982). The studies conducted by Davies et al. (2000) showed that carbon and nitrogen assimilated prior to podding can supplement the filling of seeds in both well

Table 4.15 Relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR) during growth and development of cowpea and mungbean

	Plant stages			
Crops	Seedling	Pre flowering	Early podding	Late pod development
Cowpea				
RGR ($g^{-1}\cdot g^{-1}\cdot$week)	1.37	0.42	0.42	0.48
NAR ($g^{-1}\cdot cm^{-2}\cdot$week)	0.06	0.02	0.03	0.04
LAR ($cm^{-2}\cdot g^{-1}$)	22.80	19.28	16.11	11.55
Mungbean				
RGR ($g^{-1}\cdot g^{-1}\cdot$week)	1.39	0.77	0.20	0.32
NAR ($g^{-1}\cdot cm^{-2}\cdot$week)	0.07	0.05	0.02	0.07
LAR ($cm^{-2}\cdot g^{-1}$)	21.15	15.50	11.74	4.32

watered and water stressed chickpea. Thus, remobilization of pre podding nitrogen is an essential source of nitrogen for seed filling irrespective of the environmental stresses.

A study was conducted to compare the accumulation of soluble carbohydrates in embryos of two lupin species: cultivated *Lupinus luteus* and wild *L. pilosus*. The experiments were on plants grown under normal soil humidity as well as growing with soil drought. It was observed that soil drought caused a nearly two-fold increase of soluble carbohydrate contents in both species. *L. pilosus* embryos however, responded to water deficiency by increasing the accumulation of cyclitols and galactosyl cyclitols, whereas *L. luteus* embryos enhanced accumulation of cyclitols and raffinose family oligosaccharides (Piotrowicz Cieslak et al., 2007).

Lower harvest index in grain legumes have often been attributed to source limitation (Singh et al., 1984), however, according to Jodha and Subba Rao (1986) leaf area and seed weight at different nodes both have positive effects on harvest index. The influence of physiological traits on growth and yield have been reported for different crop ontogenic stages (Sinha and Khanna, 1975). Chaturvedi et al. (1988) showed that in indeterminate crops, there is inter-organ competition for photosynthates leading to lowering of harvest index. Sinha et al. (1982) pointed out that dry matter and harvest index contribute significantly to seed yield of *Brassica compestris* and *B. napus*. However, Natarajan and Palanisami (1988) failed to find significant correlations between harvest index and seed yield in mungbean. Ganguly and Bhattacharya (2000) analyzed the changes in physio-chemical traits in developing chickpea seeds under normal and late seeding conditions and reported that carbon/nitrogen (C/N) ratio had a negative effect on harvest index during early and late seed developmental stages. However, C/N ratio had a considerable positive effect on seed dry matter at various seed developmental stages.

In situations where genetic diversity exists improvement of potential for productivity is feasible snd implementation of breeding may be appropriate. However, breeding is a relatively slow process and relevant to long term gain, whereas, substantial advances may be possible in short term from agronomic or cultural manipulation.

4.7 Transgenic Approach for Stress Tolerance

When a plant is subjected to abiotic stress, a number of genes are turned on, resulting in increased levels of several metabolites and proteins, some of which may be responsible for conferring a certain degree of protection to these stresses. A key to progress towards better crops under stress has been to understand the changes in cellular, biochemical and molecular machinery that occurs in response to stress. Modern molecular techniques involve the identification and use of molecular markers that can enhance breeding programs. However, the introgression of genetic proteins (QTLs) involved in stress tolerance often brings along undesirable agronomic characteristics from the donor parents. This is because of the lack of proper understanding of the key genes underlying the QTLs. Therefore, the development of genetically engineered plants by the introduction and/or over expression of selected genes seems to be a viable option to hasten the breeding of "improved" plants. Following these logical steps, various transgenic techniques have been used to improve stress tolerance in plants (Allen, 1995).

A large number of studies have evaluated different transgenic constructs in different plant species, and to different stresses such as drought, salinity and cold. The expression of the genes inserted as well as altered levels of metabolites have been reported in great details. However, less detail is given with regard to methods used to evaluate the stress response (Bhatnagar-Mathur et al., 2008). This lack of details applies mostly to drought stress (Holmstrom et al., 2000). Stress conditions used to evaluate the transgenic material in most of the cases are usually too severe (Shinwari et al., 1998; Garg et al., 2002) as plants are very unlikely to undergo such stresses under field conditions. While the use of PEG in hydroponics (polyethylene glycol) can be useful to test certain response of plants under given osmotic potential as reported by Pilon-Smits et al. (1996; 1999), it offers relatively different conditions than in the soil.

In a study by Sivamani et al. (2000) they reported an increased water use efficiency (WUE) in transgenic wheat. Unfortunately, there was no control over soil evaporation which probably accounts for most of the water loss and explained very low values of WUE observed. Investigating drought responses by using fresh weight (Sun et al., 2001) and other indirect estimates of performance like growth rates, stem elongation (Pilon-Smits et al., 1995; Lee et al., 2003), or survival (Pardo et al., 1998) are likely to give inconsistence results. While applying drought stress, it is important to know the stages of drought stress that the plants are exposed to. It has been stressed that one should not investigate drought response of plants without understanding the different phases of responses that the plant undergoes under drought in natural conditions (Bhatnagar-Mathur et al., 2008). These steps have been described earlier (Ritchie, 1982; Sinclair and Ludlow, 1986).

Dehydrins are the proteins that accumulate abundantly in various plant tissues in response to environmental stresses and during seed maturation. White lupins (*Lupinus albus* L.) are able to withstand periods of severe water deficit and reports suggest that the stem plays a central role as a survival structure. To investigate dehydrins involvement, investigations have been carried out on the tissue specific protein accumulation of a RAB16-like DHN in lupin during a progressive water deficit and early recovery. Differences were found between leaves, stems and roots. In leaves and roots, the accumulation of the RAB16-like DHN was independent of the water status whereas in the stem (cortex and stele), DHNs were only detected under severe plant water deficit. Dehydrin, mRNA analysis by real time PCR, showed the presence of one dehydrin mRNA regardless of the tissue or the plant water status (Pinheiro et al., 2008).

4.8 Use of Molecular Markers

Unlike the situation with insect resistance or disease resistance, progress in understanding the molecular basis of resistance toward abiotic stresses has been limited. Water deficits elicit a range of responses at the molecular and cellular levels (Bohnert et al., 1995) and stimulate a group of proteins, termed dehydrins, in a wide range of dicotyledonous plants, mosses, liverworts and “resurrection plants” (Bartels et al., 1993). Part of a group of proteins called LEA (Late Embryogenesis Abundant) proteins that are synthesized in developing seeds as water content decreased (Bartels et al., 1993), they can be induced by ABA even in the absence of stress (Bray et al., 1993; Chandler et al., 1993). However, their function is not clear as over-expression or down-regulation of the dehydrin gene, or transfer to a drought susceptible tobacco, had no influence on the response of the plants to water deficits (Itturgia et al., 1992). The genes for the over production of quaternary ammonium compounds and the compatible solutes glycine betain and proline betains have been identified (Bartels and Nelson, 1994) and increased proline production can have a marked effect on root growth and seed development in transgenic tobacco under stress conditions in the laboratory (Kavi Kishor et al., 1995). Grain legumes were originally considered to be recalcitrant to genetic manipulation. However, as a result of the recent development of direct DNA transfer technology into organized tissue, it is possible to introduce any foreign gene into most of the grain legumes (Christou, 1994).

It has been advocated that different environmental stresses imposed on a plant may result in similar responses at the cellular and sub cellular levels. This is due the fact that the impact of the stresses trigger similar downstream signal transduction chains. At the metabolic levels, osmotic adjustment by synthesis of low molecular osmolytes (carbohydrates, betains, proline) can counteract cellular dehydration and turgor loss. Extremely hydrophilic proteins such as dehydrins are common products protecting not only the biomembranes in ripening seeds (late embryogenesis abundant proteins) but accumulate also in shoots and roots during cold adaptation, especially in drought tolerant plants. Dehydrins are characterized by conserved amino acids motifs, called the K-, Y- or S-segments. Accumulation of dehydrins can be induced not only by drought but also by cold, salinity and treatment with the abscisic acid methyl jasmonate (Beck et al., 2007).

The ability to transform plants and map genes has led to the development of molecular marker technologies to identify genes in breeding populations. Use of restricted fragment length polymorphism (RFLP’s), amplified fragment length polymorphism (AFLP's), randomly amplified polymorphic DNA (RAPD's) and quantitative trait loci (QTL's) enabled a single gene or several genes to be tracked through breeding populations. By analyzing QTL's for coincidence among traits, it is now possible to test whether the characteristics are causally related (Quarrie et al., 1995). QTL analysis have been used to identify a range of drought resistance traits in wheat (Quarrie et al., 1994; 1995) and maize (Lebreton et al., 1995; Quarrie et al., 1995). Use of eighty four RFLP markers in a cross between drought resistant and drought susceptible maize as well as the coincidence of QTL's and a particular characteristic, measured 21 days after withholding water, suggested that ABA in the xylem rather than in leaves had a greater regulating effect on stomatal conductance and that ABA in xylem was significantly associated with the number of nodal roots (Quarrie et al., 1995). Yield under drought was not causally related with the ABA genes, but was strongly linked to flowering date and anthesis-to-silking intervals.

Use of molecular marker technologies enables the selection of complex morphological, physiological and biochemical traits in breeding populations and the determination of their possible role in increasing yield. Transformation technologies are not as widely developed in grain legumes as in cereals, but progress in this area is expanding rapidly Lupin (*Lupinus angustifolia* and *L. albus*), chickpea, field pea and narrow beans (*Vicia marbonensis*) have been transformed and gene maps are being developed. While molecular marker techniques are still expensive, they are becoming less expensive with time Because of the rapid progress in this field, breeders are likely to quickly adopt molecular techniques as tools in selecting for physiological and biochemical traits (Turner et al., 2003).

Efforts are going on at the International Crop Research Institute for Semi Arid Tropics (ICRISAT) using the QTL's for mapping of root traits in ICC 4958 × Annigeri RILs. The RILs showed a narrow variability for root depth. However, an SSR marker Taa 170 was identified for a major QTL that accounts for 33.4% of the variation for root dry weight and 33.1% of the variation for root depth. Transgenic chickpea for drought tolerance have also been developed and genes for drought tolerance have been identified. *DREB 1A* gene has been shown to be controlled by *rd29A* promoter. This gene construct provides enhancement of the response to several abiotic stresses (e.g., drought, chilling and salinity) as it regulates a number of genes that act together in enhancing tolerance to these stresses. The T-2 transgenic plants are currently undergoing molecular characterization. A gene coded as *P5CSF-129A* has been identified for increased proline accumulation and improved tolerance to osmotic stress. Some selected lines showed up to fivefold overproduction of proline and a concomitant decline in free radicals. Selected transgenic plants are in T-3 stage and undergoing physiological characterization.

4.9 Conclusion

There is a justified need for basic research for understanding crop responses to environment and environment x genotypic interaction complex. Crop modeling also appears to be a useful approach in understanding the interactions of various factors and in determining the critical constraints in a given situation. Transfer of these basic understandings into management practices should also be carried out where research may concentrate on individual components of cropping system.

Research must, therefore, be multidisciplinary and must address all the components of production system. Research leading to quick and spectacular increase in yield is unlikely. Instead, an integrated research programme producing steady and small incremental increase in yield is envisaged. While the food legumes are capable of high yields, this will only be achieved under good growing conditions and with good crop husbandry based on basic researches.

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Chapter 5
Consequences of Predicted Climatic Changes on International Trade in Cool Season Grain Legume Crops

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5.1 Introduction

Dry pea (*Pisum sativum*), chickpea (*Cicer arietinum*), broad bean (*Vicia faba*) and lentil (*Lens culinaris*) are the four major cool season grain legume crops produced for human consumption. This chapter considers, firstly, recent trends (2001–2007) in total world production and then the global pattern of production of dry pea, chickpea, broad bean and lentil; secondly, international trade in these crops from 2001 to 2006 highlighting the main export and import countries/regions; and thirdly, the possible consequences of climate change on international trade.

Data were obtained primarily from the Food and Agriculture Organisation of the United Nations (FAO) statistics database (FAOSTAT). FAOSTAT provides time-series and cross sectional data relating to food and agriculture for around two hundred countries with details of production and trade of crops presented on a yearly basis. The major cool season grain legume crops are grown in all continents except Antarctica and FAOSTAT (2009) lists one hundred and nine countries that produced at least one of these crops over the period 2001–2007. However, FAOSTAT figures may underestimate production in developing countries where the bulk of the crops is consumed locally and some countries with low production are not listed on the database (Oram and Agcaoili, 1994; Knights et al., 2007). Within FAOSTAT (2009), data for dry green and dry yellow cotyledon peas are combined, as are data for desi and kabuli chickpea, and green and red lentils. In addition, data for broad bean and horsebean are combined. We do not attempt to separate the different crops into their different categories.

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5.2 Production of Cool Season Grain Legumes

Over the period 2001–2007, the production of the four major cool season grain legume crops utilised for human consumption decreased in the order dry pea 10.45 ± 0.73 million tonnes annum^{-1} (mt annum^{-1}; here and elsewhere variability quoted is standard deviation) > chickpea 8.16 ± 0.85 > broad bean 4.46 ± 0.25 > lentil 3.44 ± 0.43 mt annum^{-1} (Table 5.1). These values compare with average production of 12.33 ± 1.45, 8.05 ± 0.96, 3.49 ± 0.28 and 2.82 ± 0.21 mt annum^{-1} for dry pea, chickpea, broad bean and lentil, respectively, over the period 1991–2000 (FAOSTAT, 2009). Thus production over the period 2001–2007 in comparison with the previous ten years decreased in the case of dry pea, changed little for chickpea and increased for broad bean and lentil.

Table 5.1 World production and main producers of the major cool season grain legume crops between 2001–2007

Crop	Country	2001	2002	2003	2004	2005	2006	2007	Average
Production (million tonnes)									
Dry pea	World	10.35	9.58	9.87	11.70	11.13	10.36	10.13	10.45 ± 0.73
	Canada	2.04	1.28	1.93	3.10	2.99	2.52	3.02	2.41 ± 0.69
	France	1.66	1.66	1.62	1.68	1.33	1.01	0.64	1.37 ± 0.41
	China	1.12	1.50	1.40	1.06	1.16	1.26	1.40	1.27 ± 0.17
	Russia	1.27	1.27	1.05	1.24	1.13	1.16	0.87	1.14 ± 0.14
	India	0.56	0.61	0.59	0.73	0.79	0.80	0.80	0.70 ± 0.11
	USA	0.20	0.22	0.27	0.52	0.64	0.60	0.72	0.45 ± 0.21
Chickpea	World	6.91	8.29	7.13	8.43	8.53	8.54	9.31	8.16 ± 0.85
	India	3.86	5.47	4.24	5.72	5.47	5.60	5.97	5.19 ± 0.80
	Pakistan	0.40	0.36	0.68	0.61	0.87	0.48	0.84	0.61 ± 0.20
	Turkey	0.54	0.65	0.60	0.62	0.60	0.55	0.52	0.58 ± 0.05
	Canada	0.46	0.16	0.07	0.05	0.10	0.16	0.22	0.17 ± 0.14
Broad bean	World	4.12	4.30	4.57	4.30	4.43	4.68	4.87	4.46 ± 0.25
	China	1.95	2.10	2.14	1.81	2.00	2.20	2.45	2.09 ± 0.20
	Ethiopia	0.45	0.45	0.43	0.55	0.52	0.60	0.60	0.51 ± 0.07
	Egypt	0.44	0.40	0.34	0.33	0.28	0.32	0.33	0.35 ± 0.05
Lentil	World	3.25	2.88	2.98	3.61	4.04	3.44	3.87	3.44 ± 0.43
	India	0.92	0.97	0.87	1.04	0.99	0.95	1.40	1.02 ± 0.18
	Canada	0.57	0.33	0.48	0.92	1.16	0.63	0.67	0.68 ± 0.28
	Turkey	0.52	0.57	0.54	0.54	0.57	0.62	0.58	0.56 ± 0.03

Variability quoted is standard deviation (Source FAOSTAT, 2009).

5.2.1 Dry Pea

Canada was the major producer of dry pea over the period 2001–2007 accounting for 23.1% of world production (Table 5.1). Production in Canada was followed by that in France (13.1% of world production), China (12.2%) and Russia (10.9%). No other countries were responsible for 10% or more of total world production of dry peas in any years from 2001 to 2007. However, India consistently produced 0.56–0.80 mt annum^{-1}, while production in the USA increased steadily from 0.20 to 0.72 mt annum^{-1} over this period. This increase was linked to the 2002 US Farm Act, which, for the first time, extended the marketing loan programme to dry peas (and lentil, see below) (Lucier and Lin, 2008). This programme provided producers with a minimum return for their crop, thus reducing their market risk and allowing dry pea to be included in longer-term strategic planning and crop rotations.

5.2.2 Chickpea

India accounted for 63.6% of total world production of chickpea over the period 2001–2007 (Table 5.1). Production in India was followed by that in Pakistan (11.8% of world production), Turkey (11.2%) and Canada (3.4%). Production in Canada was substantially lower from 2002 to 2007 than in 2001. Knights et al. (2007) list reasons for the decrease in production of chickpea in Canada from 2001 to 2007 as inadequate varietal resistance to ascophyta blight coupled with increasing aggressiveness of the pathogen, onset of unseasonal frosts that severely affected seed quality of crops maturing in the field and reduced export prices. In relation to ascophyta blight, progress has been made over the past few years in the selection of chickpea genotypes resistant to this disease (e.g. Muehlbauer et al., 2004; Bretag et al., 2008).

5.2.3 Broad Bean

China was by far the main producer of broad bean over the period 2001–2007 accounting for 46.9% of total world production (Table 5.1). Ethiopia was consistently the second highest producer of broad bean over this period accounting for 11.4% of world production. Egypt in 2001, was the only other country which accounted for more than 10% of total world production of broad bean in any year from 2001 to 2007.

5.2.4 Lentil

India was the main producer of lentil (29.7% of total world production) followed by Canada (19.8%) and Turkey (16.3%) from 2001 to 2007 (Table 5.1). These three countries accounted for 61.8–69.3% of total world production in all years. Although Canada is currently one of the three major producers of lentil worldwide, lentil is a relatively new crop there with production beginning in 1969 and exceeding 0.1 mt annum^{-1} for the first time in 1986 (FAOSTAT, 2009; Saskatchewan Pulse Growers, 2009).

5.2.5 Summary of Production

India with substantial production of chickpea, lentil and dry pea was the main producer of cool season grain legume crops over the period 2001–2007 at close to 7 mt annum^{-1} (Table 5.1; FAOSTAT, 2009). Production in India was followed by that in China (mainly dry pea and broad bean) and Canada (dry pea and lentil) at just over 3 mt annum^{-1}, France (primarily dry pea but also 0.29 ± 0.07 mt annum^{-1} broad bean) at ~1.7 mt annum^{-1} then Russia (mainly dry pea) and Turkey (chickpea and lentil) at ~1.1 mt annum^{-1}. In addition, Pakistan (~0.6 mt annum^{-1} chickpea), Ethiopia (~0.5 mt annum^{-1} broad bean) and the USA (~0.45 mt annum^{-1} dry pea) produced substantial amounts of one of the four main cool season grain legume crops.

Yields of the different cool season grain legume crops over the period 2001–2007 were dependent on year and country (Table 5.2). This primarily reflects the conditions under which the crops were grown. For example, the exceptionally low yields of lentil in India resulted from the crop being grown on marginal land on stored soil moisture (which is usually linked with terminal water stress and high temperature) and with no inorganic fertilizer or other chemical inputs (McKenzie et al., 2007). On high fertility soils with adequate soil moisture, lentil yields of 3 t ha^{-1} can be achieved (Andrews et al., 2001; Andrews and McKenzie, 2007). In contrast, the consistently relatively high yields of dry pea and broad bean in France in comparison with other countries are the result of the crop being grown under low abiotic stress and more agriculturally intensive conditions (Biarnès-Dumoulin and LeCoeur, 1998). The substantial variability in broad bean yields in Australia is primarily due to differences in rainfall year to year. Yields of dry pea, chickpea and lentil in Australia from 2001 to 2007 also showed similar high variability, again primarily due to differences in annual rainfall (Australian Government Department of Agriculture, Fisheries and Forestry 2009).

Table 5.2 Yields of the major cool season grain legume crops in the main countries of production between 2001 and 2007

Country	Dry pea	Chickpea	Broad bean	Lentil
Yield (kg ha^{-1})				
India	1.06 ± 0.21	0.79 ± 0.05	–	0.70 ± 0.12
China	1.33 ± 0.15	–	1.85 ± 0.26	–
Canada	1.94 ± 0.43	–	–	1.14 ± 0.30
France	4.31 ± 0.41	–	3.92 ± 0.41	–
Russia	1.60 ± 0.25	–	–	–
Turkey	–	1.00 ± 0.08	–	1.24 ± 0.12
Pakistan	–	0.60 ± 0.17	–	–
USA	2.14 ± 0.32	–	–	–
Ethiopia	–	–	1.19 ± 0.16	–
Egypt	–	–	3.25 ± 0.10	–
Australia	–	–	1.28 ± 0.54	–

Variability quoted is standard deviation (Source FAOSTAT, 2009).

5.3 International Trade in Grain Legume Crops

5.3.1 Overview

Over the period 2001–2006, a substantial proportion of dry pea (22.0–40.2% depending on year) and lentil (31.3–38.5%) produced worldwide was exported (Tables 5.1, 5.3 and 5.4). However, only 9.0–15.0% of chickpea and 9.0–13.3% of broad bean were exported during this period (Tables 5.1, 5.5 and 5.6). Thus exports

Table 5.3 Dry pea, main exporting and importing countries 2001–2006

Country	2001	2002	2003	2004	2005	2006	Average
Export quantity (million tonnes)							
World	3.51	2.75	2.19	3.10	3.97	4.16	3.28 ± 0.75
Canada	1.97	0.67	1.00	1.57	2.35	2.33	1.65 ± 0.70
France	0.57	0.84	0.53	0.57	0.49	0.44	0.57 ± 0.14
Australia	0.34	0.39	0.09	0.18	0.12	0.24	0.23 ± 0.12
USA	0.11	0.09	0.12	0.18	0.36	0.43	0.22 ± 0.14
Import quantity (million tonnes)							
World	3.47	2.71	2.48	3.27	4.03	4.48	3.41 ± 0.75
India	0.85	0.87	0.70	0.64	0.81	1.39	0.88 ± 0.27
Spain	0.52	0.21	0.19	0.72	1.03	0.66	0.56 ± 0.32
Belgium	0.41	0.22	0.25	0.36	0.39	0.34	0.33 ± 0.08
Bangladesh	0.26	0.28	0.12	0.19	0.10	0.27	0.20 ± 0.08
Netherlands	0.16	0.11	0.27	0.21	0.20	0.16	0.19 ± 0.05

Variability quoted is standard deviation (Source FAOSTAT, 2009).

Table 5.4 Lentil, main exporting and importing countries, 2001–2006

Country	2001	2002	2003	2004	2005	2006	Average
Export quantity (million tonnes)							
World	1.18	1.02	1.04	1.13	1.40	1.32	1.18 ± 0.15
Canada	0.49	0.35	0.37	0.37	0.58	0.68	0.47 ± 0.13
Australia	0.22	0.24	0.08	0.15	0.11	0.17	0.16 ± 0.06
Turkey	0.16	0.12	0.22	0.17	0.12	0.07	0.14 ± 0.05
India	0.11	0.09	0.08	0.14	0.28	0.12	0.14 ± 0.07
USA	0.10	0.10	0.10	0.09	0.16	0.13	0.11 ± 0.03
Import quantity (million tonnes)							
World	1.14	1.08	1.12	1.03	1.38	1.33	1.18 ± 0.14
Bangladesh	0.05	0.06	0.12	0.11	0.15	0.11	0.1 ± 0.04
Egypt	0.11	0.10	0.06	0.09	0.11	0.08	0.09 ± 0.02
Sri Lanka	0.09	0.11	0.09	0.09	0.09	0.08	0.09 ± 0.01
Pakistan	0.07	0.07	0.08	0.04	0.05	0.08	0.07 ± 0.02
Algeria	0.05	0.06	0.07	0.04	0.09	0.06	0.06 ± 0.02
India	0.09	0.07	0.04	0.03	0.04	0.06	0.06 ± 0.02
Turkey	0.10	0.02	0.02	0.06	0.06	0.07	0.06 ± 0.02

Variability quoted is standard deviation. (Source FAOSTAT, 2009).

Table 5.5 Chickpea, main exporting and importing countries 2001–2006

Country	2001	2002	2003	2004	2005	2006	Averages
Export quantity (million tonnes)							
World	1.04	0.80	0.86	0.76	0.86	0.95	0.88 ± 0.10
Australia	0.27	0.09	0.14	0.15	0.19	0.27	0.19 ± 0.07
Mexico	0.21	0.14	0.14	0.08	0.08	0.14	0.13 ± 0.05
Turkey	0.15	0.10	0.19	0.13	0.12	0.07	0.13 ± 0.04
Canada	0.15	0.11	0.09	0.07	0.06	0.10	0.10 ± 0.03
Iran	0.12	0.14	0.09	0.09	0.07	0.02	0.09 ± 0.04
Ethiopia	0.0001	0.05	0.002	0.05	0.09	0.09	0.05 ± 0.04
Import quantity (million tonnes)							
World	1.12	0.86	0.92	0.74	0.86	0.78	0.88 ± 0.14
India	0.52	0.22	0.26	0.13	0.28	0.13	0.26 ± 0.14
Pakistan	0.11	0.18	0.12	0.07	0.09	0.10	0.11 ± 0.04
Bangladesh	0.04	0.06	0.08	0.10	0.10	0.07	0.08 ± 0.02

Variability quoted is standard deviation. (Source FAOSTAT, 2009).

Table 5.6 Broad bean, main exporting and importing countries 2001–2006

Country	2001	2002	2003	2004	2005	2006	Averages
Export quantity (tonnes)							
World	0.43	0.57	0.52	0.57	0.46	0.77	0.55 ± 0.12
Australia	0.24	0.29	0.09	0.17	0.11	0.22	0.19 ± 0.08
France	0.05	0.13	0.21	0.20	0.16	0.25	0.17 ± 0.07
United Kingdom	0.08	0.10	0.16	0.11	0.10	0.11	0.11 ± 0.03
Import quantity (tonnes)							
World	0.56	0.63	0.67	0.63	0.68	0.81	0.66 ± 0.08
Egypt	0.24	0.29	0.31	0.31	0.38	0.46	0.33 ± 0.08
Italy	0.16	0.18	0.18	0.12	0.11	0.11	0.14 ± 0.03
Spain	0.06	0.05	0.06	0.05	0.05	0.03	0.05 ± 0.01

Variability quoted is standard deviation. (Source FAOSTAT, 2009).

of the different cool season grain legume crops over the period 2001–2006 decreased in the order dry pea 3.28 ± 0.75 > lentil 1.18 ± 0.15 > chickpea 0.88 ± 0.10 > broad bean 0.55 ± 0.12 mt annum^{-1}. The FAOSTAT (2009) values for export and import quantities of each crop in each year were strongly correlated (Tables 5.3, 5.4, 5.5, and 5.6) indicating that movement of these crops between the major exporting and importing countries is closely monitored.

Export values per year ranged from $506 to 866 million, $356 to 632 million, $348 to 565 million and $104 to 191 million for dry pea, lentil, chickpea and broad bean respectively over 2001–2006 (FAOSTAT, 2009). Corresponding import values ranged from $612 to 1126 million, $437 to 670 million, $355 to 523 million and $156 to 219 million. Differences between corresponding export and import values may primarily relate to differences in exchange rate (Lawlor and Seddighi, 2001). International prices are quoted in US dollars and are normally determined through the interaction of global demand and supply for the crops, but payments are subject to fluctuations due to depreciation/ appreciation of the US dollar.

5.3.2 Dry Pea

Canada and France, the main producers of dry pea were also the main exporters of dry pea over the period 2001–2006, accounting for 50.5% and 17.4% of total world exports respectively (Table 5.3). Exports of dry pea from Canada increased three-fold over the period 2002–2006 while those from France were relatively constant. The only other countries that were responsible for more than 10% of total world exports of dry pea in any one year over the period 2001–2006 were Australia in 2002 (14.2%) and the USA in 2006 (10.3%).

India was the main importer of dry pea from 2001 to 2006, accounting for 25.8% of all imports (Table 5.3). Spain also imported substantial amounts of dry pea. It was the main importer of dry pea in 2004 and 2005 accounting for 22.0 and 25.6% of total world imports, respectively, and accounted for 16.4% of world imports from 2001 to 2006. Belgium was consistently responsible for around 10% (7.5–11.8%) of total world imports in all years from 2001 to 2006. The only other countries that were responsible for more than 10% of total world imports of dry pea in any one year from 2001 to 2006 were Bangladesh in 2002 (10.3%) and the Netherlands in 2003 (10.9%).

5.3.3 Lentil

Canada was the main exporter of lentil in all years from 2001 to 2006 accounting for 39.8% of total world exports over the period (Table 5.4). No other country consistently accounted for more than 10% of total exports of lentil in all years from 2001 to 2006, although, depending on year, Australia and Turkey between them accounted for 16.5–35.3% of total exports. The only other countries that were responsible for more than 10% of total world exports of lentil in any one year over the period 2001–2006 were India in 2005 (20.0%) and the USA in 2005 (11.4%).

No one country consistently accounted for more than 10% of total imports of lentil each year from 2001 to 2006: Bangladesh, Egypt, Sri Lanka, Pakistan, Algeria, India and Turkey were the main importers of lentil over this period (Table 5.4).

Turkey and India were responsible for significant exports and imports of lentil from 2001 to 2006 but with the exception of Turkey in 2006, there was a net export of lentil from both countries in all years (Table 5.4). Turkey imports mainly green lentil and exports mainly red lentil (McNeil et al., 2007). Pre 2000, Turkey imported large quantities of lentils from Canada which were re-exported but changes in policy in Turkey since 2000 have made it more difficult for this to occur (McNeil et al., 2007). India also imports then re-exports lentils after processing to Sri Lanka and Pakistan in particular (McNeil et al., 2007).

5.3.4 Chickpea

Australia was the major exporter of chickpea from 2001 to 2006, accounting for 21.6% of total world exports (Table 5.5). Mexico, Turkey, Canada and Iran were the other main exporters of chickpea over this period with each country accounting for around 10–20% of total world exports annually. The only other country responsible for more than 10% of total world exports of chickpea in any one year over the period 2001–2006 was Ethiopia in 2005 (10.5%).

Chickpea is a comparatively new crop in Australia with the first commercial crop grown in 1979 (Knights et al., 2007). Production increased from 0.12 to 0.31 mt annum^{-1} between 2005 and 2007 with the 2007 value being the highest recorded (FAOSTAT, 2009). Commercial chickpea production started in Canada in 1995 at around 1,000 t but increased dramatically to a maximum of 0.46 mt in 2001: production in 2007 was 0.22 mt (Agriculture and Agrifood Canada, 2009). A comparison of production and export quantities of chickpea from Australia and Canada show that both countries export by far the bulk of the crop grown.

India was the main importer of chickpea in all years from 2001 to 2006 accounting for 29.5% of total world imports over the period (Table 5.5). India, Pakistan and Bangladesh, the three largest countries in the Indian sub-continent accounted for 38.5–59.8% of total world imports over this period. No other country was responsible for 10% or more of total world imports of chickpea in any one year from 2001 to 2006.

5.3.5 Broad Bean

Three countries, Australia, France and the United Kingdom were, depending on year, collectively responsible for 75.3–91.2% of total world exports of broad bean from 2001 to 2006 while two countries, Egypt and Italy, were, depending on year, responsible for 68.3–74.6% of the total world imports of broad bean over this period (Table 5.6). The only other country that was responsible for more than 10% of total world exports or imports of broad bean in any one year from 2001 to 2006 was Spain in 2001 (10.7% of imports, Table 5.6).

5.3.6 Trade Summary

Overall, five countries exported more than 0.2 mt annum^{-1} of cool season grain legume crops over the period 2001–2007 (Table 5.7). Canada was the main exporter of cool season grain legume crops (dry pea, chickpea and lentil) at over 2 mt annum^{-1}. Exports in Canada were followed by those in Australia (dry pea, chickpea, broad bean and lentil) and France (dry pea and broad bean) at ~0.75, the USA (dry pea and lentil) at ~0.33 and Turkey (chickpea and lentil) at ~0.27 mt annum^{-1}.

Seven countries imported around 0.2 mt annum^{-1} or more of cool season grain legume crops over the period 2001–2007 (Table 5.7). India was the main importing

Table 5.7 Main export and import countries of the major cool season grain legume crops 2001–2006

Country	Dry pea	Chickpea	Broad bean	Lentil
Export quantity (million tonne annum^{-1})				
Canada	1.65 ± 0.70	0.10 ± 0.03	–	0.47 ± 0.13
Australia	0.23 ± 0.12	0.19 ± 0.07	0.19 ± 0.08	0.16 ± 0.06
France	0.57 ± 0.14	–	0.17 ± 0.07	–
USA	0.22 ± 0.14	–	–	0.11 ± 0.03
Turkey	–	0.13 ± 0.04	–	0.14 ± 0.05
Import quantity (million tonne annum^{-1})				
India	0.88 ± 0.27	0.26 ± 0.14	–	0.06 ± 0.02
Spain	0.56 ± 0.32	–	0.05 ± 0.01	–
Egypt	–	–	0.33 ± 0.08	0.09 ± 0.02
Bangladesh	0.20 ± 0.08	0.08 ± 0.02	–	0.10 ± 0.04
Belgium	0.33 ± 0.08	–	–	–
Netherlands	0.19 ± 0.05	–	–	–
Pakistan	0.11 ± 0.04	–	–	0.07 ± 0.02

Values in parenthesis indicate standard deviation (Source FAOSTAT, 2009).

country of cool season grain legume crops (dry pea, chickpea and lentil) at ~1.2 mt annum^{-1}. This was followed by Spain (dry pea and broad bean) at ~0.6, Egypt (broad bean and lentil) and Bangladesh (dry pea, chickpea and lentil) ~0.4, Belgium (dry pea) ~0.3 and the Netherlands (dry pea) and Pakistan (dry pea and lentil) at close to 0.2 mt annum^{-1}. The export and import values for the main countries trading the major cool season grain legume crops over the period 2001–2006 are shown in Table 5.8.

Table 5.8 Export and import values for the main countries trading the major cool season grain legume crops 2001–2006

Country	Dry pea	Chickpea	Broad bean	Lentil
Export value ($ million)				
Canada	297 ± 107	40 ± 12	–	174 ± 50
Australia	46 ± 20	68 ± 36	44 ± 13	57 ± 16
France	105 ± 21	–	34 ± 16	–
USA	61 ± 31	–	–	48 ± 11
Turkey	–	67 ± 17	–	69 ± 22
Import value ($ million)				
India	211 ± 75	100 ± 51	–	20 ± 7
Spain	95 ± 58	–	11 ± 3	–
Egypt	–	–	89 ± 15	45 ± 11
Bangladesh	38 ± 14	26 ± 9	–	53 ± 21
Belgium	59 ± 14	–	–	–
Netherlands	31 ± 10	–	–	–
Pakistan	19 ± 7	–	–	25 ± 7

Values in parenthesis indicate standard deviation (Source FAOSTAT, 2009).

An obvious feature of the trade data is that the major exporting countries are primarily developed countries while India, Bangladesh and Pakistan, the three largest countries in the Indian sub-continent in terms of population, are major importers of dry pea, chickpea and lentil.

5.4 Climate Change and International Trade of Grain Legume Crops

A substantial proportion of the population of the Indian sub-continent depends on grain legumes as a major component of their diet. In relation to this, India Pakistan and Bangladesh are major producers of dry pea, chickpea and lentil. Indeed, India is by far the largest producer of cool season grain legume crops worldwide. However, production of dry pea, chickpea and lentil does not meet demand in the Indian subcontinent and there is a substantial import of these crops from developed countries, in particular, Canada, but also, France, USA, Australia and Turkey, which have production in excess of domestic requirements. There is some potential for India, Pakistan and Bangladesh to increase the productivity of cool season grain legume crops via increasing the area sown, the use of improved varieties and increased inputs such as irrigation, fertilizers, pesticides and herbicides (e.g. Materne and Reddy, 2007). However, there is limited land available for crop production. Also, water is the major constraint on cool season grain legume production with limited availability of irrigation water. In addition, the population of the Indian sub-continent is increasing, thus growing domestic needs will mean that the demand for imports of cool season grain legume crops is likely to be maintained even if gross productivity of these crops is increased (Andrews and Hodge, 2010).

Andrews and Hodge (2010), considered how the effects of projected climate change would affect yields of cool season grain legume crops in the major areas of production. It was concluded that generally, yields are likely to decrease in the Indian sub-continent. If this prediction proves to be correct then it is likely that the Indian sub-continent will need to rely more heavily on imports of cool season grain legumes. In relation to the current major exporting countries, yields are predicted to increase in Canada, the USA and France but decrease in regions of Australia and Turkey with climate change. Because of this and because Canada, the USA and France have an established infrastructure favourable to increases/shifts in production of cool season grain legumes, they are the most likely countries that would be able to respond to increased demand and they would dominate the export market.

5.5 Conclusions

In conclusion, if climate change results in decreased productivity of dry pea, lentil and chickpea in the Indian sub-continent over the next fifty years then Canada, France, and the USA are likely to be the countries that would meet the increased demand for these crops.

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Chapter 6
Impact of Climate Change on Diseases of Cool Season Grain Legume Crops

Keith Thomas

6.1 Introduction: Climate Change and Disease

6.1.1 Questions and Complexity

The simple question of how climate change may affect legume diseases is a subset of the broader question of how climate change may affect diseases in general. As ever, the simplest questions require the most detailed answers due to their scope of concern.

That there is no easy or consistent answer to these questions is due to the many facets of pathogen, host and environment impact on disease prevalence. If climate change effect on plants were simply a temperature increase it might be possible to balance the difference between plant and pathogen growth to produce a prediction. If the effects on plant growth were only due to carbon dioxide increase a parallel model might be possible. A combination of the two is not beyond calculation. However, add in factors such as rainfall and humidity, mechanical stress from wind, changes in the microbial community of soils, altered behaviour of vectors and even impacts on toxin and antimicrobial agents and predictions become multi-factorial and very difficult to quantify.

6.1.2 Climate Change Effects on Disease: A World View

The effect of climate change has been extensively discussed for human diseases. A number of major human pathogens have been identified with potential to increase their prevalence (WHO, 2003). Twelve animal pathogens identified by the Wildlife Conservation Society include many with human pathogenisity particularly bird flu, cholera, Ebola, plague, Lyme disease and TB (WCS, 2008). The World Health Organisation 2003 report (WHO, 2003) indicates that a complex pattern of disease

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change may result from climate change but that food and vector borne diseases are likely to increase. For example, the estimated risk of diarrhoea is predicted to be up to 10% higher by 2030. Malaria is similarly expected to increase in prevalence in areas bordering current endemic zones. However, temperate regions may remain unsuitable for transmission by mosquitoes and remain relatively free of malaria.

6.1.3 Climate Change Effects on Disease: A Local View

One major threat of global warming is that disease may spread into new geographical areas with the result that temperature and CO_2 changes will make new human, animal and plant populations accessible to a range of serious diseases (Epstein, 2002).

Other effects may also operate in existing disease zones. In some cases, disease organisms may be directly affected through increased or decreased growth rates. In other cases, high temperatures may kill pathogens in secondary insect hosts or conversely allow hosts to penetrate new geographical areas. Spread of disease into new geographical areas may allow novel hosts to be infected as suggested for the soil borne fungus *Phytophtora cinnamomi* currently held responsible for oak tree (*Quercus* sp) decline in the Mediterranean (Brasier and Scott, 1994).

Another effect is that high temperatures may kill fungal pathogens of these secondary hosts. For example the pathogenic fungus Culicinomyces fails to penetrate *Anopheles* and Culex mosquitoes when incubated at 30°C compared to incubation at lower temperatures. If this effect is repeated in the wild Culicinomyces may be an ineffective control of malaria if temperatures do increase (Sweeney, 1978) so resulting in greater transmission of disease.

Global warming effects will be multi-faceted and varied and their consideration must include numerous dimensions. The epidemiologic disease triangle of influences on disease prevalence is the most fundamental level of consideration (Fig. 6.1) but indirect influences provide a second layer of effect (Table 6.1).

Local conditions will be dictated by geography and environment. Gross climate changes may have very different impacts on plant growth factors in different

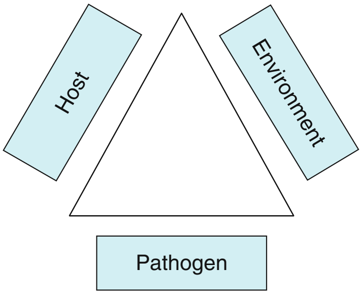

Fig. 6.1 Interacting influences in disease progression

Table 6.1 Possible effects of climate change on plant/pathogen growth and disease

Influence	Consequence	Possible disease effect
Host		
Increased host growth	Outpacing of infectious agent	Reduction
Earlier host growth initiation	Outpacing of infectious agent	Reduction
Shorter host growth season	Outpacing of infectious agent	Reduction
Agent		
Increased growth rate	More rapid infection	Increase
Increased toxin release	Faster tissue damage	Increase
Reduced pathogen competition	Increased pathogen infection	Increase
Increased resistance to host defences	Faster infection and tissue damage	Increase
Environment		
Increased temperature and CO_2	Increased host and pathogen growth	Increase/decrease
Increased humidity	Increased host and agent growth	Increase/decrease
Increased flooding	Increased host necrosis	Increase
Increased physical stress to host	Increased opportunity for infection	Increase
Increased secondary host mobility	Increased pathogen dispersion	Increase
Increased secondary host survival	Increased pathogen infection	Increase
Suppression or enhancement of anti-pathogens in soil	Increase/decrease pathogen soil load	Increase/decrease

locations due to latitude and longitude, terrain, maritime impacts, agricultural practices and many other influences.

Some examples of these are listed below and apply to human, animal and plant pathogens alike.

6.1.4 Climate Change Effects on Disease: Existing Evidence

Since climate change has been observed for some decades it may be expected that evidence of disease alterations may already exist. Examples of climate change effects have been sought: the extension of tick-borne encephalitis and Lyme borreliosis in Sweden (Lindgren, 1998; Lindgren et al., 2000) and of malaria in the East African highlands (Pascual, 2006) and in the Indian subcontinent (Bouma and van der Kaay, 1996) have been proposed as examples.

Broad weather patterns have been associated with climate change and may affect disease. Associations of disease with El-Nino have been made and indicate the potential for future epidemics if weather patterns become more variable (Checkley et al., 2000; Rodó et al., 2002).

6.2 Climate Change Prospects for Plant Disease

Inevitably the complexity of climate change effects on human and animal disease is reflected in plant disease and attempts have been made to provide broad assessments (Clifford et al., 1996; Coakley and Scherm, 1996; Chakraborty et al., 2000; Ghini et al., 2008; Mina and Sinha, 2008) as well as specific predictions of climate change (Pivonia and Yang, 2004; Elad, 2009).

Evidence of disease does not require first hand data. In plants, an increase in disease with climate change has been inferred from an increase in pesticide use for a range of crops as precipitation and temperature increased in several US locations (Chen and McCarl, 2001). In another example, the possibility of emergence of warm climate isolates of soybeans, (*Glycine max),* increasing the prevalence of Sclerotinia stem rot has also been voiced (Workneh and Yang, 2000).

Climate effects on plant diseases have been addressed predominantly to cereals, rice, *(Oryza sativa,)* soybean, and potato, (*Solarium tuberosum*) (Wang et al., 1992; Scherm and Yang, 1995; Hibberd et al., 1996) but more general models have been developed (Goudriaan and Zadoks, 1995; Chakraborty et al., 1998; Garrett et al., 2006; Evans et al., 2008). However, more limited attention has been made for diseases of cool season grain legumes.

Predictions from such general models suggest that epidemics of plant disease are likely to increase in severity and in geographic distribution but their specific impact will depend on how stable a crop plant is in its environment (Evans et al., 2008) as well as how extreme and variable any temperature increases may be (Elad, 2009).

Climate change may not only produce increased necrosis of plants but may also be a factor in overall plant productivity. Increasing plant yields due to climate warming are often implied but are not guaranteed. For example increased temperatures may encourage growth of soil microbes more than of plants leading to increased competition for nutrients (Bazzaz, 1996).

Effects may also vary with plant life cycle. Infection by take-all disease of wheat roots, (*Gaeumannomyces graminis* var. *tritici),* was found to induce an increase in root growth in the early stages of disease. However, this reduced later where the greater mass of roots was suggested to enhance disease transmission (Bailey and Gilligan, 2004).

For crops growing under conditions of increased temperature stress, desiccation is likely to be growth limiting. Fungal parasites will also be affected and disease potential may depend on how well the host and the parasite respond to the stress. The production of stress protectants, particularly compatible solutes, in plant and fungal cells is well documented and may be important adoptions for plant breeding to enhance (Ramirez et al., 2004). More specific virulence factors of plant pathogens have been identified. For example type III effector proteins released by *Pseudomonas syringae* alter abscisic acid defence mechanisms in water stressed Arabidopsis plants suggesting that pathogens may have selective advantages under these conditions (Goel et al., 2008).

Models of infection in response to changing conditions also indicate a variable view. Predictions of epidemics of *Magnaporthe grisea* on rice in Asia suggest that higher temperatures would increase the severity of disease in cool subtropical zones such as Japan and Northern China but that rainfall will have limited effect (Luo et al., 1995). In warm and humid tropical zones, however, higher temperature reduced infection levels. In addition UV-B levels were particularly effective in controlling pathogen growth.

A similar example of disease predictions as a result of climate change is that of *Mycosphaerella fijiensis* on banana (*Musa* sp) in Brazil. Using scenarios disseminated by the Intergovernmental Panel on Climate Change (IPCC) Ghini et al (2008) produced maps indicating a reduction in areas favourable for the pathogen for decades up to 2080. However, the disease is predicted to remain viable in extensive areas, particularly during the November to April period.

The competing effects of different factors have been predicted to produce no overall effect on yield in some studies. For example, Roche et al (2008) compared the effect of modelling the impact of brown rust on wheat at different sites in France and found that changes in temperature and surface wetness duration produced opposite effects on infectivity.

While static conditions of plant growth allow basic modelling, migration of crops is also likely to occur with new zones of growth developing as areas become hotter and dryer. Pathogens are likely to follow hosts into new zones but the rate of pathogen migration may not match that of the host so allowing a reduced incidence or, equally possible, new diseases to impinge (Coakley et al., 1999). The type of disease affecting migrating crops is more likely to be broad spectrum rather than specialized and to require different management approaches (Coakley et al., 1999). The difficulty of specifying these effects is illustrated by considering two of the specific factors most often associated with climate change – temperature and carbon dioxide.

6.2.1 Temperature Effects

Pathogen growth may show a different temperature response to plant growth leading to reduced yield even in the face of increased plant growth. Moreover, an increase in plant growth is not guaranteed. An extensive modelling analysis of temperature effects by Rosenzweig and Parry (1994) indicated that yields increased for a 2°C temperature rise but were reduced for a 4°C rise in three different climate change scenarios for four major crops (Rosenzweig and Parry, 1994). Simulations on infections of rice leaf blast epidemics in Asia by Luo et al (1995) suggest that different agroecological zones are likely to experience different degrees of disease. Using actual data, temperature was identified as the most influential factor in epidemics of powdery rust *(Puccinia striiformis)* and mildew (*Blumeria graminis* f. sp. *tritici*) on winter wheat in a study of disease outbreaks in the UK between 1994 and 2002 (Te Beest et al., 2008).

Resistance of plants to disease is also temperature dependent and this has been shown to include temperature at infection as well as during growth. In one example of this, Ramage and Sutherland (1995) inoculated spring wheat seedlings at 18 and 30°C and monitored infection during growth at temperatures between 18 and 30°C. Infection levels increased with growth temperature but were greater for seeds inoculated at 30°C than at 18°C regardless of growth temperature (Ramage and Sutherland, 1995).

Temperature limits of organisms are dictated by multiple factors rather than single genetic determinants. Temperature tolerance may depend on cellular physiology as much as biochemical stability of enzymes and is, in effect, an organism feature. Upper temperature limits will result from the first component to break down and initiate cell death. This may vary according to both internal plant conditions and the external environment. Since eukaryotes have more complex physiologies and cellular organisation their temperature limits (60–65°C) are lower than those of bacteria and archea (up to 80°C). Differences in temperature responses are thus likely between host and pathogen.

Protection mechanisms against high temperature effects are well documented. These include homoviscous adaption of membrane lipids to maintain fluidity, trehalose incorporation into membranes, heat stability of enzymes and ribosomes and heat shock proteins (Lba, 2002).

Under field conditions, temperature effects on disease will be complicated by interactions between fungi and other organisms. A study of interactions of competing fungi on maize indicated that Aspergillus species had the most rapid growth when in combination with other fungi but this depended on water activity. Fusarium species were dominant in conditions of high water activity and Eurotium species in conditions of lower water activity (Marín et al., 1998). Increased temperatures may thus result in different effects on disease depending on those factors affecting humidity including canopy cover and transpiration. These factors may be particularly affected by the detailed consequences of temperature increase where higher winter temperatures may have significant effects on pathogen survival (Barron, 1995). In a similar manner, increased night temperatures may have a greater effect than day temperatures as this may particularly affect moisture levels (Coakley and Scherm, 1996).

Temperature effects on pathogens may vary according to their stage in the life cycle. Infection efficiency of alfalfa rust (*Uromyces striatus*) in the USA was found to be inversely correlated with temperature at infection between 17.5 and 28°C with a 20 times difference between these extremes. However, rate of pustule appearance increased between 15 and 30°C during post-infection incubation (Webb and Nutter, 1997). Duration of leaf wetness was also a significant factor in disease development and the combination of temperature and wetness relate strongly to day/night differences in natural crop populations. The potential for higher temperatures to be associated with increased precipitation has been predicted from climate change models (Barron, 1995).

6.2.2 Carbon Dioxide

Disease response to a second major factor of climate change, carbon dioxide, may be similarly complex. Potential increases in plant growth at higher CO_2 levels may provide conditions conducive to pathogen growth. Greater biomass and canopy density may provide more opportunity for fungal growth and sporulation while more plant residues in fields may allow greater inoculae for subsequent crops. In contrast shorter growth periods and ripening give less opportunity for infection and colonisation (Ghini et al., 2008).

An extensive survey of 27 different plant diseases by Chakraborty found variable effects of elevated CO_2. Thirteen diseases produced increased crop losses, ten diseases had a reduced impact and four produced no difference (Chakraborty et al., 2008).

Plant physiology may have a direct effect on pathogen infection. Reduced stomatal density (Hibberd et al., 1996) or stomatal opening (McElrone et al., 2005) caused by higher CO_2 levels have been associated with reduced infection. Similarly a increased C/N ratio in potato induced by elevated CO_2 has been correlated with an increased resistance to *Pytophthora infestans* (Osswald et al., 2006).

Changes in infectivity involve more than just alterations in growth rate. Growth rates of *Pytophthora parasitica* in vitro were similar at low and high levels of CO_2 (350 and 700 ppm respectively) but infection was reduced in tomato roots at the elevated level.

Indirect climate change effects can include other micro organisms than the pathogen. For example the observation that soil amendments such as green waste or food by-products may reduce plant pathogen levels has potential for control mechanisms (Craft and Nelson, 1996; Garbeva et al., 2004; Chen and Nelson, 2008). However, climate change may readily alter the microbial balance in soil. For example the prevalence of *Chlonostachys rosea*, an important bio control agent of *Botrytis,* was reduced by increasing CO_2 levels. This did depend on the plant cover present and with nitrogen availability but could suggest novel means of managing infection control (Rezacova et al., 2005).

Management, however, requires more direct action in many cases and many plant groups have specialised predictor and forecasting models to provide rapid analysis of global, national and local conditions (Afifi and Zayan, 2008; Chakraborty et al., 2004).

6.3 Legume Diseases and Climate Change

Legumes including soybeans contribute around 10% of the world's food resource and because of their unique symbiosis with nitrogen fixing bacteria have considerable potential as a major security food with limited dependence on fertilizers.

How might their diseases develop in climate change conditions? It is most likely that legumes will show similarities in their responses to global changes as those observed for other crops, despite their unique bacterial symbiosis.

Legumes are no strangers to disease and extensive losses are experienced from a wide range of fungal pathogens listed in Table 6.2.

In summary the following are particularly pernicious but this varies from continent to continent and zone to zone and, at least potentially, with climate change:

Table 6.2 Pathogens of cool season legumes (after Porta-Puglia and Aragona, 1997)

Pathogen	Disease	Crop
Ascochyta fabae	Ascochyte blight	Faba bean (*Vicia faba)*
Ascochyta lentis	Ascochyta blight	Lentil (*Lens culinaris*)
Ascochyta rabei	Ascochyte blight	Chickpea (*Cicer arietinum)*
Aphanomyces euteiches	Common root rot	Pea (*Pisum sativum*), faba bean, lentil
Botrytis cinerea	Botrytis grey mould	Chickpea, lupin (*Lupinus* sp)
Botrytis fabae, B cinerea	Chocolate spot	Faba bean
Colletrotrichum lindemuthianum	Anthracnose	Chickpea
Erysiphe polygoni	Powdery mildew	Pea
Fusarium solani	Fusarium root rot	Pea, chickpea
Fusarium oxysporium ff spp	Fusarium wilt	Chickpea, pea, lupin, faba bean, lentil
Macrophomina phaseolina	Dry root rot	Chickpea
Mycosphaerella pinodes	Ascochyte blight	Pea
Peronospora viciae	Downy mildew	Pea
Phoma medicaginis var pinodella	Foot rot	Pea
Pythium spp	Seed, seedling and root rot	Pea, chickpea, lentil, lupin
Rhizoctonia solani	Seedling blight	Lentil, pea, lupin
Sclerontinia sclerotiorum	Stem rot	Lentil, lupin
Uromyces viciae-fabae	Rust	Pea, faba bean, lentil
Uromyces ciceris-arietini	Rust	Chickpea

- Chickpea: Ascochyta blight, wilt and root rot.
- Faba bean: Ascochyta blight and chocolate spot.
- Lentil: Wilt and root rot, Anthracnose
- Pea: Mildew, powdery mildew and bacterial blight.

Some legume diseases are more intensive in broad zones of growth with Rhizoctonia blight more common in tropical areas, viruses, rust and common blight more evident in warm but dry zones (Porta-Puglia and Aragona, 1997).

Legume pathogens vary in their infectivity in different locations with new varieties and species developing progressively. Anthracnose infection of *Colletotrichum truncatum* being an example in North America appearing in the 1980s with the potential to produce yield losses of up to 50% and be more destructive than blight.

In some cases disease virulence may relate to host varieties and their susceptibility and evolution. In a comparison between cultivated and wild chickpeas in Israel Ascochyta blight isolates from domesticated chickpeas demonstrated more virulence to domestic chickpea varieties than isolates from wild chickpeas (Frenkel et al., 2008). A similar virulence pattern was found with isolates from wild chickpeas being more virulent on wild varieties of chickpea than domestic varieties indicating possible effects of habitat selection possibly due to domesticated chickpeas being adapted to drier and hotter conditions compared to wild types.

Variation in severity of disease has been found to correlate with environmental factors but not necessarily as expected. In a field study between 1995 and 1998, *Sclerotinia sclerotiorum* stem rot on soybean was found to correlate positively with cooler temperatures than normal in north-central areas of the United States (Workneh and Yang, 2000). This effect was particularly related to cumulative departures from normal maximum and minimum temperatures in July and August. No association was found with precipitation, possibly because this was above minimum requirements throughout the period.

In other cases, moisture can be a critical factor. In blight development on lentils in Canada, wetness was found to be critical for infection with wetness periods of 24–48 h being optimal (Pedersen and Morrall, 1994). Temperature had a less distinct effect but produced positive correlations with incubation periods and number of lesions on leaves. Younger tissues were also found to be more susceptible.

Interactions between temperature and moisture may be important as leaf wetness periods may alter with temperature and infection may be restricted to a window of opportunity provided by exposure to moisture for germination initially followed by stimulation to grow and infect once within the host. Under controlled conditions, an eight hour period for germination and penetration in blight infestation of pea has been recorded and related to temperature and wetting periods with greater wetting being required at non optimal temperatures (Roger et al., 1999).

It is tempting to say that external factors may affect fungal infection and growth within the host in different ways requiring refined models and control methods. Differential temperature effects on infection and post infection growth have been observed on chickpea in Spain and are likely to reflect the different physiological events occurring at different stages of infection (Trapero-Casas and Kaiser, 1992).

Field conditions are inevitably more variable than those under strict experimental control and fluctuating climatic changes may both enhance disease and make predictions more difficult. Details of two example lentil diseases can illustrate these features.

6.3.1 Ascochyta

Ascochyta blight typically develops as small reddish brown lesions on leaves and tendrils which enlarge and become necrotic. Infected leaves wilt. Lesions on stems elongate and eventually coalesce to wilt the foliage above or kill the plant if at the stem base. Pod lesions are circular with fruit bodies in concentric rings.

The blight may first appear in late winter having been dispersed from infected plants by rain in autumn. In a study of infection conditions in chickpea in Spain, periods of wetness over 6 h were found to greatly increase disease severity (Trapero-Casas and Kaiser, 1992) while this was further enhanced by dry periods after inoculation. The optimum temperature for infection in young seedlings is 20°C within a range of 5–30°C although temperature after infection had limited effect on final disease severity in this study. Drying chickpea leaves after infection with *Ascochyta rabiei,* however, decreased disease severity in a later study by the same investigators although this also varied according to the period of drying (Trapero-Casas and Kaiser, 2007). Spore type is also important, with this study noting a faster germination of ascospores than conidia at all temperatures and also over a wider range of water potential.

Early studies of Ascochyta on chickpeas in Iran indicated that temperature and humidity affected not only growth and sporulation but also survival on plant tissue (Kaiser, 1973). Survival for two years was found to be possible at temperatures between 10 and 35°C and at low humidity below 30% but viability was lost at humidity above 65%. Survival was also reduced if diseased tissue was incubated at soil depths below 10 cm suggesting how post crop management may be directed. Survival of pea pathogens *Mycosphaerella pinodes* and *Ascochyta pisi* in soil in Ireland have been studied in more detail in the field and laboratory and survival found to be higher at 2°C than at 15°C (Dickinson and Sheridan, 1968). Success of survival varied between the species studied and may depend on spore development in the soil.

Analysis of variety diversity is also relevant. Molecular analysis of 40 *Ascochyta rabiei* isolates from Canada, the USA, Syria, India and Australia demonstrated similar RAPD DNA patterns suggesting a common origin, possibly from India and Syria followed by international dispersion. The high level of genetic diversity found suggests that rare pathotypes will be able to develop rapidly and easily overcome host resistance (Chongo et al., 2004) if transported to new locations. However, investigations into the pathogenicity of progeny from crosses between bean adapted (*A. fabae*) and pea adapted (*A. pisi*) Ascochyta isolates indicated that although the isolates maintained saprophytic fitness their parasitic fitness was reduced (Peever, 2007). More detailed genetic studies to elucidate full details of pathogenisity are a high priority to complete.

6.3.2 Anthracnose

Anthracnose infection is a recently emerging legume disease caused by *Colletotrichum* species. Reports in recent decades of serious crop infections have been noted from North America (Lenné and Sonoda, 1982), Australia (Ford et al., 2004) and Eastern Europe (Kaiser et al., 1994). Morphological and molecular analysis suggests that isolates from lentils were distinct from isolates of other crops and that isolates from Canada were distinct from Australian isolates (Ford et al., 2004). The possibility of Anthracnose extending its range due to climate changes should be considered.

Anthracnose typically overwinters on seeds and stubble releasing spores in spring and early summer. Disease progresses upwards through the plant infecting lower leaves first. High soil pH and wet weather in June and July encourage pathogen growth and leaf infection resulting in brown lesions on leaves. Temperatures of 20–24°C and prolonged wetness for 18–24 h enhance infection. Stem growth results in defoliation and necrosis. Crown growth reduces vigor and may lead to early ripening. Spore distribution from necrotic growth in autumn may be involved in distribution.

Lentil varieties differ in their susceptibility to Anthracnose infection. Buchwaldt et al (2004) studied 1,771 accessions from the U.S. lentil collection finding that 95% were susceptible in field testing. Only 16 accessions were found to be resistant to the disease. Variability analysis of single spore isolates of Anthracnose identified a race, Ct0, for which no resistance was identified so posing high risk to world crops.

The potential of novel *Colletotrichum* genotypes developing has been proposed on the basis of observations that twice-ambient CO_2 levels produced a 20-fold increase in spore production by *Colletotrichum gloeosporiodes* (Lupton et al., 1995).

A similar analysis of Anthracnose isolates from lupin demonstrated clustering of *Celletotrichum* isolates into a distinct subgroup within the *C acutatum* species (Talhinhas et al., 2002). Analysis of how these and other isolates may vary for their virulence in different conditions would help assess the potential for future disease severity.

6.4 Future Prospects on Legume Disease

With the many factors affecting the incidence and development of cool season legume diseases it is difficult and probably risky to develop a global or general prediction of the effects of climate change on legume productivity. Many of the conditions conducive to specific diseases of cool season grain legumes are now known and mentioned by various authors in different chapters of this book and this knowledge will become increasingly valuable in managing future epidemics of disease. Direct application of this information to specific locations, crops and conditions will be appropriate in the future, particularly where these can be clearly specified. Development of resistant varieties will also be instrumental in disease management (Bretag et al., 2006).

Considerable developments have been made on the genetics of both host resistance and pathogen infectivity to make a clearer assessment of future risk. Applying this information in the face of changing climate may require rapid analysis of disease strain features to a known host genotype. Detailed molecular analysis of host genotypes is progressing rapidly providing knowledge on susceptibility and resistance as well as indications of the evolution of varieties (Lichtenzveig et al., 2002a and b: Pilet-Nayel et al., 2005).

Molecular analysis is also providing extensive information on pathogen genetics and the variability of isolates in populations (Lichtenzveiug et al., 2002a; Talhinhas et al., 2002; Ford et al., 2004; Peever, 2007; Frenkel et al., 2008). The Grain Legumes Integrated Project (www.eugrainlegumes.org) is specifically focused on collating this information. Its use may be crucial in managing and minimising disease but may require localised application. Modelling of disease progression based on disease virulence and strain variety is likely to be equally important as suggested for Fusarium wilt on chickpea profiled using response surface plots to combine effects of variables (Navas-Cortés et al., 2007). Neural networks also show promise in compiling information rapidly and assessing risk (Chakraborty et al., 2004).

Fortunately the rapid developments of molecular diagnostics may allow this to be conducted if not in the field then in a closely adjacent facility. Direct and local response may then be possible. Specific molecular diagnostic tests using PCR analysis have been proposed for Anthracnose applications (Talhinhas et al., 2002; Ford et al., 2004; Liu et al., 2007) as well as Ascochyta infection (Taylor and Ford, 2007) and it is likely that the application of these developments holds promise in responding to climate change effects when they appear.

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Chapter 7

Pest Management in Grain Legumes and Climate Change

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7.1 Introduction

Grain legumes such as chickpea (*Cicer arietinum* L.), pigeonpea [*Cajanus cajan* (L.) Millsp.], cowpea (*Vigna unguiculata* Walp.), field pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medic.), greengram [*Vigna radiata* (L.) Wilczek], blackgram [*Vigna mungo* (L.) Hepper], bean (*Phaseolus vulgaris* L.), faba bean (*Vicia faba* L.), and grasspea (*Lathyrus sativus* L.) are the principal source of dietary protein among vegetarians, and are an integral part of daily diet in several forms worldwide. Grain legumes are cultivated on 23 million hectares, accounting for over 18% of the total arable area, but only 8% of the total grain production. There is a large disparity between yields of cereals and legumes. The global pulse production in 2006 was over 59.47 million tons over an area of 71.21 million ha, with an average productivity of 835 kg ha^{-1} (FAO, 2008). In India, the total pulse production in 2006 was 13.14 million tons on an area of 22.25 million ha, with an average productivity of 591 kg ha^{-1}. Worldwide, chickpea and pigeonpea are the two major food legumes, cultivated on an area of 10.38 and 4.57 million ha, respectively. The total production being 8.57 and 3.29 million tons, with an average productivity of 826 and 720 kg ha^{-1}, respectively. In addition to being a source of dietary proteins and income to resource poor farmers in the semi-arid tropics, food legumes play an important role in sustainable crop production. They are an important component of cropping systems to maintain soil health because of their ability to fix atmospheric nitrogen, extract water and nutrients from the deeper layers of the soil, and add organic matter into the soil through leaf drop. However, food legumes are mainly grown under rainfed conditions and the productivity levels are quite low mainly because of severe losses due to insect pests and diseases.

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7.2 Climate Change and Its Influence on Production of Grain Legumes

Despite the availability of overwhelming evidence in support of climate change, uncertainty prevails over the exact nature and consequences of climate change especially at the local level, making it difficult to plan and develop appropriate adaptation strategies, programs, and technologies. Global level simulations using climate models provide various scenarios with high levels of confidence, but these predictions become less clear as to the magnitude and timing of the changes at sub-regional, national and local levels. Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales (IPCC, 2007). However, it is widely recognized that the increased heat stress, shift in monsoons, and drier soils pose much greater threat to production of grain legumes in the tropics than the temperate regions (Rosenzweig and Liverman, 1992). With most developing countries located in the tropics and most of them being heavily dependent on agriculture for food and income, the relatively poor countries with limited resources face the costly and formidable task of adapting to climate change. Despite the many assumptions and uncertainties associated with the crop and climate models, the analysis has indicated that South Asia and Southern Africa are the two regions that are particularly sensitive to the impacts of climate change, and without sufficient adaptation measures, are likely to suffer from negative impacts of climate change, and such effects would be more severe in case of grain legumes which are more sensitive to climate change than the robust tropical cereals such as sorghum and pearl millet. Unhindered climate change has the potential to negatively impact crop production because of shortening of the cropping season, and increased severity of drought and a pest spectrum.

7.3 Insect Pest Problems in Grain Legumes and the Likely Influence of Climate Change on Distribution and Severity of Damage by Insect Pests

Grain legumes, being a rich source of proteins, are damaged by a large number of insect species, both under field conditions and in storage (Clement et al., 2000; Sharma et al., 2003) (Table 7.1). Amongst the many insect pests damaging food legumes, the pod borers, *Helicoverpa armigera* (Hubner) and *H. punctigera* (Wallengren) are the most devastating pests of chickpea and pigeonpea in Asia, Africa, and Australia. They also damage other food legumes to varying degrees in these regions (Sharma, 2001). The spotted pod borer, *Maruca vitrata* (Geyer), is a major pest of cowpea and pigeonpea, but also damages other food legumes, except chickpea and lentil (Sharma et al., 1999). The pod fly, *Melanagromyza obtusa* Malloch and pod wasp, *Tanaostigmodes cajaninae* La Sale cause extensive damage to pigeonpea in India. The leaf miner, *Liriomyza cicerina* (Rondani) is an important pest of chickpea in West Asia and North Africa (Weigand et al., 1994), and

Table 7.1 Important insect pests of grain legumes

Common name	Scientific name	Distribution	Chickpea	Pigeonpea	Cowpea	Field pea	Lentil	*Phaseolus* beans	Green gram	Black gram
Pod borers	*Helicoverpa armigera* (Hub.) *Helicoverpa punctigera* Walllengren	As, Af, Aus	xxx	xxx	X	xx	x	xx	x	x
Spotted pod borer	*Maruca vitrata* (Geyer)	As, Af, Aus, Am	–	xxx	xxx	x	–	xxx	xx	xx
Spiny pod borer	*Etiella zinckenella* Treit.	As, Af, Am	–	x	–	xxx	xx	–	–	–
Pod fly	*Melanagomyza obtusa* Malloch	As, Aus	–	xxx	–	–	–	–	–	–
Leaf miner	*Liriomyza cicerina* (Rondani)	As, Naf	xx	–	–	–	–	–	–	–
Stem fly	*Ophiomyia phaseoli* Tryon		–	–	–	xx	–	xx	xx	xx
Pod sucking bugs	*Clavigralla gibbosa* Spin. *Clavigrala tomentosicollis* (Stal.)	As, Af, Aus, Eu, Am	–	xx	xx	x	x	x	x	x
Pea and bean weevil	*Sitona* spp.	As, Naf, Am	–	–	–	xx	xx	xx	–	–
Blister beetles	*Mylabris* spp.	As, Af	–	xx	x	–	–	xx	xx	xx
Aphids	*Aphis craccivora* Koch. *Acyrthocyphum pisum* Harris *Aphis fabae* (Scop.)	Ww	x	x	xx	xx	xx	xx	xx	xx
Whitefly	*Bemisia tabaci* Genn.	Ww	–	–	–	–	–	xx	xx	xx
Defoliators	*Spodoptera litura* F., *S. exigua** Hub., *Amsacta* spp., *Spilosoma obliqua* Walk.	As, Am	–	x	x	x	x	x	x	x
Leaf hoppers	*Empoasca kerri* Pruthi	As	–	x	x	x	x	xx	xx	xx

Table 7.1 (continued)

Common name	Scientific name	Distribution	Chickpea	Pigeonpea	Cowpea	Field pea	Lentil	*Phaseolus* beans	Green gram	Black gram
Stem flies	*Ophiomyia phaseoli* Tryon.	As, Af, Aus, Eu	–	–	–	xxx	–	xx	xx	xx
Thrips	*Caliothrips indicus* Bag. *Megaleurothrips distalis* Karny	Ww	–	x	x	x	–	xx	xx	xx
Pea weevil	*Bruchus pisorum* L.	Ww	–	–	–	xx	–	–	–	–
Bruchids	*Callasobruchus chinensis* L.	Ww	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

xxx, Highly important; xx, Moderately important; x, Occasional pest; As, Asia; Naf, North Africa; Af, Africa; Am, Americas; Aus, Australia; Eu, Europe; and Ww, Worldwide distribution.

has also been reported from North India (Naresh and Malik, 1986). The spiny pod borer, *Etiella zinckenella* Triet. is a major pest of pigeonpea, field pea, and lentil. The aphid, *Aphis craccivora* Koch infests all the food legumes, but is a major pest of cowpea, field pea, faba bean, and *Phaseolus* beans, while *Aphis fabae* (Scop.) is a major pest of faba bean and *Phaseolus* beans. The pea aphid, *Acyrthosiphon pisum* Harris is a major pest of field pea worldwide. The cotton whitefly, *Bemisia tabaci* Genn. infests all the crops, except chickpea, but is an important pests of *Phaseolus* spp., black gram, and green gram. The defoliators, *Spodoptera litura* (Fab.) in Asia and *S. exigua* Hubner in Asia and North America, are occasional pests. The Bihar hairy caterpillar, *Spilosoma obliqua* Walk. is a major pest of green gram and black gram in North India, while the red hairy caterpillars, *Amsacta* spp. damage the rainy season pulses in South central India. Leafhoppers, *Empoasca* spp. infest most of the food legumes, but cause economic damage in blackgram, greengram, and *Phaseolus* beans. Pod sucking bugs (*Clavigralla tomentosicollis* Stal., *C. gibbosa* Spin., *Nezara viridula* L. and *Bagrada hilaris* Burm.) are occasional pests, but extensive damage has been recorded in cowpea by *C. tomentosicollis* in Africa, and *C. gibbosa* in pigeonpea in India. The redlegged earth mite, *Halotydeus destructor* Tucker is a seedling pest of field peas in Australia (Thackray et al., 1997; Ridsdill-Smith, 1997; Liu and Ridsdill-Smith, 2001). The pea and bean weevil, *Sitona lineatus* L. is a pest of field pea in the U.S. Pacific Northwest, while *S. crinitus* Herbst. is a pest of pea and other legumes in Asia. The thrips, *Megaleurothrips dorsalis* Karny and *Caliothrips indicus* Bag. cause extensive flower damage in food legumes. The bruchids, *Callasobruchus chinensis* L. and *C. maculatus* Fab. cause extensive losses in storage in all the food legumes worldwide. The pea weevil, *Bruchus pisorum* L. is a major pest of field pea in most production areas (Clement et al., 1999).

The geographical distribution of some of the pest will extend northwards, while the outbreaks of some other pests will become more frequent as a result of global warming. The relative importance of many of these insects will also change under global warming and climate change. The pod borers, *H. armigera* and *M. vitrata*, which are confined to tropics, may extend their range of geographical distribution to northern Europe, while there may be more number of generations due to shortening of development time due to rise in temperature. Reduced activity of natural enemies under warm and dry climates might increase the severity of damage by some pest species.

7.4 Extent of Losses

Insect pests in India cause an average of 30% loss in pulses valued at $815 million, which at times can be 100% (Dhaliwal and Arora, 1994). In Africa, insect pests can be responsible for extensive damage (up to 100%) in cowpea, the major food legume on this continent (Singh and Jackai, 1985), while in the U.S., the avoidable losses have been estimated at 40–45% (Javaid et al., 2005). In Pakistan, nearly 10% of the chickpea grain is lost due to bruchids in storage (Aslam, 2004), and at times, there may be complete loss of grain in storage. *Helicoverpa armigera* – the single largest yield reducing factor in food legumes, causes an estimated loss of US$ 317 million in pigeonpea, and $328 million in chickpea (ICRISAT, 1992). Globally, it causes an estimated loss of over $2 billion annually, despite over $1 billion worth of insecticides used to control this pest (Sharma, 2005). In general, the estimates of yield losses vary from 5 to 10% in the temperate regions and 50 to 100% in the tropics (van Emden et al., 1988). The avoidable losses in food legumes at current production levels of 60.45 million tonnes would be nearly 18.14 million tons (at an average loss of 30%), valued at nearly US$ 10 billion (Sharma et al., 2008).

7.5 Pest Management in Grain Legumes Under Climate Change

7.5.1 Monitoring and Sampling of Pest Populations

Monitoring of pest populations is the key to determine if a threshold has been exceeded and control measures are required (Sharma et al., 2002). Monitoring of pest populations through light or pheromone traps has been practiced for *H. armigera* in Asia (Trivedi et al., 2005) and *H. punctigera* in Australia (Loss et al., 1998). Sampling based on direct counts or insect damage has also been used for *H. armigera* in chickpea and pigeonpea (Wightman et al., 1995), *H. punctigera* in chickpea (Loss et al., 1998), *M. vitrata* in cowpea (Jackai, 1990; Oghiakhe et al., 1992), *L. cicerina* in chickpea (Weigand and Pimbert, 1993), *B. pisorum* in field pea (Smith and Hepworth, 1992), pea and bean weevil, *S. lineatus* in faba bean (Ward and Morse, 1995) and field pea (O'Keeffe et al., 1991)., *S. crinitis* Herbst. in lentil (Kaya and Hincal, 1987), *A. fabae* in faba bean (Ward and Morse, 1995), and *A. pisum* in field pea (Soroka and Mackay, 1990). Sweep net method has been used for *Lygus hespersus* Knight (Schotzko and O'Keeffe, 1989), *H. punctigera* (Loss et al., 1998), *B. pisorum* (Smith and Hepworth, 1992), and *A. pisum* (Maiteki and Lamb, 1985). Soil sampling has been used to assess egg density of *Sitona* spp. (Nielsen, 1990). Plant shaking has been employed to dislodge the larvae of *H. punctigera* on different crops in Australia (McIntyre and Titmarsh, 1989; Loss et al., 1998). Under global warming and climate change, there has to be a greater emphasis on regular scouting of pest populations, and use this information for forecasting pest populations, severity of damage, and pest outbreaks.

7.5.2 Economic Thresholds

Economic or action thresholds have often been used to time insecticide sprays or other interventions aimed at pest suppression. Economic thresholds have been determined for *H. armigera* on pigeonpea (one egg or larva per plant or 2% pod damage) (Goyal et al., 1990; Meenakshisundaram and Gujar, 1998) and chickpea (one larva per meter row) (Wightman et al., 1995; Khurana, 1997). Economic thresholds have been established for *H. punctigera* on chickpea in Australia (Loss et al., 1998), and *B. pisorum* on field pea (Horne and Bailey, 1991). Additionally, economic thresholds based on sweep net sampling have been established for *A. pisum* (Maiteki and Lamb, 1985, Loss et al., 1998). Small producers in many developing countries have limited resources, and are unwilling to spend money on insect control until damage is visible or large larvae are seen on the crop. At low population levels, this may be a good policy. However, when infestations are heavy, by the time spraying commences, the damage has already been done. Therefore, it is important to monitor adults, eggs and early larval growth stages, as well as plant damage, to undertake appropriate control measures in time.

7.5.3 Cultural Practices

Early and timely planting of crops can help avoid periods of peak abundance of *H. armigera* in chickpea and pigeonpea in India (Weigand et al., 1994; Dahiya et al., 1999). However, early planting of chickpea is ineffective in southern India because of moderate temperatures during the crop-growing season, which sustain high populations of *H. armigera*. Early and timely planting might become more uncertain under global warming and climate change, e.g., during the 2009 rainy season, delay in onset of monsoons by 45 days resulted in delayed plantings of pigeonpea that are more prone to damage by *H. armigera,* while heavy downpour during August lead to *H. armigera* outbreak on soybean (due to dense crop canopy and absence of other suitable hosts), on which it was a minor pest till recently. High planting densities aggravate *H. armigera* infestation in chickpea (Reed et al., 1987). Use of short-duration cultivars has often been used to avoid pest damage, but short-duration pigeonpea suffers greater damage by the spotted pod borer, *M. vitrata* in southern India. Increased infestations of *Sitona* spp. have been observed in late sown crops in Syria. Winter-sown chickpea suffers less damage by the leaf miner than the spring-sown one (Weigand et al., 1994). Early harvesting of peas reduces the losses due to *B. pisorum* in Australia (Baker, 1990a, b).

Deep ploughing of fields before planting and after crop harvest can expose insect pupae in the soil to biotic and abiotic mortality factors. For example, deep ploughing destroys the over-wintering population of *H. armigera* and other noctuids (Rummel and Neece, 1989; Fitt and Cotter, 2005). During intercultural operations, birds such as common Myna (*Acridotheres tristis* L.), egrets (*Egretta* spp.), and drongos (*Dicrurus adsimilis* L.) follow the ploughshare to eat insects that are exposed. Heavy fertilizer application results in luxuriant plant growth resulting in greater damage due to insect pests. Early termination of flowering and fruiting also reduces the population carryover from one season to another, and also reduces the number of generations of *H. armigera* (Fitt, 1989).

Careful selection of a cropping system can also minimize the losses due to insect pests. Intercropping chickpea with mustard, linseed, or safflower (Das, 1998), and pigeonpea with cowpea (Hegde and Lingappa, 1996) and sorghum (Mohammed and Rao, 1999) result in reduced damage by *H. armigera.* Intercropping can also be used as a means of encouraging the activity of natural enemies (Bhatnagar et al., 1983). Planting non-host crops before the planting of susceptible legume crops such as pea and faba bean reduces the damage by the red legged earth mite (Ridsdill-Smith, 1997). Trap crops and diversionary hosts have been widely used to reduce the damage by *H. armigera*, but there is little data to demonstrate their effectiveness under field conditions (Pearson, 1958; Fitt, 1989). Marigold, sesame, sunflower, and carrots can be used as trap crops for *H. armigera*. In Australia, chickpea and pigeonpea are used as trap crops in cotton growing regions to reduce damage by *H. armigera*. Use of plant kairomones to lure *B. pisorum* (Clement et al., 2000) and *H. armigera* (Rembold and Tober, 1985; Rembold et al., 1990) into traps or toxin baits has also been suggested. Hand picking of the larvae, nipping the plant terminals with eggs, and shaking the plants to dislodge the larvae (particularly in pigeonpea) has been suggested to reduce *H. armigera* damage (Ranga Rao et al., 2005). Crops that can serve as perches for insectivorous birds (e.g., sunflower in chickpea) or provision of bird perches can also be used to increase the predation by insectivorous birds such as myna and drongo. Egg masses and larvae of *S. litura* and *Amsacta* spp. can also be picked up by hand and destroyed. Irrigation or flooding of fields at the time of pupation reduces pupal survival and leads to decreased population densities in the following generation or season (Murray and Zalucki, 1990).

7.5.4 Host Plant Resistance

Grain legume germplasm with resistance to insect pests has been identified, but the sources of resistance have not been used extensively in breeding programs (Clement et al., 1994, Sharma and Ortiz, 2002). Insect resistance-breeding programs are underway for a few crop pests only. Entomologists and plant breeders have experienced difficulties in screening and selecting for resistance to target pests, in part, because of the lack of uniform insect infestations across locations and seasons. In addition, it is difficult to rear and multiply some of the insect species on synthetic diets for artificial infestation. Cultivars with resistance to insect pests have been identified in pigeonpea, chickpea, cowpea, black gram, green gram, and field pea (Table 7.2). However, the levels of resistance are low to moderate, but are quite effective when deployed in combination with synthetic pesticides or natural plant products such as neem seed kernel extract (Sharma and Pampapathy, 2004). Cultivars with multiple-resistance to insects and diseases will be in greater demand in future because of the concerns associated with chemical control and environmental pollution and the changes in relative importance and severity of damage due to climate change. There is a need to break the linkage between insect resistance and susceptibility to diseases, e.g., in chickpea and pigeonpea, *H. armigera*-resistant cultivars are susceptible to wilt (Sharma et al., 2005). In Australia, narrow-leafed lupins, *Lupinus angustifolius*, with resistance to aphids (Kalya and Tanjil) are being used in the field, which have greatly reduced the need to apply insecticides (Edwards et al., 2003).

Table 7.2 Identification and utilization of host plant resistance to insect pests in grain legumes

Crop	Genotypes	Reference
Pigeonpea	**Pod borer, *Helicoverpa armigera*** ICPL 332*, PPE 45-2, ICPL 84060, BDN 2, ICPL 4, Bori, T 21, ICP 7035, and ICPL 88039.	Lateef and Pimbert (1990), Kalariya et al. (1998), Parsai (1996).
	Pod fly, *Melanagromyza obtusa* ICP 10531-E1, ICP 7941E1, ICP 7946-E1, and ICP 7176-5.	Lateef and Pimbert (1990).
Chickpea	**Pod borer, *Helicoverpa armigera*** ICC 506, ICCV 7*, ICCV 10*, Dulia*, C 235*, JG 79*, BJ 256*, Vijay, and Vishal.	Lateef and Sachan (1990), Bhagwat et al. (1995), Das and Kataria (1999), Deshmukh et al. (1996a, b).
	Leaf miner, *Liriomyza cicerina* ILC 380, ILC 5901, and ILC 7738.	Singh and Weigand (1996).
Blackgram	**Pod borer, *Helicoverpa armigera*** Kalai*, 338-3, Krishna*, and Co 3*, 4* and 5*.	Lal (1987).
	Jassid, *Empoasca kerri* Sinkheda 1*, Krishna*, H 70-3, and UPB 1*.	
	Stem fly, *Ophiomyia phaseoli* Killikullam*, 338/3, P 58, Co 4*, and Co 5*.	
Greengram	**Pod borer, *Maruca vitrata*** J1, LM 11, P 526, and P 336. ML 337, ML 5, MH 85-61, and ML 325.	Lakshminarayana and Misra (1992).
	Stem fly, *Ophiomyia centrosematis* Co 3.	
Field pea	**Pod borer, *Etiella zinkenella*** EC 33860, Bonville*, T 6113*, PS 410, 2S 21, and 172 M.	Lal (1987).
	Leaf miner, *Chromatomyia horticola* P 402, PS 41-6, T 6113, PS 40, KMPR 9, P 402, and P 200.	
Cowpea	**Pod borer, *Maruca vitrata*** TVu 946, VITA 4, VITA 5, Ife Brown, and Banswara*.	Singh (1978), Lal (1987).
	Jassid, *Empoasca kerri* TVu 123, TVu 662, JG 10-72, C 152, and 3-779 (1159).	
	Aphid, *Aphis craccivora* P 1473, P 1476, and MS 9369.	

* Released for cultivation.

Screening of entire germplasm collections of chickpea and pigeonpea (over 15,000 accessions for each crop) has led to identification of a few accessions with moderate levels of resistance to *H. armigera* (Lateef, 1985; Lateef and Pimbert, 1990). However, lack of precision in evaluating thousands of accessions for resistance to the target pests probably resulted in missing many potentially good sources of resistance. In lentil, genotypic differences for susceptibility to aphid (*A. craccivora*), pod borer (*E. zinkenella*), and seed weevil have been observed, but no attempts have been made to breed for resistance to insects (Erskine et al., 1994). Sources of resistance to chickpea leaf miner have been identified, and used successfully in the breeding program (Singh and Weigand, 1996). Climate change may alter the interactions between the insect pests and their host plants. Hence, development of cultivars with stable resistance to pests would provide an effective approach in pest management. Problems with new agricultural pests will occur if climatic changes favor the introduction of cultivars that are highly susceptible to the prevalent pest spectrum. Therefore, it is important to identify and develop cultivars that are stable in expression of resistance to the target pests under variable climate.

7.5.5 Biological Control

The importance of both biotic and abiotic factors on seasonal abundance of insect pests is poorly understood. Early stage mortality is invariably the most severe, although its causes and extent vary greatly, and comparable data sets are too few to identify the factors responsible for population regulation across regions. There is voluminous information on parasitism, and to a lesser extent on predation of insect pests on different food legumes. The egg parasitoids, *Trichogramma* spp. and *Telenomus* spp. destroy large numbers of eggs of *H. armigera* and *H. punctigera,* but their activity levels are too low in chickpea and pigeonpea because of trichome exudates. The ichneumonid, *Campoletis chlorideae* Uchida is probably the most important larval parasitoid of *H. armigera* on chickpea and pigeonpea in India (Pawar et al., 1986). Tachinids parasitize late-instar *H. armigera* larvae, but result in little reduction in larval density. In India, *Carcelia illota* (Curran), and to a lesser extent, *Goniophthalmus halli* Mesnil, and *Palexorista laxa* (Curran) parasitize up to 22% of *H. armigera* larvae on pigeonpea (Bhatnagar et al., 1983), and up to 54% larvae in chickpea. There are a few reliable estimates of pre-pupal and pupal mortality of *H. armigera,* which may be as high as 80% (King, 1994). Six species of parasitoids have been recorded from field-collected *Helicoverpa* pupae (Fitt, 1989). Population of *L. cicerina* parasitoids builds up late in the season in West Asia (Weigand et al., 1994). Potential biocontrol agents for *B. pisorum* have been documented (Annis and O'Keeffe, 1987; Baker, 1990a, b). The most common predators of insect pests of food legumes are *Chrysopa* spp*., Chrysoperla* spp*., Nabis* spp*., Geocoris* spp*., Orius* spp*., Polistes* spp., and species belonging to Pentatomidae, Reduviidae, Coccinellidae, Carabidae, Formicidae and Araneida (Zalucki et al., 1986; van den Berg et al., 1988; Romeis and Shanower, 1996; Sharma, 2001). Some predators have been used in augmentative release studies, notably *Chrysoperla carnea* (Stephens) (Ridgeway et al., 1977). Although effective in large numbers, the high cost of large-scale production precludes their economic use in biological control in food legumes (King et al., 1986). Relationships between pests and their natural enemies will change as a result of global warming, resulting in both increases and decreases in the status of individual species. Quantifying the effect of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programs.

There is considerable information on entomophagous pathogens against *H. armigera* and *H. punctigera*, although to date, these tactics have not provided a viable alternative to insecticides. Spraying *Bacillus thuringiensis* (*Bt*) (Berliner) formulations in the evening results in better control than spraying at other times of the day (Mahapatro and Gupta, 1999). The entomopathogenic fungus *Nomuraea rileyi (Farlow) Samson* (@ 10^6 spores per ml) resulted in 90–100% larval mortality, while *Beauveria bassiana Balsamo* (@ 2.68×10^7 spores per ml) resulted in 6% damage on chickpea compared to 16.3% damage in untreated control plots (Saxena and Ahmad, 1997). A significant and negative correlation has been observed between insect mortality due to NPV and foliar pH, phenols, tannins, and protein binding capacity (Ramarethinam et al., 1998). In Australia, a commercially available NPV has been tested on cotton, with an additive that increases the level of control. Neem and custard apple extracts, and neem and karanj (*Pongamia*) oil based formulations have also been recommended for the management of *H. armigera* (Ranga Rao et al., 2005). Much remains to be done to develop stable and effective formulations of biopesticides for the control of *H. armigera* and other insect pests on food legumes. Vegetable oils, neem oil and karanj oil provide effective protection against bruchid damage in pulses (Reddy et al., 1996). Karanj oil, and leaf and seed extracts act as oviposition deterrents (Kumar and Singh, 2002). There is a need for a greater understanding of the effect of climate change on the efficacy of biopesticides for pest management.

7.5.6 Chemical Control

Management of insect pests in food legumes relies heavily on insecticides, often to the exclusion of other methods. Control measures directed at adults, eggs, and neonate larvae are most effective in minimizing *H. armigera* damage. Spray decisions based on egg counts could destroy both invading adults and eggs, and leave a residue to kill future eggs and neonate larvae. Young larvae are difficult to find as they burrow into the flowers where they become less accessible to contact insecticides. Spray initiation at 50% flowering has been found to be most effective (Singh and Gupta, 1997). As a result of heavy selection pressure, *H. armigera* has developed resistance to the major classes of insecticides. *Helicoverpa armigera* populations have shown resistance to endosulfan, thiodicarb, and methomyl in Australia (Daly et al., 1988; Gunning et al., 1996); cypermethrin, endosulfan, quinalphos, monocrotophos, carbaryl, chlorpyrifos, phosalone, fenvalerate, and deltamethrin in India (Armes et al., 1996; Kranthi et al., 2002); cypermethrin, cyfluthrin, deltamethrin, bifenthrin, lambda-cyhalothrin, monocrotophos, ethion, chlorpyriphos, and profenfos in Pakistan (Ahmad et al., 1997a, b); and fenvalerate in Thailand (Burikam et al., 1998). Insecticide resistance management strategies have been developed in several countries to prevent the development of resistance or to contain it. All strategies rely on a strict temporal restriction in the use of pyrethroids and their alteration with other insecticide groups to minimize selection for resistance (Sawicki and Denholm, 1987). Considerable information has also been generated on chemical control of *B. pisorum* in pea (Michael et al., 1990), *S. lineatus* and *A. fabae* in faba bean (Ward and Morse, 1995), and aphid vectors in lupins (Bwye et al., 1997). There is a need for a greater understanding of the effect of climate change on the efficacy of synthetic insecticides, their persistence in the environment, and development of resistance in pest populations.

7.6 Biotechnological Approaches for Pest Management in Grain Legumes

7.6.1 Transgenics

While several transgenic crops with insecticidal genes have been introduced in the temperate regions, very little has been done to use this technology for improving crop productivity in the harsh environments of the tropics, where the need for increasing food production is most urgent (Sharma et al., 2004; Sharma, 2009). Progress in developing transgenic plants of food legumes has been reviewed by Popelka et al. (2004). Chickpea cultivars ICCV 1 and ICCV 6, transformed with *cry1Ac* gene, have been found to inhibit the development of and feeding by *H. armigera* (Kar et al., 1997). Transgenic pigeonpea plants with *cry1Ab* and soybean trypsin inhibitor (*SBTI*) genes have been developed at ICRISAT, and are being tested against *H. armigera* (Gopalaswamy et al., 2008). Transgenic chickpea expressing cowpea trypsin inhibitor (Thu et al., 2003), and α-amylase inhibitor (Shade et al., 1994; Schroeder et al., 1995; Sarmah et al., 2004) with resistance to bruchids has also been developed. Research in Australia has led to the development of transgenic pea for resistance to pea weevil through the expression of α-amylase inhibitor (Morton et al., 2000), but this technology is not available to pea breeders in Australia, the USA, and other countries because of the concerns associated with the use of transgenic crops as food.

7.6.2 Molecular Markers

The use of DNA markers for indirect selection offers the greatest potential gains for quantitative traits with low heritability, as these are the most difficult characters to work with through conventional phenotypic selection. The quality of a marker-assisted selection program can only be as good as the quality of the phenotypic data on which the development of that marker was based. Therefore, it is essential to use large mapping populations characterized across seasons and locations, and using well-defined phenotyping protocols. Progress in marker-aided selection for resistance to insect pests in grain legumes though limited, and been discussed by Sharma et al. (2008). Mapping the complex traits such as resistance to pod borer, *H. armigera* in chickpea is only just beginning (Lawlor et al., 1998). A mapping population derived from a cross between a wilt-resistant Kabuli variety (ICCV 2) and a wilt-susceptible Desi variety (JG 62) has been used to develop the first intraspecific genetic linkage map of chickpea (Cho et al., 2002). This population has also been evaluated for resistance to *H. armigera*, and the data analysis is in progress. An interspecific population derived from ICC 4958 (*Cicer arietinum*) × PI 489777 (*Cicer reticulatum*) has been evaluated for resistance to beet armyworm, *Spodoptera exigua* (Hub.) (Clement et al., 2008) and pod borer, *H. armigera* (Sharma, H.C., Unpublished), and this population is being genotyped to identify markers for resistance to these insects. Another mapping population (Vijay × ICC 506 EB) has also been developed and evaluated for resistance to *H. armigera*. In pigeonpea, a mapping population involving *C. cajan* × *C. scarabaeoides* is under development at ICRISAT (Upadhyaya, H.D., personal communication).

A cross between an aphid (*A. craccivora*) resistant cultivated cowpea (IT 84S-2246-4) and an aphid susceptible wild cowpea (NI 963) has been evaluated for aphid resistance and RFLP (restricted fragment length polymorphism) marker segregation (Myers et al., 1996). The RFLP marker *bg4D9b* was linked to the aphid resistance gene (*Rac1*), and several flanking markers in the same linkage group (linkage group 1) have also been identified. Tar'an et al. (2002) developed the genetic linkage map of common bean. Murray et al. (2004) detected genetic loci for resistance to potato leafhopper, *Empoasca fabae* (Harris). In greengram, *TC1966* bruchid resistance gene has been mapped using RFLP markers (Young et al., 1992). Resistance was mapped to a single locus on linkage group VIII (approximately 3.6 cM from the nearest RFLP marker). Based on RFLP analysis, a progeny was also identified in the F_2 population that retained the bruchid resistance gene within a tightly linked double crossover. This progeny might be useful in developing mungbean lines resistant to bruchids, and free of linkage drag. Yang et al. (1998) used RFLP marker-assisted selection in backcross breeding for introgression of the bruchid resistance gene in greengram, while Kaga and Ishimoto (1998) studied genetic localization of a bruchid resistance gene and its relationship to insecticidal cyclopeptide alkaloids, the vignatic acids in greengram. The random amplified polymorphic DNA (RAPD) markers have also been used to identify markers linked to the bruchid resistance in mungbean (Villareal et al., 1998). The gene was 25 cM from *pM151a*. When *pM151a* and *pM151b* were considered as alleles of the same locus, the bruchid resistance gene was located 11.9 cM from the nearest RAPD marker *Q04* sub 900, and 5.6 cM from *pM151*. Progress has also been made in locating molecular markers for resistance to pea weevil in crosses between field pea (*P. sativum*) and the wild species *(P. fulvum*) (Byrne et al., 2002).

7.7 Storage Pests and Their Management

Bruchids, *Callosobruchus chinensis* and *C. maculatus* are the most important pests of grain legumes in storage, including chickpea and lentil. Bruchid infestation in grain legumes commences in the field even before the crop harvest, and then they multiply quite fast in storage, resulting in heavy losses. The *Callosobruchus* species are commonly known as spotted pulse beetle, Oriental pulse beetle, bruchid, bean weevil, bruchid seed beetle, gram bean weevil, southern cowpea weevil, cowpea weevil, etc. *Callosobruchus chinensis* and *C. maculatus* are cosmopolitan in distribution, encompassing Australia and Oceania, Europe, Asia, Africa, and the Americas (Rees, 2004). The members of the family Bruchidae have long been reported to destroy the seeds of leguminous plants. They also feed on seeds and flowers of non-leguminous plants belonging to the families Compositae, Malvaceae, Convolvulaceae, Anacardiaceae, Rosaceae, Umbelliferae, Papavaraceae, and Palmae (Arora, 1977). Among the several species of bruchids attacking edible legumes, *C. maculatus* and *C. chinensis* are most destructive, and attack almost all edible legumes, including chickpea and lentil.

Females of *C. maculatus* and *C. chinensis* lay eggs singly on seeds, which are visible to the naked eye. Bruchids tend to lay eggs singly on a given host and if all the seeds are occupied, then the female starts laying eggs on already egg-laden seeds (Messina and Renwick, 1985). The neonate larva bores into the seed beneath the oviposition site, and completes its development within a single seed. Damaged seeds are riddled with adult emergence holes, which are unfit for human or animal consumption (Schoonhoven and Cardona, 1986). The life cycle of bruchids passes through five larval instars, three pre-pupal stages, pupal, and adult stages. The egg incubation period of *C. maculatus* in green gram lasts for 3–5 days, and the combined larval and pupal period lasts for nearly 19 days. Total development is completed in about 24 days. The adults of *C. chinensis* and *C. maculatus* are easily distinguishable with the naked eyes.

7.7.1 Pre-harvest Control

Spraying monocrotophos (0.04%), fenvalerate (0.02%), and dimethoate (0.03%) at 45 and 50 days after flowering of pulses reduces *C. chinensis* damage in stored pigeonpea (Subramanya et al., 1999). Similarly, cowpea protected by spraying malathion (0.05%) at maturity reduces the bruchid damage (Ravindra, 1999). At pod maturity, the dehisced pods with exposed seeds are more vulnerable to oviposition by bruchids, and this problem can be avoided by harvesting the crop at physiological maturity.

7.7.2 Hermetic Storage

Storing grain legumes in polythene bags with a cotton lining has been found effective against *C. maculatus* (Caswell, 1973). Even though the adult females could penetrate the polythene bags, the cotton lining posed hindrance for oviposition, leaving the grains safe. Bagged grains encased in polythene sacks are also less damaged by the bruchids (Wilkin and Green, 1970).

7.7.3 Solar Treatment

High temperatures due to solar radiation have been found to kill developing bruchid larvae in the seeds (Zehrer, 1980). Exposing grain legumes to 70–80 °C temperature for short duration has been found to be effective in reducing the bruchid infestation. Solar heaters operated at 65 °C for 5 min provide 100% control of *C. maculatus* (Murdock and Shade, 1991). Solar heat treatment is being used in India for disinfesting the grains.

7.7.4 Use of Inert Dusts

Dusts remove the epicuticular lipid layer of the insects and have been used effectively against bruchids. Some of the dusts in use include bentonite clay, hydrated lime, attapulgite dust, limes, clays, synthetic silica, and sand. Treatment of pulses with fly ash also hinders emergence of *C. maculatus* adults up to 12 months.

7.7.5 Use of Traps

Pitfall traps can be used for capturing insects that are active on the grain surface, and in other layers of grain. It also serves as a monitoring cum mass trapping tool. Two models are available *viz.*, standard model and the TNAU model (Mohan and Fields, 2002). A standard model has 2 parts, perforated lid (2–3 mm) and a cone shaped bottom portion. A special coating with sticky material on the inner side of cone to hold the trapped insects is essential. The model devised by Mohan and Fields (2002) has a perforated lid and a cone shaped bottom, which tapers into a funnel shaped trapping tube. It is made of plastic, and is simple and economical. Another two-in-one trap is a combination of probe and pitfall traps, and is designed to increase the trapping efficiency. This trap is also suitable for pulse beetles as they are seen only on grain surface. It does not require coating on the inner surface with sticky materials. Beetles are captured alive in this trap. The release of pheromone by the trapped insects attracts more insects.

7.7.6 Chemical Control

Chemical methods such as fumigation with phosphine, methyl bromide, or dusting with primiphos methyl and permethrin are effective against bruchids, but have certain disadvantages such as increased costs, handling hazards, pesticide residue, and possibility of development of resistance. With the proposed ban of fumigants by 2015, there is an urgent need to develop safer alternatives to conventional insecticides and fumigants to protect stored grain from insect pests.

7.7.7 Host Plant Resistance

Several cultivars of different grain legumes have been reported to be resistant to *C. maculatus* (Lambrides and Imrie, 2000; Riaz et al., 2000; Khattak et al., 2001; Jha, 2002). Apart from the cultigens, wild relatives of several grain legumes have shown high levels of resistance to bruchids. Several varieties have been developed by crossing wild species with of the cultigens, and the results have been highly promising.

7.7.8 Natural Plant Products

Neem, *Azadirachta indica* (A. Juss) possesses antifeedant, oviposition repellant, ovicidal, and adulticidal properties against bruchids (Said, 2004; Singh and Mehta, 1998). Seed treatment with neem leaf powder at 0.5–2.0 mg 100 g^{-1} of grain, neem seed kernel powder, neem bark powder, and neem seed oil at 3% have been reported to be effective against bruchids. Neem oil and *Pongamia* oil reduce seed damage by *C. maculatus* (Durairaj and Muthiah, 2003). Singh et al. (2003) suggested the use of coconut, mustard, and groundnut oil (@ 12 ml kg^{-1}) to suppress adult emergence for two consecutive generations. Volatile oils of *Cymbopogan nardus (L)* and *C. schoenanthus.*, *Clausena anisata* (Wild.) Hook f. ex. Benth, *C. citratus (DC) Stapf., and Ocimum basilicum L.* have oviposition repellent and adulticidal effects (Boeke et al., 2004; Aslam et al., 2002). *Lantana camara L.* and *Parthenium hysterophorus L.* have also been reported to be repellent to pulse beetle in chickpea.

7.7.9 Strategies for Controlling Bruchid Damage in the Field and Storage

Prevention of infestation in the field through timely harvest of the crop or insecticide use can be quite useful for reducing bruchid infestation. Optimum drying of the grain, use of solar radiation to kill the bruchids infesting the grain, and storing the grain in polyethylene bags can be used to reduce bruchid infestation. Dusts, neem leaf or kernel powder, treatment of seed with neem, *Pongamia*, or other vegetable oils can be used for minimizing the losses due to bruchids. Under severe infestation, the grain should be fumigated to get rid of bruchids infesting the grain. An ideal IPM schedule should be as follows: spraying monocrotophos or dimethoate at pod formation stage and just before pod maturity to reduce infestation by bruchids in the field, reducing the moisture content of the grains to less that 12% before storage, using cotton lined polythene bags for storage, treatment of grains with inert dusts such as clay, silica, fine sand, or fly ash, use of pitfall traps as a low cost device for use in households and medium scale storage, and treatment of grain with botanicals such as neem oil, neem leaf powder, etc. Though the above methods are economical, developing durable varieties with resistance to bruchids through interspecific hybridization and genetic transformation would be helpful in the long run. Use of biocontrol agents, semiochemicals, and controlled atmosphere storage (CAS) has been found to be very effective, and can be used for minimizing the losses due to bruchids.

7.8 Conclusions

There is considerable information on the insect pests that damage food legumes in different countries, although the factors that influence the population build up and population dynamics of many insect species is not sufficiently clearly understood. There is a need to gain a thorough understanding of the factors that lead to heavy losses in food legumes. Cultivars with resistance to insect pests will play a pivotal role in pest management in food legumes, but only if breeding programs utilize identified sources of resistance. Resistance genes from closely related wild relatives of grain legumes should also be utilized wherever possible. Genetically engineered plants with different insecticidal genes can also play a role in IPM. Molecular marker-assisted selection has the potential to pyramid resistance genes and other desirable traits to magnify the value of host plant resistance in food legume IPM. Moreover, cultural practices that reduce the intensity of insect pests are another important element of pest control. Cropping systems that encourage the activity and abundance of natural enemies should be popularized among the farmers. Insecticides provide quick and effective pest control in food legumes. However, where insecticide resistance has developed as in case of *Helicoverpa*, a more integrative strategy may be needed. Neem seed kernel extract, *Bt*, and HaNPV have been recommended in many cases, but limitations on timely availability, quality control, and economic feasibility limit their use in pest management on a regular basis. However, biopesticides applied in combination with synthetic insecticides or in rotation can be quite effective for pest management on different crops. Release of natural enemies for biological control has been successful in some situations. The integrated strategy has to be developed for each region to suit the farming practices of the growers in that region. As a result of climate change, earlier emergence of pests and faster generation turnover will result in problems with the timing of pest control interventions. There is a need for a greater understanding of the effect of climate change on the efficacy of natural enemies, host plant resistance to insects, biopesticides and synthetic insecticides, and their persistence in the environment to develop effective strategies for pest management in grain legumes in future.

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Chapter 8
Agronomic Approaches to Stress Management

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8.1 Introduction

Droughts are generally classified into three categories, namely, meteorological, hydrological and agricultural droughts (Ramakrishna et al., 2003). Meteorological drought is a situation when there is a significant decrease (more than 25% of normal rainfall) in rainfall over an area. In the situation where a meteorological drought is prolonged, it results in a hydrological drought with the marked depletion of surface as well as ground water levels. Agricultural drought occurs when both rainfall and soil moisture are inadequate during the growing season to support a heavy crop. Droughts affect the agriculture sector to a large extent. Not only is the productivity of crops reduced under drought conditions but they also influence food security, the national economy, livestock numbers and health, etc. Drought may not be avoided but it can be managed.

There are many agronomic approaches for drought management. Some of these must be applied in anticipation of drought whereas others can be made use of when there is an actual occurrence of drought. Examples of management options include, land management changes, making an informed choice of crops and varieties to be grown, manipulation of planting date, planting method and sowing depth. Other options include the use of seed priming, changes to plant population, use of straw mulching, alterations in intercropping, improved weed control, modifications to fertilizer application and use of water harvesting, etc. These are only some of the techniques/practices which could help in managing/alleviating the adverse effects of drought on cool-season grain legumes. This chapter discusses the role of some of the more important agronomic approaches for drought management in some of the agriculturally important cool-season grain legumes in the world.

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8.2 Choice of Crops and Varieties

Farmers like to grow any crop which provides them with high profits. However, the crops and their genotypes actually grown in an area depend upon their suitability based upon climate, soil type, etc. In drought-prone areas some of the crops/genotypes are more suitable than others due to their specific characteristics such as their genetic ability to tolerate drought, crop duration, growth pattern, rooting pattern, etc.

Crops do vary in their ability to tolerate drought. For example, Lathyrus (*Lathyrus sativus* L.), a crop of dry areas, can better tolerate moisture stress than fieldpea (*Pisum sativum* L.). *Desi* chickpea (*Cicer arietinum* L.) generally has a greater drought resistance than *kabuli* chickpea (Yadav et al., 2006). Some of the reasons for this greater tolerance can be explained by the physiology and phenology of the crops.

Under drought conditions short duration varieties generally perform better than long duration ones, which could be due to their ability to escape terminal drought. For example, Silim et al. (1993) found 49% of variation in yield of lentil lines was a result of early flowering leading to drought escape. Robertson et al. (2002) have taken this explanation further by quantitative modeling of the effects of drought on several legumes and indicated that earliness (eg Early Bunch peanuts) can directly benefit yield under drought. In many parts of the world, crops like chickpea experience high temperatures and moisture stress during the reproductive phase. As indicated above varieties which mature earlier better escape moisture stress than those which take a longer period to reach maturity. However, other factors may adversely affect the ability to flower early. In areas such as southern Australia and northern South Asia where average temperature at flowering are <14–16°C, pod setting in chickpea is delayed and crops experience terminal drought. There is thus a need to search for reproductive chilling tolerance (Berger, 2007) so that there is early pod formation and early maturity before the occurrence of terminal moisture stress. Two chilling tolerant chickpea varieties namely, Sonali and Rupali, have been released in Australia (Clarke et al., 2005) which have this character and thus better escape terminal drought. Further, double-podded genotypes, such as ICCV 96029, a very early germplasm line of chickpea, are more suitable for drought-prone conditions (Kumar and Rao, 2001). Rubio et al. (2004) suggested double podding leads to greater yield stability under droughted conditions independent of earliness. In addition to avoiding terminal drought there may be benefits in growth habit differences to modify evapotranspiration (Rubio et al., 2004). In Australia, it has been established that for improving water use efficiency, soil evaporation should be reduced by genotypes/practices which promote earlier-developing canopies during winter whereas transpiration needs to be reduced by minimizing canopy development to some extent in spring (Siddique and Sedgley, 1987).

As well as these phenological changes some genotypes may perform better under moisture stress conditions than others due to physiological differences. Examples are reported in chickpea (Mhase et al., 2006; Bakhsh et al., 2007; Raut et al., 2003), narrow-leafed lupin (*Lupinus angustifolius*) (Palta et al., 2004) and lentil (*Lens culinaris* Medik.) (Shrestha et al., 2006). These improvements in performance under drought may be due to accumulation of soluble constituents such as soluble protein, phenolics and sugars, and proline (Raut et al., 2003), faster rate of seed growth (Palta et al., 2004), deep and prolific root systems (Kashiwagi et al., 2005; 2006) as well as the development of rapid ground cover and early flowering and podding (Siddique et al., 2001) as previously described.

In faba bean (*Vicia faba* L.) plants originating from very small (<700 mg) and small (700–1,000 mg) seeds are reported to be faster in emergence and earlier in flowering, podding and maturity and higher yielders compared to the plants from large (>1,500 mg) and medium (1,001–1,500 mg) seeds (Al-Rifaee et al., 2004), especially under low rainfall conditions. Poor germination from large seeds could be due to slower water imbibition and the need for a greater amount of water for imbibition, which is actually not available under such situations. Thus under moisture stress conditions, genotypes with small seed size should be preferred for sowing.

Chickpea is able to draw water from depths greater than 60 cm, though most of the active roots are concentrated in the top 0–30 cm and most of the water use comes from this layer only (Anwar et al., 2003). In another study, rooting depths of about 120 cm in chickpea and 90 cm in lentil have been reported (Zhang et al., 2000) and due to greater root system and longer growing period, chickpea has a greater ability to utilize soil moisture than lentil. Therefore, genotypes with longer root system should be preferred under drought-prone areas. An early study (Robertson et al., 1980) suggested that the ability of peanut and soybean to maintain root length under drought explained their better yield stability compared with corn which could not maintain its root system as well.

8.3 Tillage and Water Conservation

Well-leveled and cultivated fields ensure more intake of rain water than the un-leveled and non-cultivated ones. In the case of the latter there could be high rainfall losses. Not only is the rain water lost but also the fertile surface of the soil is washed away. For efficient capture of rain water, infiltration rate needs to be enhanced. Prior to the high rainfall season, fields are cultivated to conserve moisture for the next post-rainy season crops. In rainfed agriculture in semiarid regions, conventional tillage is done with four main purposes (Van Duivenbooden et al., 2000): (i) to prepare a seedbed, (ii) to promote infiltration, (iii) to conserve water within the soil profile, and (iv) to prevent wind and water erosion. The fields should be cultivated as soon as the conditions permit. For example, in dry areas, due to little moisture in the soil at the time of harvest owing to extraction by the crop, it may not be possible to cultivate the field immediately and the farmers have to wait till some rain showers occur.

It has been found that in bread wheat (*Triticum aestivum*)-chickpea-watermelon and durum wheat-lentil-watermelon crop rotations, chickpea and lentil do not need deep tillage (Pala et al., 2000) and shallow cultivation was found promising. Compared with deep tillage practices, zero tillage and minimum tillage practices left more water at harvest for the following crop. Many of the benefits of tillage are lost if they bring moist soil to the surface to increase soil evaporation, expose more soil to sunlight and wind by removal of stubble or lead to increased compaction and reduced infiltration below the plough layer. Therefore, increasingly in some areas zero or minimal-tillage is practised with stubble retention. Zero-tillage with stubble retention increases rain water use efficiency and grain yields (Li et al., 2005). Especially at sowing, no-tillage provides greater amounts of soil moisture compared to conventional tillage (Li et al., 2005; Lenssen et al., 2007). In many crops, no-tillage provides similar grain yields to those after conventional tillage. However, zero tillage can have problems if followed for a long period as more infestation of weeds may cause reduction in crop yields if other methods for weed control are not adequate.

8.4 Planting Date

In drought-prone areas, the crop should be sown as soon as adequate rainfall is received to make best use of the available moisture at sowing. Otherwise, in the case of prolonged drought, it may not be possible to sow the crop at all or its sowing could be delayed to such an extent that the productivity will be too low. In some areas, particularly drier areas of Eastern Australia (http://www.dpi.nsw.gov.au/agriculture/field/field-crops/pulses/general/dry-sowing), dry sowing is practiced to get the benefits of the earliest suitable rains. However, this may result in poor germination and weed problems if followed by brief showers or prolonged hot dry weather. The planting time, based on past experiences, should be decided in such a way that the crop does not suffer for the want of moisture during its growing season. Forecast of the drought is not very reliable as it is influenced by a large number of factors. However, increasingly climate modelers are attempting (with some success) to improve their forecasting tools. Price et al. (2006) are using these tools in a real collaboration with growers in Australia with in season climate forecasting in conjunction with crop response modeling (Yield Profit) being increasingly used in Australia to determine in season practices such as extra fertilizer application (www.yieldprophet.com.au/).

In southern Europe where faba bean is being introduced as a new crop, November sowing has been found to be more suitable than February sowing, mainly because the plants flower earlier and pods fill before the drought period, resulting into high yields (Stagnari et al., 2007). Similarly winter sown chickpea produces almost twice the yield of the spring sown crop in Syria (Malhotra et al., 2007) and Jordan (Al-Rifaee et al., 2005), as the crop benefits from better moisture conditions, resulting in better vegetative as well as reproductive development. In the whole Mediterranean region, shifting the sowing date from spring to winter could increase the productivity of cool-season grain legumes to a great extent through better utilization of moisture.

In chickpea, Ascochyta blight, caused by *Ascochyta rabiei*, is a serious disease. In Turkey, it has been found that a delay in sowing by 6–9 weeks could almost eliminate blight, however, yields are reduced considerably due to drought stress (Dusunceli et al., 2007). In Australia, early sowing of lentil in late April or early May resulted in more water use and consequently higher yields than delayed sowing in late June or early July (Siddique et al., 1998). In the case of chickpea sowing has to be shifted from spring to winter season for making best use of the available moisture as described earlier, there will be a need to develop Aschochyta blight resistant genotypes or management options (Bretag et al., 2003).

8.5 Sowing Depth

Optimum moisture in the seeding zone is required for germination of the crop. In the situation where there is inadequate moisture in the soil, a patchy plant stand results in consequently low crop yields. At sowing time, when there may be drought or less availability of moisture in the upper few centimetres of the soil, sowing a crop at shallow depth may result in poor germination. However, placing the seed deep in the deeper moist soil layer is expected to provide reasonably good germination.

In western Australia, the optimum sowing depth for chickpea and faba bean has been reported to be 5–8 cm and for lentil 4–6 cm (Siddique and Loss, 1996; 1999) due to greater soil moisture and consequently better crop establishment at this depth than at shallower depths. When chickpea is sown at 5, 10 or 15 cm depths the yields are either similar (Dahiya et al., 1988a) or highest with highest depth of 15 cm (Dahiya et al., 1988b) or 9 cm (Khan et al., 1999). Furthermore, the incidence of *Fusarium oxysporum* f.sp. *ciceris* is low when chickpea is sown at a deeper depth of 15 cm (Dahiya et al., 1988b). Though seedling emergence may be slightly delayed with deeper sowing depth (Sivaprasad and Sarma, 1989; Siddique and Loss, 1996) the plant stand is generally not affected.

8.6 Seed Priming

After the seed is sown, it imbibes water and then germination takes place. Thus water imbibition by seed is an important step before germination. Under moisture stress conditions, there is little moisture for imbibition by the seed, with the result there is very poor germination. Under such situations, however, germination can be improved by soaking seed in water for specific period prior to sowing. Soaking of seed could be in normal water only or in water containing some chemicals.

Many benefits of on-farm seed priming – a technique in which seed is soaked overnight, surface dried and then sown the normal way – have been reported under moisture stress conditions in different crops including chickpea (Harris et al., 1999; 2001; Musa et al., 2001). These benefits include faster emergence; better, more uniform stands; more vigorous plants; better drought tolerance; earlier flowering; earlier harvest and higher grain yields (Table 8.1). The optimum period of seed soaking could vary with different crops. However, for chickpea seed should not be soaked for more than 8 h (Harris et al., 1999) as longer period of soaking may cause

Table 8.1 Plant characters, yield components and yield of chickpea from on-farm trials of seed priming in chickpea [modified from Musa et al. (2001)]

Variable	Primed	Non-primed	Increase due to priming (%)
Emergence (seedlings/m^2)	35.1–36.7	28.8–30.2	21–22
Early growth height (mm)	99–105	82–86	21–22
Height at harvest (mm)	364–413	330–371	10–11
Number of plants at harvest (no./m^2)	30.6–32.4	25.0–26.7	22
Number of pods/m^2	1226–1493	1074–1105	11–39
Grain yield (t/ha)	1.44–1.63	1.11–1.21	20–47
Straw yield (t/ha)	1.88–2.00	1.53–1.68	12–31

sprouting of seeds, which could be more susceptible to physical damage during the sowing operation. This low cost technology could help poor farmers in drought-prone or otherwise moisture stress areas in a big way by reducing risk of crop failure.

8.7 Plant Population

Optimum plant population is a pre-requisite for obtaining high yields of crops. In the case where there is drought at the time of sowing, it may not be possible to sow the crop or there may be very low germination and consequently a very thin plant stand. However, germination could be improved by following practices such as deep sowing and seed priming, as explained above. In tall and erect genotypes a higher seed rate may be needed in comparison with the rate needed for more spreading types.

Sometimes crops experience drought during the vegetative or reproductive phase of their growth. At that stage there may be quite high evapo-transpiration, with greater moisture loss with high plant population. Under such situations the crop may not reach its maturity due to continued loss of moisture from the soil. However, there may be benefits if the crop is thinned by removing some of the plants within a row or removing alternate rows. Potentially, in some situations, grazing may also reduce leaf mass though it may also reduce growing tips and vegetative parts causing problems of its own. These management options may reduce moisture loss through reducing evapo-transpiration and the water so saved could be used by the remaining plants to yield something.

8.8 Straw Mulching

In some parts of the world crop residue is considered waste and is burned, which results into the loss of valuable nutrients, loss of microflora and microfauna and causes lot of environmental pollution. The straw could be used as a mulch, which has many advantages with moisture conservation as one of the most important. Straw mulching reduces soil evaporation and evapo-transpiration and improves water use efficiency (Deng et al., 2006). Straw mulch may be applied immediately after sowing or at a later stage. Straw mulch application at sowing should be at such a rate that it does not create any hindrance in the germination of the crop. At a later stage, the straw mulch is applied between the crop rows. Though the application of straw mulch involves some cost to the farmer it offers many advantages, such as conservation of moisture, weed control and high crop yields. However, during drought periods availability of straw for mulching purposes may be poor on a large scale as there is a scarcity of green fodder for animals during drought and straw may be used as fodder. Under such situations, there is a need to test the use of plastic film mulch. Zero tillage also has the benefit of leaving standing stubble as mulch but may require the use of special equipment for sowing.

8.9 Intercropping

Intercropping is the practice of growing two or more crops in different rows on the same piece of land in the same season. This system is followed to have at least one crop succeed in the case the other crop(s) fail due to some adverse condition such as drought.

Chickpea + mustard (*Brassica juncea*) is an important intercropping system in the Indian subcontinent (Arya et al., 2007). Intercropping is generally followed by small holding farmers who perform different field operations manually. Some of the practices such as weed control, irrigation application, insect pest control and harvesting need to be specifically designed such that neither of the crops suffers in the intercropping system.

In inter/mixed cropping system, crops compete with each other above ground as well as below ground for various resources. Some grain legumes or genotypes of a grain legume may differ in their ability to compete in inter/mixed cropping system. The leafy genotype of peas "Bohatyr", due to its higher growth rate owing to its greater leaf area, was found to be more competitive with maize (*Zea mays* L.) than a semi-leafless genotype "Grafila" (Semere and Froud-Williams, 2001). Furthermore, under water stressed conditions, root as well as shoot competitive abilities of pea were higher than those of maize. Wheat + chickpea intercropping has been found advantageous over monoculture due to the higher than 1.0 land equivalent ratio (Gunes et al., 2007). However, some researchers reported wheat + chickpea mixed/intercropping not to be a promising system due to low yields of both the crops (Jahansooz et al., 2007) or due to sensitiveness of chickpea to salt stress (Agarwal et al., 2003).

8.10 Weed Management

Weeds compete with crop plants for moisture, nutrients and sunlight and thereby reduce crop yields. The reduction in crop yields depends on the stage and duration of crop-weed competition, weed quantum and flora present, etc. Weed control is a must for realizing high crop yields particularly when an additional stress such as drought is present. Weeds may be controlled by using herbicides, cultural practices, hand weeding, etc.

Sowing is usually done when the soil has an adequate moisture for proper germination and this moisture level is sufficient for effective control of weeds using pre-plant incorporation or pre-emergence herbicides. Post-emergence herbicides could also be used for controlling weeds in cases where there is sufficient moisture level at the time of application of such herbicides. In the case where the crop is experiencing moisture stress at the optimum time of application of post-emergence herbicide, the application of herbicide should be avoided, otherwise there may be poor weed control and the crop may be adversely affected due to the toxicity of the herbicide (Sikkema et al., 2005). Further, under drought, water may not be available for spraying herbicides. Under such situations, weeds may be controlled manually and weed biomass so collected could serve the purpose of fodder for animals, the availability of which is generally scarce during drought.

8.11 Nutrient Management

Under moisture stress conditions the soils are not only thirsty but hungry too. Fertilizer application is known to increase crop yields under optimum moisture conditions. However, it has been found that under moisture stress conditions also the fertilizer application may have beneficial effects in improving the crop yields. Application of phosphorus and potash singly as well as in combination improved the yield of chickpea under water stress conditions (Kumar et al., 2003; 2005). Phosphorus has beneficial effect on root growth, which, in turn, helps in extracting more moisture and ultimately leads to high yields under moisture stress environments. However, the financial benefits of applying fertilizers to relatively low yielding crops need to be factored into the decision.

As discussed earlier, terminal drought is experienced by many cool-season grain legumes in many parts of the world. Remobilization of pre-podding nitrogen is an important source for seed-filling in grain legumes, as reported in chickpea (Davies et al., 2000). Foliar application of urea, equivalent to 30 kg N/ha, at first flower or at 50% flowering i.e. before the occurrence of terminal drought, increases grain yield and seed protein content in chickpea (Palta et al., 2005). Foliar application of urea increases grain yield by increasing the number of pods with more than one seed and not by increasing pod number/plant or increasing seed size (Table 8.2). Foliar application of urea after the occurrence of drought does not have any beneficial effect as the uptake of nitrogen is limited due to leaf senescence. Therefore, foliar application of urea should be made in anticipation of drought, especially in those areas where terminal drought is a regular feature.

Genotypes may also vary in acquiring nutrients from soil. For example, ICC 4958, a drought tolerant chickpea genotype with a large root system, acquired more phosphorus than other genotypes (Ali et al., 2002). Higher uptake of N, P, K, Ca, Zn, Mn and B does occur in drought tolerant chickpea genotypes (Gunes et al.,

Table 8.2 Effect of foliar application of nitrogen through urea during flowering and podding on various parameters of chickpea under conditions of terminal drought induced at first podding [Adapted from Palta et al. (2005)]

Time of application	Biomass (g/plant)	Seed yield (g/plant)	Pods/ plant	Seeds/ pod	Seed weight (mg/seed)	N content at maturity (mg/plant)	Seed protein content (%)
First Flower	21.5	5.6	41	1.4	191	445	28.9
50% Flowering	21.4	5.1	39	1.3	196	439	27.8
50% pod set	18.8	4.2	36	1.0	209	379	25.9
End of podding	18.0	4.1	41	1.0	205	385	26.1
No foliar application	17.9	4.0	42	1.0	206	335	25.1
l.s.d. (P=0.05)	2.5	0.8	n.s.	0.2	n.s.	55	1.5

n.s., Non-significant.

2006). So there is a need to develop genotypes which have greater ability to acquire nutrients under moisture stress conditions so that yield is limited to lesser extent due to nutrient deficiency under such situations.

Cool-season grain legumes fix atmospheric nitrogen in the soil. However, under drought conditions nodulation and nitrogen fixation are adversely affected as reported in chickpea (Kurdali et al., 2002), pea (Hill and McGregor, 2004), faba bean (Kurdali et al., 2002) and narrow-leafed lupin (Hill and McGregor, 2004). Potash application increased dry matter production and total N_2 fixed under moisture stress conditions in faba bean (Kurdali et al., 2002; El-Sayed and Ahmad, 2003) and peas (El-Sayed and Ahmad, 2003). Chickpea inoculated with vesicular arbuscular mycorrhiza (VAM) *Glomus macrocarpum* have more growth rate and nutrient levels under moisture stress than the ones without VAM association (Anilkumar and Kurup, 2003). So there is a need to use biofertilizers to improve nitrogen fixation, nutrient content in plants, growth and yield of cool-season grain legumes under drought stress conditions.

8.12 Water Harvesting

Water harvesting may be defined as the process of concentrating precipitation through runoff and storing it for beneficial use (Oweis and Hachum, 2006). Under rainfed or drought-prone areas some rainfall does occur. This rain water needs to be conserved and used efficiently. Micro-catchments and macro-catchments techniques may be used for water harvesting. Micro-catchment water harvesting techniques include contour ridges, semi-circular and trapezoidal bunds, and small runoff basins whereas in macro-catchment systems runoff water is collected from relatively large catchments. Rain water may be harvested and then used later to irrigate the crop at the most sensitive stage(s). The pod initiation stage is the most critical with respect to moisture stress in different cool-season grain legumes. Therefore, life-saving

Table 8.3 Effect of supplemental irrigation (SI) on aboveground dry biomass and grain yield of lentil and chickpea [4-year averages worked out by these authors from Oweis et al. (2004a) for lentil and Oweis et al. (2004b) for chickpea]

	Lentil				Chickpea			
Irrigation treatment	Number of irrigations	Total SI (mm)	Above ground dry biomass (t/ha)	Grain yield (t/ha)	Number of irrigations	Total SI (mm)	Above ground dry biomass (t/ha)	Grain yield (t/ha)
Rainfed	0	0	4.34	1.10	0	0	3.17	1.32
1/3 SI	2	68	5.43	1.56	3	80	4.03	1.57
2/3 SI	2	137	6.43	1.80	3	160	4.82	1.89
Full SI	2	206*	6.46	1.93	3	241*	5.17	2.02

* Amount applied to full supplemental irrigation. 1/3 SI and 2/3 SI treatments were irrigated at the same time but with 33 and 67% of the amount.

irrigation at this stage results in high yields (Soltani et al., 2001). Compared to traditional furrow irrigation, the use of alternate furrow irrigation has been found promising in some crops (Karajeh et al., 2000; Kang and Zhang, 2004) and this technique needs to be tested in cool-season grain legumes. In the case of less availability of water, the crop may be irrigated two or three times as per the need but with lower amounts of water (may be 1/3 or 2/3 of the full irrigation) and still high biomass and grain yield may be obtained (Table 8.3) as reported for lentil (Oweis et al., 2004a) and chickpea (Oweis et al., 2004b). With more availability of water, irrigation with the full amount of water needed may be applied which improves the crop yields further.

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Chapter 9
Major Nutrients Supply in Legume Crops Under Stress Environments

M. Yasin Ashraf, M. Ashraf and M. Arshad

9.1 Introduction

Scarcity of water is the primary limiting factor for crop production globally under arid and semi-arid conditions (Hussain et al., 2004). Drought can suppress nearly all the processes of plant growth and metabolism. However, the extent of the drought stress response by the plant depends upon the intensity, rate and duration of exposure and the stage of crop growth (Wajid et al., 2004). Without optimum moisture supply, application of fertilizers and cultivation of high yielding crop varieties are likely to fail to produce economical yields (Maiti et al., 2000). Consequently application of relatively high quantities of fertilizers under low soil moisture conditions is considered risky as well as a cost-intensive means of nutrient management for crops exposed to water limited conditions. However, to reduce the cost to benefit ratio an optimized system of fertilization can be devised to achieve higher yields where there is low availability of soil moisture. Release of from fertilizers of phosphorus, potassium and sulphur is relatively slow when applied under limited soil moisture. Thus they should be applied at rates which keep in mind the soil properties and total nutrient uptake needed by a crop to achieve its maximum yield potential in a season with moderate availability of soil moisture. Nitrogen if needed as a starter to replace failed N fixation should be applied as a series of split applications, which may be adjusted during the season according to the degree of water stress observed. By careful estimation of yield potential, and appropriate adjustments of soil fertility, this type of soil management could be practiced to reduce the cost to benefit ratio (Piha, 1993; Ruben and Lee, 2002).

Nutrient availability has a vital role in plant growth and productivity. However, uptake of nutrients by plants from soil is not simple and depends upon the interaction between plant, soil and water (Postel, 2000). Plants possessing an extensive and efficient rooting system (i.e., with high rates and levels of root extension, root radius, root hair density and root length; Ashraf et al., 2005; Fageria et al., 2002;

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Samarah et al., 2004) may thrive well under drought conditions. But plant rooting systems are adversely affected by soil moisture stress and as a result of which absorption of nutrients is severely reduced under drought (Marschner, 1995; Baligar et al., 2001). Different plant species and genotypes within a species respond differently with respect to their nutrient uptake under water limited conditions (Garg, 2003). Due to this reduction in nutrient uptake under drought, reduced growth and disturbances in physiological and metabolic activities of plants are commonly observed (Baligar et al., 2001).

Legumes are severely affected by moisture stress in terms of their growth and productivity and more than 50% of countries of the world are facing this problem (Postel, 2000). Nutrient deficiency is common in the soils of small landholders in developing countries, where most of the world's acreage of grain-legumes are cultivated and farmers cannot afford costly fertilizers.

Legumes are second to cereals in providing food for human being world-over (Kamal et al., 2003). In comparison with cereal grains, legume seeds are rich in protein, and thus are a source of nutritionally rich food (Ahlawat et al., 2007). For example, bean, lentil, peas and chickpeas are very rich in protein. Legumes can be grown on a wide range of soils varying in texture and fertility but when they are grown on arid and semi-arid soils their productivity is very low due to the low fertility of these soils. Thus for attaining optimum legume productivity proper supply of essential nutrients is vital.

Drought stress severely reduces the nitrogen fixing process in legumes by decreasing nodulation in plants (Streeter, 2003). But in soybean, it was observed that leaves suffer more from water stress than nodules (Gonzalez et al., 1995). However, there are leguminous plant species or varieties which are well adapted to arid environmental conditions such as *Medicago sativa*, *Arachis hypogaea*, *Cyamposis tetragonoloba*, and *Melilotus* spp. In addition to these species, a drought-tolerant cultivar of *Phaseolus vulgaris* was identified (Ramos et al., 1999).

Nutrient deficiencies commonly observed in major legume producing areas are those of nitrogen (due to low rate of N fixation), P, S, Fe, Zn and B (Ali et al., 2002). Samarah et al. (2004) were of the view that proper nutrient management of legumes in drought stressed land improves the drought tolerance potential and plant productivity of legumes. The literature also indicates that nutrient use efficiency in plants is reduced under to low soil moisture conditions. However, for economical grain legume yield, cultivation of drought tolerant genotypes is vital (Baligar et al., 2001). Nutrient use efficiency can also be enhanced with proper supply of nutrients to crops grown under drought stress (Ali et al., 2002).

The chapter summarizes the role of nutrient management of soils with low moisture to attain optimum plant productivity from legumes.

9.2 Nitrogen

Legumes have an inherent ability to fix atmospheric nitrogen through symbiosis (Soon et al., 2004) but symbiotic N_2 fixation is highly sensitive to limited water conditions (Toker et al., 2007). Legumes such as *Medicago sativa*

(Meuriot et al., 2004), *Pisum sativum* (Soon et al., 2004), *Glycine max* (Kamal et al., 2003), *Arachis hypogaea* (Redfearn et al., 2001), the shrub legume *Adenocarpus decorticand* (Moro et al., 1992), *Vicia faba* (Guerin et al., 1990), *Vigna* sp. (Pararjasingham and Knievel, 1990) and *Aeschynomene* (Albrecht et al., 1981), exhibited a severe reduction in nitrogen fixation when subjected to water deficit conditions. Reduction in nitrogen fixation is due to a decrease in nodule formation and initiation (Zahran and Sprent, 1986; Ashraf et al., 2005).

Legumes are known to improve soil physical conditions by deriving substantial amount of N through biological nitrogen fixation (BNF). However, a starter dose of 10–15 kg N per ha is often recommended for most leguminous crops (Ramakrishna et al., 2000). In fields where the rhizobial population is low or water is limited, late-sown legumes respond to applications of N up to 40 kg N per ha. The application of N may not only be directly beneficial to the legumes but also could be useful for the succeeding crops. Nitrogen is one of the integral components of proteins, which are essential for healthy crop growth and optimum physiological development. Nitrogen is also needed to synthesize chlorophyll, an important pigment for photosynthesis. New leaves may contain up to 6% N. It is a very mobile nutrient because it moves from older to newer leaves. It is taken up throughout the growing season and is transported and stored in the leaves. In legumes, the N requirement

Table 9.1 Recommendations and effect of N application in improving growth, yield and other parameters of legumes under drought conditions

Legume species	Recommended Rate of N	Effect of N on plants	Reference
Pea (*Pisum sativum*)	1.1–1.3 g N m^2	Seed weight and N uptake increased under 90 mm rainfall	Soon et al. (2004)
Alfalfa (*Medicago sativa*)	2 mM (NH_4NO_3) as foliar spray	Improved growth, leaf area and N uptake under limited water supply conditions	Meuriot et al. (2004)
Alfalfa (*Medicago sativa*)	85 mg N kg^{-1} soil	Increased shoot, root, and crown growth and nutrient uptake under moisture stress environments	Barber et al. (1996)
Chickpea (*Cicer arietinum* L.)	20–45 kg N ha^{-1}	Increased yield and nutrient uptake under low soil moisture contents	Saeed et al. (2004) Walley et al. (2005)
Groundnut (*Arachis hypogaea*)	60–130 kg N ha^{-1} 110–220 kg N ha^{-1}	Increased yield and nutrient uptake in sandy soil environments.	Hafner et al. (1992) Redfearn et al. (2001)
Common bean (*Phaseolus vulgaris*)	2.64 g N L^{-1} as foliar spray	Improved the rate of photosynthesis drought conditions	Santos et al. (2006)
Faba Bean (*Vicia faba*)	9–36 kg N ha^{-1}	Improved yield under water stress in limited soil moisture conditions	Ghizaw et al. (2001)
Chickpea (*Cicer arietinum* L.)	50 mg N kg^{-1} of soil as NH_4NO_3	Improved plant growth and nutrient uptake	Gunes et al. (2006)

for pod development is partially met from N stored in the leaf canopy. So, proper supply of N is necessary for optimum growth and plant productivity under environmental adversaries. Hafner et al. (1992) found that application of 60 kg N ha^{-1} is beneficial to enhance shoot dry matter production but it was not found to be effective in increasing pod dry matter in groundnut (*Arachis hypogaea* L.). The same authors found that plants supplied with N were more drought tolerant than the control plants. In contrast to the above findings, Vadez and Sinclair (2001) reported that water deficit caused a considerable reduction in N_2-fixation and application of urea was not effective in mitigating the adverse effects of drought on N_2-fixation because most of urea applied was lost due to ammonia-generation during drought. Walley et al. (2005) also reported that seedbeds with low moisture are not conducive for nitrogen fixation in chickpea and recommended 30–45 kg N ha^{-1} for "desi" type chickpea cultivars to have an optimum crop production. Legume crops under drought conditions often show the symptoms of nitrogen deficiency so application of N is necessary to mitigate the adverse effects of drought on formation of nodules in the chickpea. Application of 20 kg N ha^{-1}, as a starter dose was effective in maintaining the plant vigour of chickpea under drought condition (Ahlawat et al., 2007). While Barber et al. (1996) found that 85 mg nitrate N kg^{-1} of soil was effective in re-growing of alfalfa. Recommendations regarding N application and its effect on improvement in growth, yield and other metabolic activities are summarized in Table 9.1.

9.3 Phosphorus

Legumes require a high amount of P for their optimum growth and productivity (Dodd and Orr, 1995) and are less tolerant to low P availability which is very common in soils with low moistures. Therefore, application of P is recommended to maximize plant productivity of legumes on soils experiencing water deficit conditions. Application of P was effective in increasing the dry matter yield in lablab (*Lablab purpureus*) but it was not effective in the case of mucuna (*Mucuna cochinchinensis*) (Carsky et al., 2001). In contrast to the above reports, Hafner et al. (1992) found that application of P fertilizer (16 kg P ha^{-1}) did not affect pod yield of groundnut (*Arachis hypogaea* L.). Ramakrishna et al. (2000) recommended 17–26 kg P ha^{-1} to increase seed yield of legumes under normal conditions and suggested higher rates of P fertilizer for soils encountering water deficit conditions.

Plants absorb P in the form of phosphate ion; a very low amount of organic P is also absorbed (Bucher, 2007). However, P ion in the form of solution undergoes several physicochemical changes which in most of the cases make it less available to plants (Genre et al., 2005). The physiochemical alterations involve immobilization or fixation reactions that are highly dependent on pH (Dodd and Orr, 1995). In the soils with low pH, aluminum and iron suppress the mobilization of P. In neutral and alkaline soils, calcium compounds react with P and reduce its availability to plants (Bucher, 2007). Soil organic matter also plays an important role in the absorption of P, because some organic compounds promote its adsorption while others compete with phosphate ions for adsorption sites in plants, resulting in less immobilization of phosphate ions (Santos et al., 2004). So the P fertilizers are highly soluble and available at the time of their application and P availability decreases with time. Because of this P fertilizers are applied before or at sowing time, and localized along the area that is exploited by the young roots (Forde and Lorenzo, 2001; López-Bucio

Table 9.2 Recommendations and effects of P application in improving growth, yield and other parameters of legumes under drought conditions

Legume species	Recommended rate of P	Effect of N on plants	References
Groundnut (*Arachis hypogaea*)	16 kg P ha^{-1}	Not effective in improving yield and nutrient uptake under water stress conditions	Hafner et al. (1992)
Guar (*Cyamopsis tetragonoloba*)	75–300 mg KH_2PO_4 kg^{-5} of soil	Improved water relation and chlorophyll contents under drought conditions	Shubhra et al. (2004)
Moth bean (*Vigna aconitifolia*)	40 kg P ha^{-1}	Improved drought tolerance potential, photosynthesis, starch, soluble protein and nitrate reductase activity under drought conditions	Garg et al. (2004)
Common bean (*Phaseolus vulgaris*)	10 g Pi L^{-1} as $NH_4H_2PO_4$ as foliar spray	Improved photosynthetic activity and water relations thereby improving drought tolerance	Santos et al. (2006)
Vicia faba	17.5–52.5 kg P ha^{-1} (banding amendment)	Improved yield, yield components and drought tolerance potential	Turk and Tawaha (2002)
Faba Bean (*Vicia faba* L.)	15–45 kg P_2 O_5 $faddan^{-1}$	Increased leaf and stem dry weight, yield and its components and NPK contents in seeds and straw and NPK uptake under drought conditions.	El Habbasha et al. (2007)
Faba bean (*Vicia faba)*	23–69 kg P_2O_5 ha^{-1}	Improved seed yield under water stress conditions	Ghizaw et al. (2001)
Chickpea (*Cicer arietinum* L.)	50 mg P kg^{-1} of soil	Improved Plant growth and nutrient uptake under low moisture availability conditions	Gunes et al. (2006)
Soybean (*Glycine max*)	30 mg P kg^{-1} soil	Alleviated the adverse effects of drought stress on plant growth and enhanced nutrient uptake under water stress conditions.	Jin et al. (2006)
Groundnut (*Arachis hypogaea.*)	30 and 60 kg P_2O_5/fad	Increased vegetative growth, yield and its components as well as seed quality under water stress conditions	Gobarah et al. (2006)

et al., 2003). Phosphorus levels should be maintained in the high range, because P is an important element for ATP, an energy currency in plants and animals (Bucher, 2007). Phosphorus also plays a major role in root growth and survival of newly established seedlings of plants (López-Bucio et al., 2003).

Available P for plants in soils can be improved with the acidification of the rhizosphere. Most plants acidify their rhizosphere, which in turn improves the solubility of P fractions. Generally, legumes like clover, alfalfa and faba beans cause acidity during the nitrogen fixing process which is reduced due to drought stress (Soon et al., 2004) as a result of which P availability to plants is reduced. However, application of nitrogen fertilizers enhances acidification of the rhizosphere (Soon et al., 2004). Some research findings suggest that under low soil moisture, legumes need N and P fertilizes to optimize their productivity (Carsky et al., 2001; Santos et al., 2006).

Phosphorus (P) fertilization improves tolerance to drought stress in many plants (Shubhra et al., 2004). Jin et al. (2006) examined the interactive effects of P nutrition and drought stress on accumulation and translocation of P in plants, seed yield, and protein concentration in soybean [*Glycine max* (L.) Merr.]. They found that drought stress reduced P translocation to the seed. However, addition of 30 mg P kg^{-1} of soil enhanced the concentration and accumulation of nitrogen (N) and P in shoots and seeds of the soybean cultivars under study. However, drought stress increased the concentration of N in shoot and protein in grains. The addition of P alleviated the effect of drought stress on plant growth, P accumulation, and grain yield in all the cultivars examined. Their results suggest that application of P fertilizers mitigated the adverse effects of drought stress at the reproductive stage, resulting in less yield losses and improved grain quality of soybean grown in P-deficient soils. Similarly, El Habbasha et al. (2007) reported that application of P increased the seed yield and yield components, and NPK uptake in faba bean grown in sandy soils (Table 9.2).

9.4 Potassium

Potassium plays a multitude of roles in plant metabolism (Mahajan and Tuteja, 2005). In addition it improves resistance to different abiotic stresses (Ashraf et al., 2003). Reduction in potassium uptake results in a reduced rate of photosynthesis, translocation of assimilates and enhanced rate of dark respiration (Fu and Luan, 1998; Kabir et al., 2004). However, application of potassium improves the rate of photosynthesis and plant productivity. Potassium fertilizer mitigates the adverse effects of water stress on legume plants (Jouany et al., 1996). Addition of external K alone or in combination with P, Ca and N can significantly increase plant growth and productivity under saline conditions (Idrees et al., 2004; Shirazi et al., 2005). Foliar application of potassium during vegetative growth is one of the potential means of enhancing plant growth and productivity. Potassium is essential in osmoregulation and has a positive impact on stomatal closure which plays a vital role in water stress tolerance (Ashraf et al., 2008). Moreover, it is involved in activating a wide range of enzyme systems which regulate photosynthesis, water use efficiency and movement, nitrogen uptake and protein building (Nguyen et al., 2002). In this regard, Thalooth et al. (1990) found that potassium application improves the water content in the leaves of broad beans and the plants showed great tolerance to drought stress. In another study Thalooth et al. (2006) found that foliar application of K was very effective in increasing the leaf area, number and weight of leaves plant^{-1} as well as number and weight of pods plant^{-1} in mungbean. Basole et al. (2003) recorded improvement in growth parameters in soybean by the foliar application of K. Jouany et al. (1996) also found that K fertilization improved the crop yield in calcareous soils. Application of K and farmyard manure improved the seed yield and water use efficiency of soybean (Hati et al., 2006). Tawfik (2008) also reported that soil amendment with K is very effective in improving the WUE of mungbean under water limited conditions. It was observed that transpiration rate and stomatal conductance decreased significantly due to water deficit (Ashraf and Iram, 2005), as

Table 9.3 Recommendations and effect of K application in improving growth, yield and other parameters of legumes under drought conditions

Legume Species	Recommended rate of K	Effect of N on plants	References
Vicia faba and *P. vulgaris*	0.8 or 0.3 mmol K L^{-1}	Improved nodulation and N_2 fixation under water stress conditions	Sangakkara et al. (1996)
Soybean [*Glycine max* (L.) Merr.]	Broadcast application 140–560 kg K ha^{-1}	Grain yield increased under low soil moisture availability	Nelson et al. (2005)
	Foliar application 9, 18, and 36 kg K ha^{-1}		
Mungbean (*Vigna radiata)*	Foliar application of 2.0% KNO_3	Increased all growth parameters meters under limited water availability	Thalooth et al. (2006)
Mungbean (*Vigna radiata*)	50 g potassium/30 kg of soil as K-biofertilizer	Mitigated the effect of drought stress on plant growth	Tawfik (2008)
Chickpea (*Cicer arietinum*)	62.5 mg K kg^{-1} of soil as (KH_2PO_4)	Improved growth rate and nutrient uptake under water stress conditions	Gunes et al. (2006)
Groundnut (*Arachis hypogaea.*)	48 kg K_2O/fad	Increased oil and protein content in seeds and overall yield	Darwish et al. (2002)
Vicia faba and *P. vulgaris*	Presence of 0.8 or 0.3 mM K	Improved the nodulation under low water regimen (25% depletion)	Sangakkara et al. (1996)

a result of closure of stomata to prevent the transpirational water loss (Mansfield and Atkinson, 1990). However, application of potassium is effective in improving the rate of photosynthesis by regulating stomatal conductance and transpiration (Tawfik, 2008). Similarly, plants fertilized with K maintained the highest content of photosynthetic pigments under stress conditions (Ali and Moswafy, 2003; Garg et al., 2004). N and K contents were high in leaves of stressed mungbean plants fertilized with K under water stress conditions (Nandwal et al., 1998). Sangakkara et al. (1996) found that application of K alleviated the adverse effects of water shortage on symbiotic N_2 fixation of *Vica faba* and *Phaseolus vulgaris*. The presence of 0.8 or 0.3 mmol K L^{-1} allowed nodulation and subsequent nitrogen fixation in *V. faba* and *P. vulgaris* under water stress conditions. Sangakkara et al. (2001) reported that potassium fertilizer application mitigates the adverse effects of water stress and increases the growth and seed yield in mungbean (*Vigna radiata* L. Wilczek) and cowpea (*Vigna unguiculata* L. Walp). Darwish et al. (2002) found that application of 48 kg K_2O /fad (fad.=4,200 m^2) combined with spraying zinc (1,000 mg L^{-1} zinc sulphate) gave the highest seed and oil yields per fad and protein percentage in groundnut grown under osmotic stress conditions (Table 9.3).

9.5 Sulfur

Sulfur (S) being an essential major element, is involved in multiple metabolic processes including the synthesis of fatty acids and proteins. It takes part in the synthesis of some important S-containing amino acids such as cystine, methionine and thiamine, thereby improving the quality of proteins (Havlin et al., 1999). Generally, soils of arid regions are deficient in S. The deficiency of S may also result due to excessive use of chemical fertilizers, intensive cultivation of exhausting crops like rice, higher cropping intensity and limited supply of organic matter/fertilizers. Dubey et al. (1997) found that application of sulphur to lentil was effective in enhancing the number of branches per plant, capsules plant^{-1}, number of seeds per capsule and 1,000-grain weight of the crop. In groundnut, application of sulphur improved the number of branches and number of pods plant^{-1}, plant height and 100 seed weight of groundnut (Chaubey et al., 2000). Sarker et al. (2002) studied the influence of S and B fertilizers on yield, quality and nutrient uptake in soybean using five levels of S and B (0, 10, 20, 30 and 50 kg S ha^{-1} and 0, 0.5, 1.0, 2.0 and 4.0 kg B ha^{-1}). The results showed that protein and oil contents of soybean significantly increased with the increase in both B and S levels. In another study, pod length of soybean was improved by the application of S (Hemantarajan and Trivedi, 1997). Gupta et al. (2003) found deficiency of S in arid soils and recommended foliar application of 1% H_2SO_4 or 25 kg ha^{-1} gypsum as soil amendment to overcome S deficiency and to improve the growth and yield of mungbean (*Vigna radiata* L.) under arid environmental conditions. However, high rates of S application are toxic, which can substantially reduce crop productivity (Tripathy et al., 1999).

9.6 Calcium and Magnesium

Calcium plays a key role in maintaining cell integrity and membrane permeability. It speeds up germination and growth activities as well as the enzymes involved in mitosis, cell division and elongation (White and Broadley, 2003). It also has an active role in protein synthesis processes. Some workers also reported that it is involved in the transfer of carbohydrates synthesized during photosynthesis (Montoro et al., 1995). Calcium (Ca) can also detoxify the toxic actions of heavy metals in plants (Hepler and Wayne, 1985). Therefore, optimum concentration of Ca in plants is necessary for normal growth and metabolic activities of plants to maintain proper growth rate and productivity under water deficit conditions. Usually, drought prone areas in arid regions are also salt-affected where Ca^{2+} can counteract the excess uptake of Na^{+} in plants (Zhu, 2002; 2003). Generally, calcium is able to counteract toxicity problems caused by a number of other minerals by improving the balance of nutrients in the soil. Calcium deficiency can be seen as the death of crop apical meristems, root tips and even buds as well as reduction in plant size, and poor yield or forage production. While conducting a series of experiments, Amede and Schubert, (2003) found that drought-induced solute accumulation can improve drought resistance in grain legumes such as common bean (*Phaseolus vulgaris*), faba bean (*Vicia faba*), pea (*Pisum sativum*), and chickpea (*Cicer arietinum*). Reduction in growth and yield was observed in all the grain legumes. However, chickpea and common bean grown under drought had relatively higher yields which may be due to the maintenance of tissue trugor. Turgor maintenance resulted due to decrease in osmotic potential. Calcium in inorganic form contributes up to 19% of the pool in osmotic adjustment and thus may be important in turgor maintenance during drought stress.

Magnesium is a mobile element in the plant and its deficiency cannot be easily corrected. In the case of Mg deficiency, plants may show chlorosis, yellowing or necrotic spots. These spots are very commonly found under water deficit conditions, because Mg availability is closely linked with proper water supply. Foliar application of magnesium is recommended to reduce the crop yield losses due to drought stress (Thalooth et al., 2006). Magnesium has several physiological and biochemical roles such as in chlorophyll formation, activation of enzymes, synthesis of proteins, carbohydrate metabolism and energy transfer (Shaul 2002; Cakmaka and Kirkby, 2008). It also acts as a catalyst in many oxidation-reduction reactions in the plant tissues, as well as it may increase crop resistance to drought. Foliar application with magnesium sulphate increases net assimilation rates, seed yield and crude protein content of faba bean growing under adverse environmental conditions (Saad and El-Kholy, 2000). Thomas et al. (2004) reported that a water deficit imposed at the vegetative, flowering or pod formation growth stages, significantly reduced growth, yield and yield components as well as contents of photosynthetic pigments. However, foliar application of Zn, K or Mg had a beneficial effect on growth, yield and yield components but the effect of K application was more than that of the two other nutrients in mungbean (Table 9.4).

Table 9.4 Recommendations and effects of S, Ca and Mg application in improving growth, yield and other parameters of legumes under drought conditions

Legume Species	Recommended rate of S or Ca or Mg	Effect of N on plants	References
Mungbean (*Vigna radiata*)	50 ppm Mg as foliar application	Improved yield and yield components	Thalooth et al. (2006)
Mungbean (*Vigna radiata* L.)	H_2SO_4 at 0.1% as foliar and S (gypsum) at 25 kg/ha (soil) were also applied	Improved the yield and growth in arid environmental conditions	Gupta et al. (2003).
Soybean (*Glycine max*)	30 kg S ha^{-1}	Improved protein and oil contents	Sarker et al. (2002)
Chickpea (*Cicer arietinum* L.)	20–30 kg S ha^{-1}	Improved the growth and yield	Ahlawat et al. (2007)

9.7 Micronutrients

The involvement of micronutrients in different physiological and biochemical activities of the legume plants is well documented. Mostly positive correlations exist between micronutrient supply and crop growth and productivity (Baligar et al., 2001; Samarah et al., 2004). Use of micronutrients like zinc, iron, boron, copper, manganese and molybdenum has now become a common practice to enhance crop yields under normal as well as adverse environmental conditions. Plants deficient in micronutrients may become susceptible to diseases and abiotic stresses (Ali et al., 2002). Soils of arid and semi-arid regions are often deficient in micronutrients particularly zinc, iron, boron and copper. Therefore, applications of micronutrients could play an important role in improving the stress tolerance potential indirectly because micronutrient-deficient plants not only exhibit an impaired defense response but also a number of metabolic phenomena are disturbed (Gunes et al., 2006). As an example in much of the dry areas of Australia fixation is limited by Mo deficiency. Thus, soil or foliar applications of micronutrients are recommended to achieve optimum crop productivity from soils low in moisture and micronutrient content.

9.8 Conclusions

Reviewing the above literature it can be concluded that application of N, P, K through the soil or as a foliar spray, is necessary to obtain economical seed yields of legumes from soils with low moisture contents. Similarly, many drought prone areas are also salt-affected, so amendment of Ca and Mg is beneficial in enhancing the crop seed yield. Soils of arid lands are often deficient in S as a result of which deficiency of some essential proteins and susceptibility to diseases increase. Therefore, proper supply of S is necessary to achieve the maximum legume yield from drought prone lands. However, the literature on methods regarding fertilizer application and crop stages at which nutrient amendment is necessary, is scanty. Well planned research is required to select the proper method of nutrient application through which maximum fertilizer use efficiency can be achieved in legumes under limited soil moisture availability conditions. Similarly investigations are also required to work out the crop growth stages for the application of different nutrients, where yield losses should be minimum and fertilizer use efficiency should be maximum.

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Chapter 10
Salinity and Drought Management in Legume Crops

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Abbreviations

%	Percent
<	Lesser than
>	More than
**	Highly significant
al.	Allies
B	Boron
Ca	Calcium
$Ca(HCO_3)_2$	Calcium bi carbonate
$CaCO_3$	Calcium carbonate
$CaSO_4$	Calcium sulphate
Cd	Cadmium
CEC	Cation exchange capacity
Cl	Chloride
CO_3	Carbonates
Cr	Chromium
$d\ Sm^{-1}$	Desi siemens per meter
Ddw	Depth of drainage Water
Diw	Depth of irrigation Water
EC_{dw}	Electrical conductivity of drainage water
EC_{iw}	Electrical conductivity of irrigation water
ECa	EC threshold
ECe	Electrical conductivity of saturated soil extract
ESP	Exchangeable sodium percentage
FAO	Food and agriculture organization
$g\ L^{-1}$	Gram per liter
H_2SO_4	Sulphuric acid
ha	Hectare

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HCO_3	Bicarbonate
K	Potasium
Lab	Laboratory
Li	Lithium
LR	Leaching requirement
mg L^{-1}	Milligram per liter
Mg	Magnesium
mm	Millimeter
$mmol_cL^{-1}$	Millimole charge per liter
Na	Sodium
NaCl	Sodium chloride
P	Phosphorus
Pb	Lead
pH	Negative log of hydrogen ion activity
PPM	Parts per million
r	Correlation coefficient
RSC	Residual sodium carbonate
SAR	Sodium adsorption ratio
SAR_{iw}	Sodium adsorption ratio of irrigation water
Se	Selenium
SO_4	Sulphate
UNESCO	United Nations Education, Social and Cultural Organization
μ S m^{-1}	Micro siemens per meter
US	United States
USA	United States of America
X	Clay exchange complex
Zn	Zinc

10.1 Introduction

With the publication of the IPCC 4th report (2007) global climatic changes are now almost accepted fact by most of the world's governments and scientists. The existence of effects at present is supported by evidence of observations and recent events like cyclones, floods, excessive rainfall and droughts and melting of ice. The increasing surface temperature and evapo-transpiration will influence strongly the water cycle of many regions and may result in either more or lesser precipitation, desiccation and continuous droughts due to changes in already varying patterns of regional climates. Changing phenomenon of snowfall and ice melting in higher latitudes and mountainous regions may increase the likelihood of larger springtime floods and runoff. Some scenarios indicate that dry regions of the world would become drier. It may become more difficult for water scarce countries to cope with natural conditions with even lesser water than what is now available (Bino, 2008). Surface water scarcity will increase pressure on utilization of groundwater, the major part of which is not of safe and usable quality. All these expected changes are closely related to surface salinity and sodicity because high temperature, low rainfall and excessive evaporation favor salt concentration and salinity build up. Thus, secondary salinity can be enhanced tremendously that will affect crop growth and yields negatively. Most of the legumes are sensitive to salts. Cool season grain legumes are often described as having very high sensitivity to salinity stress. Sodicity, in particular, impairs physical properties of soil that also creates an inverse relationship with plant growth and resultant yields. Therefore, special management practices have to be adopted for coping with the global climatic changes, especially increased soil and water salinity/sodicity. More precise and accurate predictions of climate, especially rainfall will be important to face hard and critical climatic changes (Anonymous, 2009).

10.2 Soil Salinity and Sodicity

Soil salinity and sodicity are global problems and are included in major threats to the present world's agriculture. Based on the FAO/UNESCO Soil Map of the World, the total area of saline soils is 397 million hectare while that of sodic soils is 434 million ha. Out of the current 230 million ha of irrigated land, 45 million ha are salt-affected soils (19.5%) and of the almost 1,500 million ha of dry land agriculture, 32 million ha are salt-affected (2.1%), to varying degrees by human-induced processes (Oldeman et al., 1991). Primary salinity resulted from natural geological cycles such as migration and redistribution of salts. Also deposition of salts during processes of weathering and soil formation by surface and groundwater resulted in salinization. Secondary salinization is caused by soil and water mismanagement through improper irrigation, un-leveling, leaving the lands uncultivated and poor drainage.

The term soil salinity is used in dual senses. In its true sense it denotes a particular condition of a soil when its soluble salts exceed a specified limit (4 dS m^{-1}). In a broader meaning, soil salinity indicates all problems and conditions of soil related to salts including sodicity as well. However, technically salinity and sodicity are two separately distinguishable stresses with well defined definitions and limits. Soil sodicity indicates excess of Na on soil exchange sites. Under sodic conditions, the physical properties (bulk density, porosity, permeability, water infiltration rate and hydraulic conductivity) of the soil are deteriorated. Problems like hardening of soil, closure of macro pores, restricted penetration of air, less infiltration of water, more runoff, more evaporation, lesser availability of water to plants, standing of water on soil surface for longer periods, less root development and proliferation, decreased workability emerge and consequently very low yields are obtained from a soil in degraded physical conditions. Thus, soil and water salinity, sodicity, physical properties and crop yields are interrelated and inter-dependent. These relationships are important to understand for appropriate management, especially under the changing climate.

Salt affected soils can be classified in many ways like; natural occurrence, genesis, original soil taxonomical classes or manmade grouping. However, identification on the basis of dominating salts (soluble salts and exchangeable Na) present in a soil is now globally accepted.

10.2.1 Saline Soils

These soils have concentration of soluble salts that adversely affects the growth of most of plants. The general limit specified for classification is $EC_e > 4$ dS m^{-1} (Soil Science Society of America, 2008) while pH and SAR are less than 8.5 and 13 $(mmol_cL^{-1})^{1/2}$ respectively. Soil salinity is usually measured through electrical conductivity of the extract of saturated paste (EC_e), although suspensions of higher soil to water ratios (1:1, 1:2 or 1:5) are also used. However, the critical limit of EC 4.0 dS m^{-1} is just arbitrary and wide variations can be observed among different plants and crop varieties as well as under variable soil and climatic conditions. Structure and other physical conditions of these soils are not impaired. Therefore, these soils remain permeable.

10.2.2 Sodic Soils

Sodic or black alkali soils have EC_e lesser than 4 dSm^{-1} but ESP (Exchangeable Sodium Percentage) more than 15 or SAR (Sodium Adsorption Ratio) more than 13 $(mol_cL^{-1})^{1/2}$ while pH is more than 8.5. Soil sodicity can be measured by determination of exchangeable cations and calculating Exchangeable Sodium Percentage (ESP) but Sodium Adsorption Ratio (SAR) can also denote sodicity because a very close relationship was found between the two parameters (US Salinity Laboratory Staff, 1954). The parameter of SAR can be determined from analysis of saturation paste extract using Na and Ca + Mg values. The organic matter present in the soil gets dissolved and gives dark brown or black color to these soils. The soil structure deteriorates and physical characteristics are impaired. Rehabilitation of such soils becomes difficult and needs an amendment application.

10.2.3 Saline Sodic Soils

Values of EC_e and SAR of these soils are more than 4 dS m^{-1} and 13 $(mmol_cL^{-1})^{1/2}$ respectively while pH may or may not be more than 8.5 depending upon relative magnitudes of soluble salts (EC_e) and exchangeable sodium (measured through ESP or SAR). Thus, these soils have the characteristics of both saline and sodic soils. Initially, these soils have good permeability but physical conditions may deteriorate gradually when rainfall or irrigation water leach down soluble salts and sodium becomes dominant and consequently physical characteristics become closer to a sodic soil.

10.3 Water Salinity and Sodicity

Although irrigation of crops can achieve higher yields but is also coupled with variety of associated problems, like waterlogging from seepage, soil salinization and sodication, specific ion effects; especially from boron, carbonates and bicarbonates, sodium and chlorides, impairment of soil physical properties and related health hazards. When the irrigation water is coming from rivers and canals, it is mostly problem free though not always as indicated in the Australian Murray region (Tee et al., 2003) but groundwater and untreated industrial effluents cause manifold problems to soils and plants. Enhanced utilization of such waters has become major sources of salts addition and accumulation even in fertile soils during recent decades. Like soils, water can be saline, sodic or saline sodic as well.

At least four hazards are associated with use of saline waters in particular. These are; loss in soil productivity due to salinity, sodicity or waterlogging, pollution of associated water resources with salts and toxicants by drainage, damage to the prevailing ecosystems and increased risk to public health resulting from water pollution and waterlogging (FAO, 1992). Consistent usage of salty water for irrigation purpose has emerged as the biggest cause of secondary salinization in arid and semi arid regions. In studies of Hussain et al. (2002b) soil EC and SAR were tremendously increased (Figs. 10.1 and 10.2) in three years (after harvesting of six crops) when saline sodic water ($EC_{iw} = 1.43$ dS m^{-1}, SAR 6.5 and RSC 5.7 $mmol_c\ L^{-1}$) was used continuously that resulted in conversion of normal soil into saline sodic.

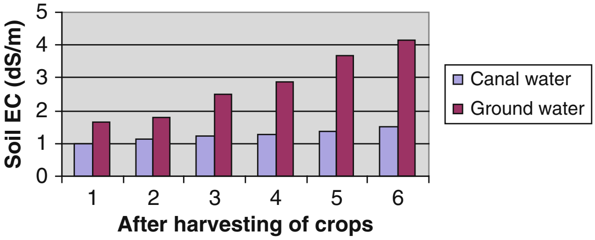

Fig. 10.1 Effect of groundwater on soil EC [Source: Hussain et al. (2002b)]

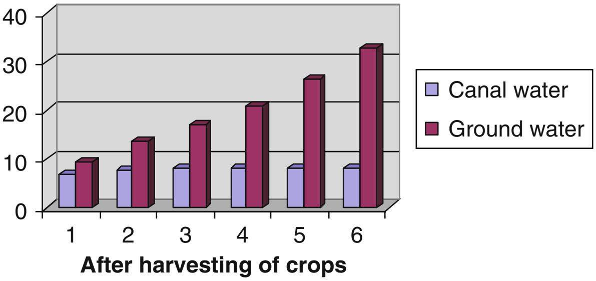

Fig. 10.2 Effect of groundwater on soil SAR [Source: Hussain et al. (2002b)]

Fig. 10.3 Effect of groundwater on soil hydraulic conductivity [Source: Hussain et al. (2002b)]

The hydraulic conductivity was also reduced significantly (Fig. 10.3). Most of the legumes are highly sensitive to saline or sodic waters and are negatively affected when irrigated with salty waters. For example, in general, threshold of water salinity for beans has been reported as 0.7 dS m^{-1} whereas 50% reduction in yield was recorded at 2.4 dS m^{-1}(Ayers and Westcot, 1985).

10.4 Salinity Effect on Transpiration, Photosynthesis, Plant Growth and Crop Yields

Soil and water salinity stress has threefold effects on the plant: reducing water potential, causing ion imbalance and disturbing availability of nutrient ions. Terms like physiological unavailability of water or physiological drought are used when the plants become unable to take water from the soil due to its increased osmotic potential, although water may physically be present in sufficient quantities. Such alteration in water status leads to loss of turgor pressure, closure of stomata, significant reductions in transpiration, photosynthesis, protein synthesis, and energy and lipid metabolism. Consequently, many physiological and morphological disorders in plants may emerge. Ion uptake and transportation by vascular tissues (xylem and phloem) can be retarded due to impaired water flow within the plants. The energy requirements are increased due to more utilization in osmoregulation to save the plants from stress damage. The final consequences are growth reduction and limitation of plant productivity. Growth suppression is directly related to total concentration of soluble salts or osmotic potential of soil water. The detrimental effects are observed at the whole-plant level.

Suppression of growth occurs in all plants, but their tolerance levels, rates of growth reduction and lethal concentrations of salt vary widely among plants. Proline accumulation in plants may be a symptom of stress in less salinity-tolerant species and may play multiple roles in plant stress tolerance (Alia et al., 1995; Yoshiba et al., 1997; Hayashi and Murata, 1998; Yeo, 1999; Sanchez et al., 1998; Munus, 2002; Ramoliya et al., 2004; Flowers, 2004; Sanchez-Blanco et al., 2004; Parida and Das, 2005; Benlloch-Gonzales et al., 2005; Rabie and Almadini, 2005; Ghadiri et al., 2005).

10.5 Salinity and Global Climatic Changes

Soil and water salinity are the problems of arid and semi arid regions because these are directly associated with levels of precipitation and temperature. More rainfall causes dissolution of salts that are leached down the soil profile and subsequently drain horizontally into the natural drainage system. These processes occur during weathering of minerals of the parent material and soil genesis. But dissolution and leaching processes remain incomplete when the rainfall is insufficient, as is the case in arid and semiarid regions. The salts generated during soil formation or subsequent weathering or added through irrigations or runoff remain in the profile and come to the surface or subsurface with the capillary movement of soil water under dry conditions coupled with high temperature. The water evaporates and leaves dissolved salts on the surface or just underneath. When such a process continues for longer periods the consequence is salinization (accumulation of salts) followed by sodication (Substitution of Ca + Mg by sodium on the clay complex). Irrigation or rainfall temporarily revert these processes but prolonged dry periods and high temperatures persisting in arid climates prove favorable to salinization. Thus, relatively small mismanagement of soil and water as well as cultural practices like fallowing (leaving the lands uncultivated) or unleveled conditions may become a big factor in creating secondary salinity. Data of Hussain et al. (2002a) presented in Table 10.1 indicate a close relationship between salinity/sodicity parameters (Soil EC and SAR) and rainfall. There was salt accumulation during pre monsoon periods in the cases of lesser or scanty rainfalls but the accumulated salts were washed away during intensive monsoon rainfall, especially that of the year 2001.

Climatologists claim that arid and semi arid regions may become drier and environmental temperatures of hot regions may increase due to global climatic changes. These two important factors are closely related to salinity and sodicity. Evaporation may tremendously increase under high temperature and less relative humidity. Consequently, net capillary movement of water will remain upwards during major part of the year. Thus, soil and water salinity/sodicity problems are expected to enhance under changing environments of the future. The data and observed evidences of the last two decades support this hypothesis. Despite all best possible

Table 10.1 Relationship of rainfall, soil EC and SAR

Seasons	Rainfall (mm)	Soil EC (dS m^{-1})	Soil SAR ($mol_c\ L^{-1})^{1/2}$
Pre monsoon 2000	11	6.8	75
Post monsoon 2000	123	4.9	72
Pre monsoon 2001	121	17.8	200
Post monsoon 2001	500	6.1	103

(Hussain et al., 2002a)

efforts and improved technologies, it has not been possible by the global community to reduce sanity and sodicity menaces.

10.6 Legumes and Salinity/Sodicity

Salinity decreases plant growth and yield, depending upon the plant species, salinity levels, and ionic composition of the salts. Increase in the salinity of soils or use of saline water for irrigation result in decreased productivity of most crop plants and leads to marked changes in the growth pattern of plants. Large differences are found between plant species under saline environment. For example, with 200 mmol NaCl a salt-tolerant species such as sugar beet might have a reduction of only 20% in dry weight, a moderately tolerant species such as cotton might indicate 60% reduction, and sensitive leguminous species such as soybean might be dead at the same level (Greenway and Munns, 1980; Cordovilla, 1994; Delgado et al., 1994; Tate, 1995). Because most of the legumes have no salt tolerance mechanisms like osmoregulization or ion selectivity therefore suffer more. Similar to other plants, legumes may be affected through; osmotic impact of salts, specific ion toxicity, nutritional imbalances and allied effects on different plant parts. Most legumes may suffer due to restricted long distance transport of nutrients and metabolic processes like, transpiration, photosynthesis, respiration, energy transformations and excretion of toxicants under excessive salt conditions.

The dominant ions in saline water and soils are Na^+ and Cl^-. Excess Na^+ often harms non-halophytes by displacing Ca^{2+} from root membranes and thus changes their integrity and normal functioning (Cramer et al., 1985). Excessive concentration of salts under saline conditions and drastic shifts in soil pH may affect the conversion of ions into soluble forms. Consequently, ions like Na, Cl, B, Li, Se, Cd, Cr and Pb may have toxic effects on legumes when their concentration within the plants exceeds a specific level. These effects may appear as improper functioning or death of cells and tissues, or suppressing the uptake of other essential ions. The growth is retarded at lower concentrations of such ions while mortality of legumes may occur when the concentration of toxic ions are very high and beyond the tolerable levels. Data presented in Table 10.3 indicted that threshold of Cl ion in cool season legumes, especially beans is very low (10–15 mol m^{-3}) and negative effects may appear with relatively lesser concentrations of this ion as compared with other plants. Similarly, most of the legumes are grouped in sensitive class with respect to effects of Na ion (Table 10.4).

10.6.1 Nutritional Imbalances in Legumes Under Salinity

Soil infertility in arid zones is often due to the presence of large quantities of salts. Imbalanced plant nutrition is an indirect effect of salinity and sodicity in contrast to direct osmotic and specific ion effects. Soil and water salinity and sodicity bring drastic changes in availability and uptake of many plant nutrients. The absorption and passive uptake of ions like N, K, Ca, Mg, P and Zn may decrease and plants can suffer scarcity of required nutrients while concentrations of Na, B, CO_3, HCO_3, Cl and SO_4 may increase to excessive limits. Thus, the plants may suffer simultaneously for want of certain essential nutrients or toxicities of others due to higher concentrations. Legume plants may be special victims of this phenomenon because these are devoid of any specially developed mechanisms to face the saline environment.

Experimental evidence from previous studies indicated that increased treatment of NaCl induced significant increase in Na^+ and decrease in K^+, Mg^{2+} and Ca^{2+} levels in shoot system of faba bean plants. High salt (NaCl) uptake competes with uptake of other nutrient ions, especially K^+, leading to K^+ and other ion deficiencies. Increasing salt concentrations may have a detrimental effect on soil microbial populations as well, either due to direct toxicity or through osmotic stress. Therefore, bacterial nitrogen fixation (NBF) in legumes may decrease under salinity stress. The activities of nitrogenase and phosphates enzymes (acid and alkaline) were significantly reduced by raising salinity in faba bean (Khan, 2001; Ferreira et al., 2001; Rao and Tak, 2002; Yano-Melo et al., 2003; Parida et al., 2004; Zandavalli et al., 2004; Rabie et al., 2005).

10.6.2 Root Development of Legumes Under Salinity Stress

Roots are the first plant part affected by increased salt concentration in the rhizosphere. These are in direct contact with salts and the root radical starts suffering right from germination. Roots remain exposed to the salt stress throughout the life cycle of the plant. The roots of legumes which are devoid of any tolerance mechanism may lose growth, proliferation and bearing of root hairs. There may be root mortality in acute cases either for want of water and nutrient uptake or toxic ions, and extreme hardening of soil. Roots may also suffer due to restricted respiration under less aeration, a consequence of closure of macro pores, soil dispersion and temporary or prolonged waterlogging. Significantly reduced fresh and dry mass of roots of different legumes was recorded with increasing levels of salinity up to 16 dS m^{-1}. The nodulation and symbiotic nitrogen fixation was suppressed significantly or even lost totally. Salinity inhibited nitrogen fixation by reducing nodulation, mineral nitrogen level, protein content and nitrogenase activity in faba bean plants. (Soussi et al., 1999; Serraz et al., 2001; Parida, Das, 2005; Rahman, 2008).

10.7 Salt Tolerance in Legumes

Salt tolerance in plants is a complex phenomenon that involves morphological and developmental changes as well as physiological and biochemical processes. It is a complex; quantitative and genetic character controlled by many genes and can be measured in different ways. Plant salt tolerance is generally inherent ability of the plant to withstand the effects of high salts in the root zone or on the plant's surfaces without a significant adverse effect. Salt resistance is another term that is often used for this phenomenon. Although some have tried to differentiate the two terms (Levitt, 1972), these are mostly used interchangeably. In an agronomic context, salt tolerance is described as a complex function of yield decline across a range of salt concentrations (Maas and Hoffman, 1977; Van Genuchten and Hoffman, 1984). Using a simple convention, salt tolerance can be measured on the basis of two parameters: the EC threshold (ECa), the salinity that is expected to cause the initial significant reduction in the maximum expected yield and the slope. Slope (S) is simply the percentage of yield expected to be reduced for each unit of added salinity above the threshold value. Relative yield (Y) at any salinity level (ECe) exceeding ECa can be calculated as

$$Y = 100 - S(ECe - ECa) \quad \text{where } ECe > ECa$$

As with most cultivated crops, the salinity response of legumes varies greatly and depends on factors like climates, soil properties, and the stage of growth. While most crop legumes are sensitive to salinity stress a large variability of salt tolerance also exists among them. Some legumes, e.g., *Vicia faba*, *Phaseolus vulgaris*, and *Glycine max*, are more salt tolerant than others, e.g., *Pisum sativum*. It has been reported that some *Vicia faba* tolerant lines sustained nitrogen fixation under saline conditions. Tree legumes, such as *Prosopis, Acacia* and *Medicago sativa* are salt tolerant (Abdel-Wahab and Zabran, 1981; 1983; Cordovilla et al., 1995a, b, c; Fagg and Stewatt, 1994; Zhang et al., 1991).

Studies using three attributes; shoot dry weight, plant height, and visual symptoms of salinity toxicity to determine salt tolerance of 309 accessions of lentil (*Lens culinaris* Medik.) indicted that 237 of the 309 screened accessions were significantly affected by 6 dS m^{-1} NaCl. Australian cultivars generally had low tolerance to NaCl. Only one accession that performed well in all three attributes was LG128 (ILL3534) from India (Meher et al., 2003). Selected salt tolerance data from different studies on cool season legumes have been presented in Tables 10.2, 10.3, 10.4 and 10.5. These data suggest that cool season cereal legumes are classified as sensitive (S) to moderately sensitive (MS) with very low threshold (1.0–3.4 dS m^{-1} even below the critical level of 4 dS m^{-1} used for classification of saline soils and high slope (percent decrease of yield/growth) varying from 9.6 to 19.0. These legumes are also sensitive to sodicity and Cl ions at very low levels. Studies on soybeans, chickpeas, peas and faba-bean (Elsheikh and Wood, 1990; Delgado et al., 1994; Elsheikh and Wood, 1995) showed reduced shoot growth in these plants when treated with NaCl concentrations (0.05 and 0.1 mol L^{-1}). This reduced shoot growth was based on reduction in nodule number and mass, percentage of nitrogen, and dry tissue mass. In *Phaseolus vulgaris*, concentrations 0.05 mol L^{-1} NaCl caused stunted growth from a salt-induced reduction in photosynthates (Brugnoli and Lauteri, 1991).

Table 10.2 Salt tolerance of cool season legumes

Crops		Salt tolerance parameters			
Common name	Botanical name	Threshold (EC_e) dS m^{-1}	Slope % per dS m^{-1}	Rating	References
Chickpea	*Cicer arietinum*	–	–	MS	Manchanda and Sharma (1989); Ram et al. (1989)
Broad bean	*Vicia faba*	1.6	9.6	MS	Ayers and Eberhard (1960)
Milk vetch	*Astragalus cicer*	–	–	MS	USSL Staff (1954)
Vetch common	*Vicia angustifolia*	3.0	11	MS	Ravikovitch and Porath, 1967
Bean, common	*Phaseolus vulgaris*	1.0	19	S	Bernstein and Ayers (1949); Hoffman and Rawlins, (1970); Nieman and Bernstein (1959); Osawa (1965)
Gram black	*Vigna mungo*	–	–	S	Keating and Fisher, 1985
Peas	*Pisum sativum*	3.4	10.6	MS	Cerda et al. (1982)

(FAO, 1992). S, sensitive; MS, moderately sensitive.
Note: These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending upon climate, soil conditions, cultural practices and crop varieties.

Table 10.3 Chloride tolerance of cool season legumes

Legumes	Threshold of Cl ion (mol m^{-3})	Percent decrease in yield at Cl concentration above threshold (per mol m^{-3})
Bean	10	1.0
Broad bean	15	1.0
Vetch, common	30	1.1
Cowpeas	50	1.2

(Maas, 1990)

Table 10.4 Grouping of legumes for relative tolerance to sodicity (ESP)

Sensitive (ESP < 15)	Semi tolerant (ESP 15–40)	Tolerant (ESP > 40)
Green beans, Peas, Mung bean, Lentil, Groundnut, Gram and Cowpeas	Clovers Berseem	Alfalfa Sesbania

(Ghafoor et al., 2004)

Table 10.5 Sodicity tolerance of cool season legumes

Legumes	Botanical name	Original soil ESP	Slope (%)	ESP for 50% yield
Cow peas	*Hordium vulgare*	13.5	3.5	22.3
Gram	*Cicer arietinum*	7.7	5.0	17.7
Lentil	*Lens esculentum*	4.9	5.5	14.0
Lin seed	*Linum sitatissnum*	13.3	2.3	25.0
Peas	*Pisum Sativum*	7.7	4.1	19.9

(Gupta and Sharma, 1990)

10.8 Drought Management Techniques with Respect to Salinity, Sodicity and Brackish Water Irrigation

To cope with future consequences like aggravation of salinity/sodicity, enhanced use of brackish water and deterioration of soil physical properties, special management techniques are the only alternative to avoid worsening of situation.

10.8.1 Improved Hydraulic Techniques

Less availability of water will remain as the major and permanent constraint of crop production in arid and semiarid regions. It has to be tackled through appropriate, timely, effective, economic and easily practicable techniques of hydraulic management.

10.8.1.1 Leaching of Salts

Salt accumulation, salinization and sodication are the ultimate results of aridity, drought, high temperature and supplemental irrigations with brackish water but concentration of salts in rhyzosphere must remain within tolerance potential of legume crops to be grown otherwise significant reduction in growth and yield may occur. Therefore, accumulated salts must necessarily be leached down either through rainfall or deep and continuous irrigations with good quality water. When crops are irrigated with saline water but monsoon rains are effectively harvested the accumulated salts can be leached down fully or partially depending upon intensity of rainfall. In some of investigations, the surface salinity build-up (ECe and ESP) during an irrigation cycle was taken care of by one above average yearly rainfall or two sub-seasonal rainy seasons, especially monsoon rains (Dhir, 1977; Jain, 1981). Rains could convert or keep 40 cm soil surface as non-saline. For this purpose, the field boundaries should be kept strong and fallow plots need to be plowed to control water runoff and increase infiltration during the rainy season.

When irrigation with brackish water is a continuous practice then extra water over that used by the crops has to be utilized for preventing salt accumulation and keeping the flow of water going into lower soil depths so that the rooting zone of the soil remains salt free or within tolerable limits of the crops under cultivation.

The additional water is called leaching water (Leaching fraction; LF or Leaching requirement LR). This is dependent upon quality and quantity of irrigation water and crop tolerance of plant for salt stress. It can very easily be calculated by dividing Depth of drainage water (D_{dw}) by Depth of irrigation water (D_{iw}) or EC of irrigation water (EC_{iw}) by EC of drainage water (EC_{dw}) as proposed by US Salinity Laboratory Staff (1954).

$$LR = D_{dw}/D_{iw} = EC_{iw}/EC_{dw}$$

However, when the irrigation water is sodic as well then some amendment like gypsum has also to be added that can be calculated on the basis of soil or water analysis. There may also be problems with this method because it may cause rise of water table where subsoil drainage is poor which has also to be improved simultaneously.

10.8.1.2 Drainage

Natural drainage is the soil's ability to drain water (rainfall or irrigations) away laterally or horizontally. Excessive or impeded drainage can both cause problems. Rapid drainage of soil will allow less water for plant utilization whereas poor drainage can cause waterlogging coupled with poor aeration and salt accumulation. If the soil is poorly or well drained, its drainage must be improved artificially by addition of organic matter for rapid drainage or adding an artificial drainage system (surface or sub-surface) in case of impeded drainage. The open and tile drains must also be maintained for effectiveness of performance.

10.8.1.3 Improved Irrigation Practices

Irrigation practices for crops and legumes have to be amended under the changing scenes of climate. Requirements for irrigation will increase due to lesser or scanty rainfall that will demand increased usage of groundwater, the major part of which will be brackish. Therefore, not only water saving strategies will direly be needed but also such practices and techniques have to be selected that can control or minimize the deleterious effects of enhanced quantities of saline or sodic water. In the first step the irrigation system itself has to be changed and modified into sprinkler, drip or sub-surface instead of surface irrigation. Early warning systems for prediction of irrigation scheduling will be required so that under and over irrigations are avoided. When water is saline then leaching fractions (Section 9.9.1.1) have to be added into consumptive water use of crops. Cyclic use of brackish and good quality water is also a good and safer strategy (Hussain et al., 2002b) but awareness of sensitive stages to salinity stress of different crops and knowledge of their salt tolerance will have to be acquired. Brackish water can wisely be used at relatively salt tolerant stages of various crops or salt tolerant crops of different rotations. More frequent irrigations may be required under salinity stress because available water between field capacity and permanent wilting point is lesser under stressed conditions. Treatment of sodic water before its entry into field with powdered gypsum or gypsum stone (put in the tube well tank) has also proven to be a useful technique to reduce SAR and RSC of water. To increase the partial usefulness of gypsum stone, its supplemental placement in the water channel in a zigzag manner at distance of 0.5 m on both sides was also found useful. The effectiveness increased directly with the increase in length of gypsum stone lining (Hussain et al., 2002b)

10.8.2 Appropriate Agronomic Practices

Appropriate agronomic practices have to be adopted to cope with future climatic changes. However, these practices have to be selected according to prevailing set of conditions of soil, climate and crops/legumes to be grown.

The selection of cultural practices must match prevailing conditions. The concept of minimum tillage is emerging rapidly and may be appropriate under highly mechanized agriculture. However, in order to reduce salt accumulation, deep plowing/chiseling has to be practiced regularly (may be once a year or before sowing of crop/legume), especially if crops are being irrigated with saline water. Cultural and land preparation practices like; rotavation and disc plowing have proved helpful (Sadiq et al., 2007) in opening of soil pores (Decreasing bulk density and increasing soil porosity and hydraulic conductivity), movement of salts into lower profiles and keeping root zone less saline. These practices also prove helpful in conserving the moisture for longer periods and facing drought, the early establishment of roots, rapid growth and proliferation resulting in healthy and stout plants making plants capable of dealing with stresses and favorable soil physical properties.

Runoff occurs when the land is unleveled resulting in wastage of precious water. Contour plowing can be helpful to control runoff when the fields naturally vary in topography. Over and under irrigation may be the ultimate outcome in unleveled fields. Plants suffer on higher parts of fields (that become drier early) for want of water and on lower parts due to more water, especially in early growth stages (may be submergence of seedlings or temporary waterlogging that creates root aeration problems). The higher parts are converted into salinity patches slowly and gradually. Thus, patchy salinity develops. A more uniform application of water achieves better leaching of salts.

Application of organic matter helps a lot in improving water infiltration, keeping the soil porous, and increasing microbial activity, supplying plant nutrients. Plants growing in high organic matter soil are stronger and able to face unfavorable conditions and stresses. Organic matter applications like; farm manures, composts, crop residues, industrial wastes, green manures etc. also help in fighting against salinity. The release of H ions during decomposition of organic material behaves like Ca ions and keeps the soil aggregated resulting into larger porosity and less evaporation that ultimately cuts down surface salt concentrations. Application of farm manure, rice straw and compost helped to mitigate deleterious effects of soil and water salinity on soil chemical and physical parameters and controlled yield losses (Hussain et al., 1995; Hussain et al., 1998). Balanced nutrition of legumes can also assists plant growth. However, nutrient carriers and method of application have to be selected according to soil texture, type and method of irrigation and crops being grown. Type and quantity of soil and water salinity must also be considered in selection of fertilizer sources and their application method. When the soil is sodic or sodic water is in use for irrigation, the acidic or acid forming nutrient sources prove more useful. Band placement, especially of P sources and split application of nitrogen that has to be increased by 15–20% over recommendations for crops of the rotation under normal conditions have been found to give good yields. Of course, nitrogen fixation from cool season legumes in the crop sequence has also to be considered.

Special sowing methods for crops and legumes have to be adopted under the scenario of global climatic changes. Line sowing results in saving water because irrigation only to plant lines can be provided. Planting on the shoulder of ridges has been highly beneficial because this area has the least salt concentration. High seed rates/more seedlings can improve populations reduced by salinity stress. Problems of poor germination (Welbaum et al., 1990) high mortality and less tillering can be overcome through these techniques and yields almost equating those under normal conditions may be obtained.

Mulching is another agronomic technique that helps to reduce evaporation, conserve moisture and thus reducing salt accumulation. This technique may be helpful in sowing of crops and legumes that are sown in lines. Putting a few centimeters of chopped date palm residues on the soil surface significantly cut down evaporation, kept the soil with higher moisture and cooler than black plastic sheet during tomato growing in the Sultanate of Oman (Al-Wahaibi et al., 2007). Brackish water was used for irrigation but salt concentration (Soil ECe) was less than found in the control (without any mulch). Hence, mulching can be adopted as proven technology to face drought and salinity stresses simultaneously.

10.8.3 Inclusion of Legumes in Crop Rotation

Inclusion of leguminous plants in crop rotations is very beneficial and proven agronomic practice that not only ensures good yields but also keeps physical properties of soil favorable for good plant establishment and subsequent growth under severely stressed conditions. This practice also helps in conserving moisture and keeping water available for longer periods for the subsequent crop either through burying in fresh material or crop residues of grain legumes. The symbiotic N fixation also helps in cutting fertilizer application. All these outcomes favor management of salinity keeping it under control or at least in the tolerable range of cool season legumes and other cereal and forage crops of the sequences.

10.8.4 Application of Amendments

When salts in soil solution are dominated by carbonates and bicarbonates of Na instead of chlorides and sulphates and ESP/SAR exceed critical limits, the stage is set for sodication. To mitigate sodicity and get rid of excessive Na from the exchange complex, application of amendments like gypsum, sulphuric acid, sulphur, FeS, CaS becomes necessary (Hussain et al., 1995; Hussain et al., 2002b; Qadir et al., 2001). The divalent ion (Ca) can also be released from native lime ($CaCO_3$) in the soil by application of inorganic acids. The excessive Na will leach down with subsequent irrigations.

In the case of sodic water irrigations, amendments have also to be added regularly to mitigate the negative effects of Na otherwise the physical properties of the soil rapidly deteriorate and expressed in reduced growth and yields. Calculations for quantities of amendments can be made on the basis of soil and water analysis.

10.8.5 Appropriate Selection of Plants

The selection of crops and crop sequences is highly important and must necessarily be decided in view of the site specific conditions of soil, climate and available water. It was suggested that the best option is selection of suitable crops well suited to local conditions of a water scarce country like the Sultanate of Oman (Hussain et al., 2006). Inclusion of a legume in the crop sequence is a positive practice to face the effects of climatic changes. Symbiotic N fixations and incorporation of all the crop and legume residues help a lot in maintenance of soil physical properties and keeping down the salt concentration. In the case of water scarcity and utilization of increasing quantities of saline or sodic water, at least one salt tolerant crop must be included in the crop rotation that can safely be irrigated with such water. However, management practices have also to be adopted simultaneously so that salinity status left over after harvest of salt tolerant crop may not prove detrimental for the subsequent crop/cool season or any other legume. Hence, appropriate selection of crop sequences including a legume will be of prime importance to face the expected climatic changes.

10.8.6 Genetic Variability and Breeding for Salt Tolerance

When it is expected that salinity and sodicity can increase manifold (Depending upon soil texture, irrigation and management practices) under the scenario of global climatic changes, the responsibility of plant breeders also enhance accordingly. Although cool season legumes are classified in sensitive and moderately sensitive groups with respect to their salt tolerance potential as compared with salt tolerant legumes like *sesbania*, alfalfa and *Acacia ampliceps* as well as cereals like wheat, rice and barley but still a large genetic variability exists in different parts of the world. For example Maliro et al. (2007) screened 200 germplasm accessions of chickpea (*Cicer arietinum*) and its wild relatives, originating from 22 different countries for salt tolerance (EC 6 dSm^{-1}). He rated (by weighted scores) 47 (23.7%) accessions, from 7 countries of 4 geographical regions (Middle East, South Asia, USA and Ethiopia) as tolerant to NaCl. Five of these accessions rated as most tolerant included CPI 060546, ILC 01302 (from Turkey), ICC6474 from Iran, ICC

8294 from India and UC 5 from United States of America. None of the wild relative accessions rated as tolerant to NaCl. Therefore, screening studies on all cool season legumes can help to identify relatively salt tolerant accessions which can further be used as salt tolerant gene pool.

Breeding for salt tolerance has not been the major objective in the past in most of the countries even facing salinity hazard. Now it is direly required that strong breeding programs be started to evolve salt tolerant varieties in countries growing cool season legumes as important crops. Modern techniques like mutation, biotechnology and genetic engineering can help a lot in this regard.

10.9 Conclusions

1. Increase in temperature, droughts, evaporation, utilization of brackish water and salinity are expected under predicted global climatic changes in arid and semiarid regions.
2. Plant growth, crop yields and soil characteristics (chemical and physical) can negatively be affected due to water scarcity, enhanced secondary salinity and inappropriate management practices.
3. Legumes are mostly sensitive to salinity and can be affected largely at lower levels of salt stress.
4. Special management practices have to be adopted for coping with changing global climate that may include:

    - Suitable hydraulic options (leaching and drainage).
    - Appropriate agronomic practices like; leveling, deep plowing, rainfall harvesting, application of organic matter, balanced nutrients, suitable sowing methods, mulching, selection of crop sequences that can withstand salinity stresses, increased seed rate/number of seedlings, inclusion of legumes in the crop rotations etc.
    - Appropriate irrigation technologies; scheduling, modification of irrigation system (shifting from surface irrigation to drip, sprinkler or sub-surface), cyclic use of good quality and brackish water.

5. Starting strong screening studies for genetic variability and breeding programs supported by modern approaches; Biotechnology, Mutation and Genetic Engineering to identify and evolve salt tolerant cultivars.

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Chapter 11
Nutrients Use Efficiency in Legume Crops to Climatic Changes

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11.1 Introduction

Increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance, increased CO_2 and increased temperatures have implications for future food availability (IWGCC, 2007) and hence legume availability as a major global food source. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) dismissed many uncertainties about climate change. Warming of the climate system is now unequivocal and according to IPCC the increase in global temperatures observed since the mid-twentieth century is predominantly due to human activities such as fossil fuel burning and land use changes. Projections for the twenty-first century show that global warming will accelerate with predictions of the average increase in global temperature ranging from 1.8 to 4°C. The primary greenhouse gases associated with agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20). Climate change is a global problem, affecting every nation and every living thing including cool season legumes as covered in this book.

These changes have implications for food production, food security and food safety. It is widely understood that the risks of global climate change occurring as a consequence of human behavior are inequitably distributed, since most of the actions causing climate change originate from the developed world, but the less developed world is likely to bear the brunt of the public health burden (Campbell-Lendrum et al., 2007).

The 670–750 genera and 18,000–19,000 species of legumes (Polhill et al., 1981) include important grain, pasture, and agro-forestry species (Graham and Vance, 2003), and they are going to play a very important role in the possible alterations in nutrient use efficiency under climatic change. Crop nutrients, particularly nitrogen, are intimately involved with the soil's exchange of gases involved in warming the

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global climate (Bruulsema and Griffith, 1997). Improving of nutrient use in agriculture, carbon sequestration and reductions in greenhouse gas emissions can occur through a variety of agriculture practices (Schahczenski and Hill, 2009). This work provides an overview of the relationship between agriculture, climate change, and nutrient use efficiency, and also suggests possible options for farmers and ranchers to have a positive impact on the changing climate and presents opportunities around incorporation of legumes and sustainable practices in cropping systems to improve nutrient use efficiency.

11.1.1 Environmental Degradation and Accelerated Desertification

Agriculture soil and water contamination and variation on levels of contaminants have been associated with alternate periods of floods and droughts. The frequency of these seasonal periods will be increased due to increased climate variability and changes. Impacts of climate change in physical systems or processes are exacerbated in areas where the environment has been damaged by humans for agriculture, mining or industrial purposes (Abberton et al., 2008).

These impacts may lead to very highly contaminated regions and therefore contamination and effects on local food supply. An illustrative example is the Aral Sea in Central Asia, which was once the fourth-largest lake in the world and has been one of the world's largest environmental disasters during the last 20 years. In the Aral Sea area, agriculture mis-management and accelerated desertification due to both environmental degradation and climate change, have resulted in serious contamination of soil, water and local foods with high levels of POPs and dioxins, leading to critical health and socio-economic impacts to local populations (Muntean et al., 2003).

11.1.2 Interactions with Soil Processes

Soil is one of the most influenced resources by climate change both directly through elevated CO_2 and indirectly through other environmental changes. That is very relevant for microbial infestation and activity in the soils, which affect the nitrogen fixation by bacteria associated with legumes (Zahran, 1999); a competitive and persistent rhizobial strain is not expected to express its full capacity for nitrogen fixation if limiting factors (e.g., salinity, unfavorable soil pH, nutrient deficiency, mineral toxicity, temperature extremes, insufficient or excessive soil moisture, inadequate photosynthesis, plant diseases, and grazing) impose limitations on the vigor of the host legume (Brockwell et al., 1995; Zahran, 1999). Kimball et al. (2002) have thoroughly reviewed the direct effects of elevated CO_2 on soil microbiology (as well as plant parameters) and indicate published changes in soil biodegradation of residues, mycorrhiza content, microbial N mineralization and gas outputs, disease infections, total microbial activity, soil respiration and importantly rhizobial numbers and infection rates.

Climate change can also potentially alter the transfer and the bioavailability of trace elements from the soil to the plant. Deficiency of nutrients or excess of toxic elements may results in lower resistance to insect, pests and plant diseases including the attack of toxigenic fungi and the consequent biosynthesis of mycotoxins. Fertilizer regimes may affect fungal incidence and severity of colonization either by altering the rate of residue decomposition, by creating a physiological stress on the host plant or by altering the crop structure (Yohe et al., 2007).

11.1.3 Legumes

Grain and forage legumes are grown on some 180 million ha, or 12 to 15% of the Earth's arable surface. They account for 27% of the world's primary crop production, with grain legumes alone contributing 33% of the dietary protein nitrogen needs of humans. Under subsistence conditions, the percentage of legume protein N in the diet can reach twice this figure. In rank order, bean (*Phaseoulus vulgaris*), pea (*Pisum sativum*), chickpea (*Cicer arietinum*), broad bean (*Vicia faba*), pigeon pea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), and lentil constitute the primary dietary legumes. Legumes (predominantly soybean and peanut [*Arachis hypogeae*]) also provide more than 35% of the world's processed vegetable oil (Vance et al., 2000; Graham and Vance, 2003).

11.2 Factors Associated with Changing Nutrient Use Efficiency

11.2.1 N-Fixation

A property trait of legumes is their ability to develop root nodules and to fix N_2 in symbiosis with compatible rhizobia. Crop, pasture and tree legumes are very important both ecologically and agriculturally because they are responsible for a substantial part of the global flux of nitrogen from atmospheric N_2 to fixed forms such as ammonia, nitrate, and organic nitrogen. Some 40–60 million metric tons (Mt) of N_2 are fixed by agriculturally important legumes annually, with another 3–5 million Mt fixed by legumes in natural ecosystems (Smil, 1999). This is amazing efficiency given the miniscule quantities of nitrogenase involved (Bruulsema and Griffith, 1997). In addition to its role as a source of protein N in the diet, N from legume fixation is essentially "free" N for use by the host plant or by associated or subsequent crops. Replacing it with fertilizer N would cost $7–10 billion annually, whereas even modest use of alfalfa in rotation with corn could save farmers in the U.S. $200–300 million (Peterson and Russelle, 1991). Furthermore, fertilizer N is frequently unavailable to subsistence farmers, leaving them dependent on N_2 fixation by legumes or other N_2-fixing organisms.

One of the driving forces behind agricultural sustainability is effective management of N in the environment (Graham and Vance, 2000). Application of fertilizer N increased approximately tenfold to 90 million Mt between 1950 and 1995 (Frink et al., 1999) up to 101 million Mt in 2007/8 (Heffer and Prud'homme, 2009) with significant energy consumption for N fertilizer synthesis and application. Further increases in N needs for agriculture are projected for the future (111 million Mt in 2012/2013, Heffer and Prud'homme, 2009) with much of this increased N application aimed at overcoming limitations due to other factors. Limitations which will certainly increase in some regions due to climate change. Legume fixation is seen as a major mechanism to overcome "Progressive Nitrogen Limitation" (PNL) in a world of increasing CO_2 (Luo et al., 2004). PNL results from increasing levels of CO_2 unbalancing C/N ratios and preventing the benefits of the fertilization effects of the CO_2 being realized. There are constraints to N_2 fixation which may reduce the ability of N fixing legumes to overcome PNL. These include drought, soil acidity, N fertilization, and nutrient limitations. Maximum benefits from N_2 fixation depend on soil P availability, while reserves of rock phosphate could be depleted in only 60–90 years (Abelson, 1999).

The ability of legumes to sequester C has also been seen as a means to offset increases in atmospheric CO_2 levels while enhancing soil quality and tilth. Resh et al. (2002) found that soils under N_2-fixing trees sequestered 0.11 kg m^2 $year^{-1}$ of soil organic carbon.

The common bean *Phaseolus vulgaris* is the most important food legume for human consumption worldwide, especially in Latin America and Africa, where its cultivation as a staple food extends into marginal areas. Symbiotic nitrogen-fixation potential in common bean is considered to be low (Pereira and Bliss, 1987) in comparison with other legumes. Nitrogen fixation in common bean is more affected by P deficiency than in other legume crops such as soybean. P is one of the most limiting nutrients for plant growth in the tropics, and it is estimated that over 50% of common bean production in tropical soils is limited by phosphate deficiency (CIAT, 1992; Olivera et al., 2004). Thus future potential benefits of increased fixation and C sequestration by legumes may not be fully realized.

11.2.2 Elevated CO_2, Photosynthesis and Soil Nutrients

CO_2 is one of the greenhouse gases which is rapidly increasing. Recent reviews confirm and extend previous observations that elevated CO_2 concentrations stimulate photosynthesis, leading to increased plant productivity and modified water and nutrient cycles (Kimball et al., 2002; Nowak et al., 2004). Experiments under optimal conditions show that doubling the atmospheric CO_2 concentration increases leaf photosynthesis by 0.30–0.50 in C_3-plant species (including legumes such as soybeans and clover) and by 0.10–0.25 in C_4-species, despite a small but significant down-regulation of leaf photosynthesis by elevated atmospheric CO_2 concentrations at some sites (Ellsworth et al., 2004; Ainsworth and Long, 2005).

A number of studies have found that plants grown in conditions of high nutrient supply respond more strongly to elevated atmospheric CO_2 concentrations than nutrient-stressed plants (Poorter, 1998). Some experiments confirm that high N soil contents increase the relative response to elevated atmospheric CO_2 concentrations

(Nowak et al., 2004). Under elevated atmospheric CO_2 concentrations, *Lolium perenne* showed a significant reduction in the concentration of shoot N (Soussana et al., 1996; Zanetti et al., 1996). With a non-limiting N fertilizer supply, the concentration of leaf N (N, mg g^{-1} dry matter) declined with the dry matter (DM) yield of shoots (DM, g) according to highly significant power models in ambient ($n = 49\ DM^{-0.38}$) and in elevated ($n = 53\ DM^{-0.52}$) atmospheric CO_2 concentrations.

When other nutrients are not strongly limiting, a decline in N availability may be prevented by an increase in biological N_2-fixation under elevated atmospheric CO_2 concentrations (Gifford, 1994). Indeed, in fertile grasslands, legumes benefit more from elevated atmospheric CO_2 concentrations than non-fixing species (Hebeisen et al., 1997; Lüscher et al., 1998) resulting in significant increases in symbiotic N_2 fixation and avoidance of PNL. Other nutrients, such as phosphorus, may act as the main limiting factor restricting growth and responses in yield in legumes to atmospheric CO_2 concentrations. Elevated CO_2-induced changes in C and N cycling below-ground. Plants grown under elevated atmospheric CO_2 concentrations generally increase the partitioning of photosynthates to roots which increases the capacity and/or activity of below-ground C sinks.

Studies (Newton et al., 1996; Cardon et al., 2001) have suggested a higher C turnover rather than a substantial net increase in soil C under elevated atmospheric CO_2 concentrations. Elevated atmospheric CO_2 concentrations reduced to a greater extent the harvested N derived from soil than that derived from fertilizer, and significantly increased the recovery of fertilizer-N in the roots and in the particulate soil organic matter fractions (Loiseau and Soussana, 1999). The increase in the immobilization of fertilizer-N in the soil fractions was associated with a decline in fertilizer-N uptake by the grass sward, which supported the hypothesis of a negative feedback of elevated atmospheric CO_2 concentrations on the N yield and uptake of swards. The actual impact of elevated atmospheric CO_2 concentrations on yields in farmers' fields could be less than earlier estimates which did not take into account limitations in availability of nutrients and plant–soil interaction.

Elevated CO_2 concentrations tend to reduce the sensitivity of grassland ecosystems to low levels of precipitation but induce progressive nitrogen (N) limitation on plant growth which can be alleviated by supplying a significant external input of N in the form of mineral fertilizer or through the increased use of N-fixing legumes. Other nutrients, such as phosphorus, can act as the main limiting factor restricting the growth response in legumes to atmospheric CO_2 concentration (Soussana and Lüscher, 2007).

11.2.3 Temperature, Photosynthesis and Soil Nutrients

Warmer temperatures are likely to enhance the growth response of most C_3-dominated grasslands and cropping systems to higher CO_2 and hence their productivity and demand for nutrients, particularly where water is not limiting, as in North and North West Europe (Hopkins and Del Prado, 2006). In high- and mid-latitude rangelands, currently subject to severe cold-temperature restriction on growth rate and duration, warmer temperatures alone are likely to enhance production (Polley et al., 2000). According to Baron and Bélanger (2007), effects in continental America include (a) a limited northward shift in production areas in US and Canada arising from higher temperatures and the frost-free season extending by 1–9 weeks, and (b) subtropical conditions extending further north with changes in relative distribution of C_3 and C_4 species (Abberton et al., 2008). However, in arid and semi-arid zones of Central and South America, Africa, Middle east, Asia and Australia, positive effects of temperature may be lessened or negated by accompanying increases in evapotranspiration and water deficit, leading to reductions in photosynthesis. In a European context, the vulnerability of grassland to negative temperature-related impacts of climate change is likely to be greatest in Mediterranean and southern Europe (Schroter et al., 2005), due to summer heat and drought, and also at the highest latitudes where natural ecosystems are threatened. While demand for nutrients may increase due to temperature induced changes it is not as clear with respect to availability. Soil nutrient mineralization rates may also be affected by increasing temperatures. C and N mineralization generally increases with increasing temperature as does, however, potential losses to the environment. P mineralization may also increase but soil availability may decrease due to more rapid binding or uptake by soil organisms (Nadelhoffer et al., 1991).

11.2.4 Drought, pH, Salinity, and Crop Nutrient Efficiency

Drought problems for legumes are likely to worsen with the projected rapid expansion of water-stressed areas of the world from 28 to 30 countries today to 50 countries encompassing 3 billion people by 2030 (Postel, 2000). There is a crucial need to increase drought tolerance in legumes; increasing salinity tolerance is a parallel requirement in many areas. The more drought-tolerant legumes, such as cowpea, are deeply rooted and may have reduced leaf size with thickened cuticles to reduce water loss. Deep rooting may enhance ability to extract nutrients (and toxic elements) from deep in the profile but drier soils may reduce availability of nutrients in the top of the soil profile. Less tolerant legumes such as beans can be selected for early maturity, efficiency in the partitioning of nutrients toward reproductive structures, and phenotypic plasticity (Beaver et al., 2003). Pinto Villa, now grown over 90% of the pinto bean area in Mexico, has these characteristics. Irrespective of demands from changing climates nutrient depletion of soil is a particular problem for small landholders in developing countries, where much grain-legume production occurs, and many farmers cannot afford to use fertilizers. Sanchez (2002) suggests average annual nutrient depletion rates across 37 African countries of 22 kg N ha^{-1}, 2.5 kg P ha^{-1}, and 15 kg K ha^{-1}. Sardans and Penuelas (2007) indicated in a Mediterranean environment drought increased total soil soluble organic P and reduced both P and K uptake by plants. Thus increased drought due to climate change may have negative effects on NUE.

Soil acidity affects more than 1.5 billion ha worldwide, with acid soil constraints to legume production likely to increase as the result of acid rain, long-term N fertilization, and natural weathering (Graham and Vance, 2000). H ion concentration per se, Al and Mn toxicity, and P, Mo, or Ca deficiency all contribute to the problem (Graham, 1992). Nodulation and N fixation and survival of rhizobia in soil are particularly affected under low P, acid soil conditions. Soil acidity may also interact with drought to increase its negative effects on crops and reduce nutrient uptake under drought conditions. Barszczak and Barszczak (1994) showing negative interactions in yield and N use efficiency when drought and soil acidity in oilseed rape. Thus where acid soils exist (eg the Wheat belt of Australia which produces large amounts of lentils, peas and chickpeas) greater negative effects on yield and NUE may result under climate change conditions.

Nitrogen-fixing is a process particularly sensitive to water stress or drought which is likely to increase regionally in response to climate change. The reduction of atmospheric nitrogen to ammonia can only be carried out by rhizobia. The plant benefits from the micro-organism that takes on the task of capturing nitrogen from the air and converting it into ammonia in such a way that the plant can use it. However, under drought conditions, a reduction in nodule sacarose synthesis activity has been observed. This drop occurred simultaneously with a decrease in nitrogen-fixing, enabling the establishment of a high correlation between both processes in adverse conditions. As a consequence of the inhibition of sacarose synthesis activity, a drop in the concentration of phosphate sugars and organic acids was also observed, indicating a decrease in carbon flow in the nodules, a drop which, in turn, limits the supply of carbon to the bacteroid and the capacity of the bacteroid to fix nitrogen thus affected (Galvez, 2005). Similarly under high temperature and drought conditions soil rhizobial survival and nodulation may be reduced adversely affecting fixation (McNeil and Materne, 2007).

Other problem that is increasing as the clime changes is the salinity. The response of legumes to salt stress is complex since it varies with salt concentration, ion type, other environmental factors and the stage of plant development. Some of the structural changes in plants subjected to salinity stress include fewer leaves, but information on the underlying mechanism for these structural changes is inadequate. Salinity can also interfere with root uptake capacity for essential ions such as potassium, nitrate or phosphate. Root growth and function may be restricted by high Na+/Ca++ (Esechie and Rodriguez, 1999).

11.3 Mechanisms to Overcome Reductions in Nutrient Use Efficiency

11.3.1 Sustainable Fertilizing Practices for Improving Crop Nutrient Efficiency and CO_2 Sequestration

Intensive high-yield agriculture is dependent on addition of fertilizers, especially industrially produced NH_4 and NO_3. Between 1960 and 1995, global use of nitrogen fertilizer increased sevenfold, and phosphorus use increased 3.5-fold (Tilman et al., 2002); both are expected to increase another threefold by 2050 unless there is a substantial increase in fertilizer efficiency (Cassman and Pingali, 1995; Tilman et al., 2002).

Fertilizer use and legume crops have almost doubled total annual nitrogen inputs to global terrestrial ecosystems (Vitousek and Matson, 1993; Galloway et al., 1994). Similarly, phosphorus fertilizers have contributed to a doubling of annual terrestrial phosphorus mobilization globally (Carpenter et al., 1998). Today, only 30–50% of applied nitrogen fertilizer (Smil, 1999) and 45% of phosphorus fertilizer (Smil, 2000) is taken up by crops. A significant amount of the applied nitrogen and a smaller portion of the applied phosphorus is lost from agricultural fields. This nitrogen contributes to riverine input into the North Atlantic that is 2- to 20-fold larger than in pre-industrial times (Howarth et al., 1996). Such non-point nutrient losses harm off-site ecosystems, water quality and aquatic ecosystems, and contribute to changes in atmospheric composition (Tilman et al., 2001; 2002).

Climate change adaptation for agricultural cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is soil organic matter, which improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without causing surface run off, which could result in soil erosion and, further downstream, in flooding. Soil organic matter also improves the water absorption capacity of the soil for during extended drought (IWGCC, 2007). Innovative farming practices such as conservation tillage, organic production, improved cropping systems, land restoration, land use change and irrigation and water management, are ways that farmers can address climate change.

The development and preferential planting of crops and crop strains that have higher nutrient-use efficiency are clearly essential. Cover crops or reduced tillage can reduce leaching, volatilization and erosional losses of nutrients and increase nutrient-use efficiency. Closing the nitrogen and phosphorus cycles, such as by appropriately applying livestock and human wastes, increases legumes and in general crop production per unit of synthetic fertilizer applied (Tilman et al., 2002). These practices are having promising results in Baja California Sur, México, one of the driest regions in the world. Principal actions there include: application of green manure using legume as cowpea and *Lablab purpureus* (Fig. 11.1) and conservation tillage (Fig. 11.2) for vegetable production (Beltran-Morales et al., 2006). With both activities, it has been achieved to increase the levels of organic matter and microbial activity in desert, arid soils. Good management practices have multiple benefits that may also enhance profitability, improve farm energy efficiency and boost air and soil quality (Schahczenski and Hill, 2009); however, more research on improving efficiency and minimizing loses from both inorganic and organic nutrient sources is needed to determine costs, benefits and optimal practices (Tilman et al., 2002). Conservation agriculture and organic agriculture that combine zero or low tillage and permanent soil cover (mainly using legumes) are promising adaptation options promoted by FAO for their ability to increase soil organic carbon, reduce mineral fertilizers use and reduce on-farm energy costs (IWGCC, 2007).

Fig. 11.1 *Lablab purpureus* grown in arid soil in order to be used as green manure. Baja California Sur, México

Fig. 11.2 Test of hot-wild-pepper grown under conservation tillage (using cowpea as mulch) in arid soils. Baja California Sur, México

Carbon sequestration and reductions in greenhouse gas emissions can occur through a variety of agriculture practices. Carbon sequestration in the agriculture sector refers to the capacity of agriculture lands and forests to remove carbon dioxide from the atmosphere. Carbon dioxide is absorbed by trees, plants and crops through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage and roots and soils (EPA, 2008). Conservation tillage refers to a number of strategies and techniques for establishing crops in the residue of previous crops, which are purposely left on the soil surface. Reducing tillage reduces soil disturbance and helps mitigate the release of soil carbon into the atmosphere. Conservation tillage also improves the carbon sequestration capacity of the soil.

Some of the most important strategies to improve the N efficiency include the use of cover crops and manures (both green and animal); nitrogen-fixing crop rotations; composting and compost teas. Low fertilizer nitrogen-use efficiency in agricultural systems is primarily caused by large nitrogen losses due to leaching and gaseous emissions (ammonia, nitrous oxide, nitric oxide, nitrogen). It is axiomatic then that most strategies that increase the efficiency use of fertilizer nitrogen will reduce emissions of N_2O (Schahczenski and Hill, 2009).

While N fertilizer is one of the direct contributors to N_2O emission, it also plays a positive role in the stabilization of soil C, and can help to mitigate CO_2 emissions. There are extensive reports from long-term trials indicating that wherever N enhances the yields of crops, the accumulation of C in the soil is increased. In addition, there is evidence that N itself is chemically involved in stabilizing soil C (Bruulsema and Griffith, 1997).

In other hand, nutrient-use efficiency is increased by better matching temporal and spatial nutrient supply with plant demand. Applying fertilizers during periods of greatest crop demand, at or near the plant roots, and in smaller and more frequent applications all have the potential to reduce losses while maintaining or improving yields and quality (Matson et al., 1996; Tilman et al., 2002).

Multiple cropping systems using crop rotations or intercropping (two or more crops grown simultaneously) may increase nutrient- and water-use efficiency (Tilman et al., 2002). Agroforestry, in which trees are included in a cropping system, may improve nutrient availability and efficiency of use and may reduce erosion, provide firewood and store carbon.

11.3.2 Genetic Adaptations

Biodiversity in all its components (e.g. genes, species, ecosystems) increases resilience to changing environmental conditions and stresses which are likely to occur due to climate change. Genetically-diverse populations and species-rich ecosystems have greater potential to adapt to climate change. FAO promotes use of indigenous and locally-adapted plants and animals as well as the selection and multiplication of crop varieties and autochthonous races adapted or resistant to adverse conditions. The selection of crops and cultivars with tolerance to abiotic stresses (e.g. high temperature, drought, flooding, high salt content in soil, pest and disease resistance) allows harnessing genetic variability in new crop varieties if national programs have the required capacity and long-term support to use them. To strengthen capacity of developing countries to implement plant breeding programmes and develop locally-adapted crops, FAO and other like-minded institutions are planning the Global Initiative on Plant Breeding Capacity Build (GIPB) initiative, to be launched at the governing body meeting of the International Treaty on Plant Genetic Resources for Food and Agriculture (Abberton et al, 2008).

11.4 Conclusions

Climatic change constitutes a challenge to be solved in the near future. Food production is being threatened by increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance. As a consequence of these changes there is a marked potential to alter nutrient demand, availability and consequently plant nutrient use efficiency from soil, fertilizer and biologically fixed nutrients. Legumes are going to play a very important role in maintaining high N availability in part through enhamced N fixation overcoming Progressive Nitrogen Limitation under elevated CO_2 conditions. This review recognizes the role of legumes and their association with rhizobia to improve soil fertility and nutrients use efficiency, compared to other ways, such as increased use of fertilizer-N. However, it also recognizes the susceptibility of legumes to drought and temperature stresses which may both increase and decrease regionally as a result of climate change. Several symbiotic systems of legumes which are tolerant to extreme conditions of salinity, alkalinity, acidity, drought, fertilizer, metal toxicity, etc. must be exploited. These associations might have sufficient traits necessary to establish successful growth and N_2 fixation under the conditions prevailing in unfavorable regions. The use of legume as source of organic matter, combined with conservational tillage practices is another of the very important roles of this group of species as a mechanism to reduce adverse effects of climate change on nutrient use efficiency.

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Chapter 12
Water Use Efficiency Under Stress Environments

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12.1 Introduction

Global warming has taken a heavy toll of natural resources particularly water due to depletion of glaciers and destruction of forests. The change in climate is changing the pattern and intensity of rainfall in many regions. Drought (rainfall deficit for a prolonged period) is often aggravated by erratic and low rainfall, occurrence of high temperatures, increased solar radiation due to reduced cloud cover, strong winds, etc. These factors are responsible for limited water supply to crops in many temperate regions that are causing food shortages around the world. Water is a primary input in enhancing crop production as it is directly or indirectly involved in all the physiological processes in plants.

In rainfed agriculture, precipitation is the only source of water either directly or through earlier storage in the soil. Cultivation of grain legumes occurs mostly under the rainfed conditions globally. According to estimates, more than 80% of the area of grain legumes is rainfed. Under these conditions grain legumes play a vital role in improving soil health through biological nitrogen fixation and are the cheapest source of dietary protein for human health. Their yields are low and unstable, because these usually suffer from receding soil moisture at the time of sowing and drought during their grain development stage. Thus, to improve the productivity of grain legumes the topic of increasing the efficiency of water use by these crops is of great concern. Increased allocation of water is generally not an option as Hamdy et al. (2003) reported that of the world's allocative water resource, 80% is currently consumed by agriculture. With a burgeoning population, in the future more water will be needed for domestic, industrial and agricultural purposes. It will require substantially more efficient production from a smaller irrigation water resource and higher water use efficiency (WUE) from rainfed agriculture. Wang et al. (2002) contend that several new strategies will be required

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to improve the productivity of water use in irrigated and rainfed agriculture. These strategies should include breeding of crop varieties that are more efficient in their water use, better management of soil and water resources and development of new water-saving agronomic techniques. None of these strategies should be seen as operating in isolation. They can provide greater gains through complementary approaches and there is thus a great need to integrate the full spectrum of water management techniques to achieve higher crop productivity.

Water use efficiency is a robust concept used for yield targeting, breeding targeting, bench marking paddock and farm performance and to examine management practices. In drought prone environments large variations in yield are recorded because of variable rainfall and its time of occurrence (Condon et al., 2004). The need to compare productivity under different conditions makes WUE a quick and simple calculation to analyse how well rain can be converted to grain. WUE also provides a guide to future crop expectations. Oweis and Hachum (2006) showed that substantial and sustainable improvements in water productivity can only be achieved through better crop selection, improved genetic make up, appropriate cultural practices and timely socio-economic interventions. There is a great need to revise conventional water management guidelines for attaining maximum water productivity instead of land productivity. Therefore, in this chapter, the approaches towards water requirement, effect of drought, rain water conservation, improving WUE through breeding, soil and agronomic management and efficient methods of irrigation, crop nutrition and crop residue management to improve WUE of cool season grain legumes have been discussed.

12.2 Concept of Water Use Efficiency

Scientists defined WUE in different ways depending on the scale of measurement and the units of exchange being considered. According to physiologists, the basic unit of production is usually moles of carbon gained in photosynthesis (A) in exchange for water used in transpiration (T). The A/T ratio can be defined mathematically:

$$A/T = \{G_c(C_a - C_i)\}/\{G_w(W_i - W_a)\}$$

A is the amount of stomatal conductance of CO_2; G_c is the conductance value for CO_2 through the stomata with a gradient in concentration of CO_2 between the outside (C_a) and inside (C_i) of the leaf; T is the amount of stomatal conductance of water vapour; G_w is the conductance value for water vapour through the stomata with a gradient in concentration of water vapour from the inside (W_i) to the outside (W_a) of the leaf.

When the CO_2, concentration is greater in the air and outside the leaf, and the reverse is true for water vapour.

Further the ratio of the diffusivities of CO_2 and water vapour in air has a value of approximately C= 0.625 (Xu and Hsiao, 2005). Thus,

$$A/T = 0.625\ C_a(1 - C_i/C_a)/(W_i - W_a)$$

This equation indicates two possible routes for improving leaf level WUE. One is to lower the value of C_i/C_a, thereby increasing the value of $(1–C_i/C_a)$. The other is to make $(W_i–W_a)$ smaller i.e. to make the gradient for transpirational water smaller.

For agronomists, the unit of production is mainly grain yield of harvested product from the water made available to the crop through rainfall and/or irrigation. Thus, agronomist defines WUE as a ratio of grain yield (Y) to crop water consumed, expressed as evapotranspiration (ET) or total water output (ET) from the soil surface, plant leaves and through the stomates (transpiration) to the system in a defined season.

$$\mathrm{WUE(kg\ ha^{-1}) = Y(grain\ yield,\ kg\ ha^{-1})/ET(mm)}$$

Farmers also consider the agronomic definition of WUE to be the best one. Tanner and Sinclair (1983) summarized the different forms of relationships that have been used to characterize WUE. Earlier, deWit (1958) showed that plant yield and transpiration were linearly related in areas with high solar radiation (e.g., Western USA) as described by:

$$Y/T = m/T_{max}$$

Where, Y is total dry matter production, T is the transpiration, m is a coefficient, and T_{max} is the cumulative daily free water evaporation during the growing season. Changes in WUE can be manifested through soil management. So soil scientists consider surface energy balance as under:

$$ET = R_n - G - H - P$$

Where ET is evapotranspiration, R_n is net radiation, G is soil heat flux, H is sensible heat flux, and P is photosynthetic flux. These terms can be expressed in a variety of units (e.g., W m^{-2} and KJ m^{-2} s^{-1}). These terms affect the water balance in the soil within a growing season and across growing seasons.

Condon et al. (2004) explained that the breeding target is a framework of the following components:

$$\mathrm{Yield = ET \times T/ET \times W \times HI}$$

Where ET is the evapotranspiration, T/ET is the proportion of water actually transpired by the crop, W is the transpiration efficiency of biomass production, i.e., how much biomass is produced per millimetre of water transpired and lastly, how effectively the achieved biomass is portioned into the harvested product, i.e., the ratio of grain yield to standing biomass termed as the harvest index (HI). This framework is not based on the notion of "drought resistance", but rather on the broad processes by which crops actually achieve yield in water limited environments (Passioura, 1977; Condon and Richards, 1993; Richards et al., 2002). Leaf-level WUE, A/T, is directly related to only one of these components, W, the transpiration efficiency of biomass production. So A/T has the potential to influence each of the other three components in the yield framework.

12.3 Water Requirement of Grain Legumes

Water requirement (WR) may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for normal growth under field conditions at a place. This includes the losses due to evapotranspiration (ET) or consumptive use (CS) plus the losses during the application of irrigation water (unavoidable losses) and quantity of water required for special field operations. Water needed to fulfill the demands of ET and metabolic activities of the plant is called consumptive use. The CS of water of a crop is very small (1–2% of its total water requirements). It may be written as:

$$\text{WR} = \text{ET or CS} + \text{application losses} + \text{special needs}$$

Water requirement, is therefore, a "demand" and the "supply" would consist of contributions from all available sources of water, the major sources being irrigation water (IR), effective rainfall (ER) and soil profile contributions (S), including that from shallow water tables. Numerically it can be written as:

$$\text{WR} = \text{IR} + \text{ER} + \text{S}$$

The field irrigation requirement of a crop, therefore, refers to the WR of crops exclusive of ER and S, and can be denoted as:

$$\text{IR} = \text{WR} - (\text{ER} + \text{S})$$

Crop water requirement usually varies with genotype, crop duration, planting density, soil factors (texture, structure, depth of water table, topography, etc.), climatic factors (precipitation, temperature, relative humidity, wind velocity, etc.) and crop management practices (tillage, time of sowing, scheduling of irrigation, nutrients, weeding etc.). Various findings show that WR of a crop is location and season specific (Prihar and Sandhu, 1968; Singh and Pannu, 1998; Ahlawat and Rana,

Table 12.1 Total water use (E_l mm) and WUE for dry matter production (WUE_{dm} kg ha^{-1}) and grain total (WUE_{gr}, kg ha^{-1} mm^{-1}) of various cool season grain legume species at two locations

	1993			1994		
Species	E_l	WUE_{dm}	WUE_{gr}	E_l	WUE_{dm}	WUE_{gr}
	Merredin					
L. cicera	288	21.4	5.7	176	13.9	5.2
P. sativum	266	22.8	7.3	176	17.6	6.0
L. ochrus	287	27.4	8.1	178	12.6	4.2
V. benghalensis	283	23.7	7.9	187	11.9	4.1
L. sativus	281	13.7	a	176	11.7	2.8
V. sativa	292	17.4	5.6	188	12.9	5.6
Mean	283	21.1	5.9	180	13.4	4.7
L.S.D. (P=0.05)	ns	9.6	ns	ns	5.8	1.8
	Mullewa					
L. cicera	179	21.4	8.3	182	25.5	9.2
P. sativum	177	25.7	12.6	175	38.7	15.9
L. ochrus	170	23.2	7.0	178	20.6	4.9
V. benghalensis	181	26.2	9.8	168	22.4	8.9
L. sativus	186	27.3	9.0	172	25.1	7.1
V. sativa	177	19.4	9.2	173	22.4	9.6
Mean	178	23.9	9.3	175	25.8	9.3
L.S.D. (P=0.05)	ns	ns	3.7	ns	8.8	3.1

a, Seed yield affected by thunderstorm in October 1993.
Source: Siddique et al. (2001).

2002). The total water use and WUE of various cool season grain legume species is presented in Table 12.1.

12.4 Effect of Drought

A prolonged period of scanty rainfall affects the functioning of plant and crop yield. Wery et al. (1993) showed that not all plant functions are similarly affected; cell elongation and nitrogen fixation are more susceptible than photosynthesis and translocation. In grain legumes, the key stages of growth and development determine the establishment of each yield component. For a given drought intensity, the time at which it occurs in the plant's life cycle will affect plant production through its yield components (total biomass, vegetative biomass, number of seeds, seed weight and water content).

The grain legume life cycle can be divided into five phases. Phase 1 – from seedling emergence to beginning of flowering; phase 2 – from beginning of flowering to beginning of seed formation; phase 3 – from beginning of seed formation to the end of this stage; phase 4 – from end of seed formation to physiological maturity, phase 5 – from physiological maturity to harvest. Based on the data for "potential climatic deficit", chickpea and pea will have the greatest potential to experience drought in phases 3, 4 and 5. Thus, for these crops, resistance screening tests on seedlings will be of little significance. Drought in phase 3 will reduce the number of seeds per pod as well as the 100-seed weight while drought in phase 4 will reduce only the 100-seed weight. Drought in phase 5 adversely affects seed quality (Wery et al., 1993).

12.4.1 Mechanism of Drought Stress Resistance

Most drought resistance mechanisms, except tolerance to dehydration can be understood only at the plant level, unlike resistance to thermal stresses which is located mainly at the cell level (Blum, 1988). In drought stress, the preference is given to adaptive mechanisms as in the field drought is established more slowly than freezing or heating.

Turner (1986) gave three mechanisms of drought resistance, viz., drought escape, drought tolerance at high water potential (dehydration postponement) and drought tolerance at low water potential (dehydration tolerance).

Drought escape involves plants having early flowering and pod initiation. Siddique et al. (1999) reported that these plants have early vigour, faster canopy development and less number of days to flowering, podding, seed filling and maturity. In chickpea, the presence of glandular hairs increases the leaf reflectance and can help in avoiding drought to some extent (Khanna-Chopra and Sinha, 1987).

In drought tolerance at high water potential, plants may avoid drought by avoiding tissue dehydration. In this mechanism plants combat drought either by stomatal control or by increasing water use through deep root system or by accumulation of solutes (inorganic and organic) to maintain turgor as water shortage develops i.e. osmotic adjustment. Chickpea is able to realize osmotic adjustment mainly with organic acids and associated ions. Malic acid represent 50% of these acids (Singh, 2002).

In drought tolerance at low water potential, plant cells have the ability to continue metabolism at low leaf water status. This mechanism involves maintaining stability of membranes which could be assessed through electrolyte leakage from desiccated tissues but often it is not correlated with dehydration tolerance. Accumulation of proline (an organic nitrogen source) in cells in response to water deficit is another mechanism protecting protein structures as cells dehydrates. Dehydration tolerance is related to the degree of osmotic adjustment (Hsiao et al., 1984).

12.4.1.1 Osmoregulation

Osmoregulation or osmotic adjustment is a key mechanism for improving WUE and grain yield of crops subjected to a drought environment (Zhang et al., 1999). Osmotic adjustment maintains stomatal conductance, photosynthesis at low leaf water potential, delays leaf senescence, reduces flower abortion and improves root growth by extracting more water from the soil (Ludlow and Muchow, 1990). When soil water availability becomes limiting to physiological processes, crops are more likely to benefit from a conservative approach in the use of remaining soil water, rather than rapidly using water by keeping leaves turgid, stomata open and tissue growing. So for advantageous yield responses to osmotic adjustment the main emphasis should be on stimulation of root development. Serraj and Sinclair (2002) revealed that osmotic adjustment had more significance for root growth rather than any relation with grain yield.

Recent studies conducted at the Indian Institute of Pulses Research (IIPR), Kanpur, India, showed genotypic variation for osmotic potential, indicating the extent of flexibility in osmotic potentials at which legumes can survive and grow (Basu and Singh, 2003). Singh (2002) showed that the high osmotic adjustment of chickpea cultivars (C 214, G 130 and H 208) enabled them to absorb 20–30 mm more water from sub-soil layers than the cultivar (P 324) which was in the low osmotic adjustment class. Thus, osmotic adjustment is not related to the grain yield only but also has an internal physiological consistency for various intervening steps related to growth and yield of plant. Serraj et al. (2004) suggested that the inheritance of osmotic adjustment in chickpea was under the control of a few genes. Therefore, more attention is needed during genetic improvement on adaptation to intermittent drought.

12.4.1.2 Root Growth Dynamics

Roots play an important role in plants such as anchoring the plant and absorbing water and nutrients from the soil. Dicots have tap roots as well as lateral roots. The root system has a vital role in determining yield of grain legumes grown in residual soil moisture under rainfed environments. Summerfield et al. (1981) pointed out that roots extract soil moisture for transpiration that helps in cooling of the plant. Under limited moisture conditions deep rooting is advantageous as it increases drought tolerance (Silim and Saxena, 1993). High root biomass maintains high leaf turgor and leaf water potential provides extra moisture to reduce canopy temperature and provides accessibility to deeper soil and thereby enhances the vegetative biomass. Root size, morphology, depth, length, density and hydraulic conductance are the basic parameters that affect the ability of plants to meet the transpirational demands of the shoot (Passioura, 1983).

Saxena et al. (1993) visualized two contrasting strategies in chickpea to maximize grain yields under water limited environments. The first approach can be an early use of stored soil water ensuring a vigourous early crop growth associated with early maturity. The second approach can be a conservative early use, leaving enough water for later stages in order to ensure a better HI. The genotype ICC 4958, a drought tolerant genotype, has been shown to have the first approach. ICC 4958 has higher root length density at deeper soil layers, which is normally expected to extract more soil moisture. The early shoot growth of ICC 4958 is vigorous (20.4 ± 1.53 g m^{-1} vs 14 g m^{-2}) at 28 days after sowing matching the root growth and enabling an early ground cover so as to reduce evaporative soil water loss. However, this approach can only work well where the soils have adequate depth. The second approach can be maintenance of a low root: total plant ratio from the early stages of growth so as to achieve high transpiration efficiency. The root growth of Annigiri and ICCV 90039 is less with a low root to total plant ratio. Both genotypes were found to yield well under moderate drought stress and well irrigated conditions at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 1993) in a deep vertisol with a progressively receding soil water situation. This approach does not favour highest yields under severe drought stress in a semi-arid environment.

In the mini core germplasm collection studies on chickpea for drought avoidance genotypic variation was observed for root and shoot growth. Therefore, there was a great need to identify quantitative trait loci (QTLs) for the root traits across different growth conditions. A comparison of the two genotypes ICCV 2 and JG 62 exhibited a contrasting temporal interaction for root mass. The root growth of ICCV 2 at early stages was good and, therefore, some of the existing Recombinant Inbred Lines (RILS) of JG 2 × ICCV 2, although not conclusively bred for this purpose, can also be expected to possess a better root system (Krishnamurthi et al., 2003).

12.4.1.3 Water Stress and Microbial Activity

In legumes symbiotic nitrogen fixation is an essential component for their appropriate growth and development. The soil moisture that is adequate for seed germination is also adequate for bacterial movement and nodule development. However, this condition changes with time and may not be optimum for subsequent nodulation growth and their potential activities. It has been noticed that following successful infection reduced water supply can retard nodule development, accelerate senescence of nodules and lead to lower nitrogen fixation rate (Gallacher and Sprent, 1978). Due to limited moisture in soil the soil temperature increases. Sprent et al. (1983) and Rupella and Saxena (1987) reported that water and temperature markedly influenced the rate of formation and fixation and duration of nodules.

Water stress affected the hormonal content of nodules (Hsiao, 1973). The nodules are an active site of synthesis of auxins and cytokinins. Poor biological nitrogen fixation results in poor plant growth and that leads to poor yield and low WUE.

12.5 Factors Influencing Water Use Efficiency

12.5.1 Breeding Approaches

Different grain legumes and their genotypes behave differentially under drought conditions due to their canopy structure, root system and growth periods. There is a dire need to target the specific traits in a breeding program that may lead to higher WUE. Condon et al. (2004) pinpointed three key processes to exploit the breeding work for improving WUE i.e., (i) moving more of the available water through the crop rather than it being wasted as evaporation from the soil surface or drainage beyond the root zone or being left behind in the root zone at harvest, (ii) acquiring more carbon (biomass) in exchange for the water transpired by the crop i.e. improving crop transpiration efficiency and (iii) partitioning more of the achieved biomass into the harvested product. The relative importance of any of these processes will vary depending on water availability during the crop cycle. However, these three processes are not independent.

Differences in plant architecture might be expected to influence the ability of the crop canopy to use available soil moisture and thus affect WUE. Under reduced soil moisture, a semi-leafless line of pea may make more efficient use of available soil moisture in dryland conditions. Early vigour (fast leaf area development) is an important trait for adaptation to terminal drought in Mediterranean environments as it improves the T/ET ratio and encourages growth when evaporative demand is low. The reduction in soil evaporation can be achieved through shading of soil that is possible through rapid development of leaf area. Good stand establishment also covers the soil surface quickly and checks evaporation.

Fababean and lentil, due to early maturity have more opportunity to avoid terminal soil moisture stress. However, chickpea, because of late maturity is affected badly by terminal drought. Late maturity with a poor soil moisture supply leads to reduction in the number of pods per plant because of flower senescence and poor seed development results in poor yields and low WUE. Therefore, in chickpea early maturity even by a single week may produce higher yield and higher WUE. However, in the case of too early maturity cool temperatures are harmful for pod setting and seed filling.

Biederbeck and Bouman (1994) showed that WUE of green manure legumes varied between 11–29 kg ha^{-1} mm^{-1}. Among various legumes, fieldpea and chickling vetch (*Lathyrus sativus* L.) used water more efficiently than other legumes. Monica et al. (2007) revealed that there was a great genetic variability for moisture stress

Table 12.2 Grain yield and drought characters as influenced by irrigation in chickpea genotypes

	Grain yield t ha^{-1}		Per cent reduction in yield	Drought tolerance efficiency (%)	Drought severity index (%)	Membrane injury index	
Genotypes	I_0	I_1				I_0	I_1
BGD 127	0.87	1.44	31.1	60.8	1.05	0.18	0.13
RSG 688	0.96	1.50	35.9	64.0	0.97	0.21	0.22
Phule G 96006	1.26	1.76	28.6	71.3	0.78	0.19	0.16
Phule G 5	1.12	1.76	38.3	60.6	1.05	0.25	0.25
Phule G 94147	0.74	1.34	45.0	54.9	1.22	0.32	0.36

I_0, no irrigation; I_1, Irrigation.
Source: Deshmukh et al. (2004).

tolerance in lotus germplasm. Proline was one of the metabolites that showed high association with water stress.

Deshmukh et al. (2004) showed that Phule G 96006 had minimal reduction in grain yield due to moisture stress. Further, this genotype had the highest drought tolerance efficiency (DTE), least susceptibility index (drought severity index) and minimum membrane injury (Table 12.2). Data indicated that the genotype Phule G 96006 may be rated as tolerant genotype for moisture stress conditions.

12.5.2 Soil Management

Manipulations of the soil surface can lead to changes in the soil water balance in terms of soil water evaporation and infiltration into the soil profile. Hatfield et al. (2001) reported four major factors that influence evaportranspiration. These are (i) the availability of energy (Rn), (ii) gradients of water vapour, temperature and wind speed, (iii) amount of soil water stored in the soil profile, and (iv) the ability of the plant to extract water from the soil profile. These factors are not independent but work jointly to improve WUE. The changes of the soil surface are possible through tillage, surface residue management or mulching. The impact of these factors on WUE varies across locations and cropping systems.

12.5.2.1 Tillage

Tillage roughens soil surface and breaks the soil crust. The roughness of the soil surface though leads to increased water storage by increased infiltration into the soil yet increased soil water losses by evaporation compared with a residue-covered surface or an undisturbed surface. Burns et al. (1971) and Papendick et al. (1973) showed that tillage disturbance of the soil surface increased soil water evaporation relative to untilled soils. Hatfield et al. (2001) reported that the total soil water evaporation fluxes in Dowa were 10–12 mm for a 3-day period following each cultivation operation while these were less than 2 mm from no-tillage fields in the same period.

Cresswell et al. (1993) found that the tillage of bare soils increased saturated hydraulic conductivity (rate of water movement when the soil is saturated) while soil water content before tillage had no noticeable effect. Unsaturated hydraulic conductivity (rate of water movement at water content less than field capacity) was affected by tillage sequence and excessive tillage caused the lowest conductivities because of the increase in air filled pores. The effect of tillage on water infiltration was still considered to be positive. Excessive tillage may reduce infiltration through the effect of hydraulic conductivity. In another study, Aase and Pikul (1995) found that decreasing tillage intensity showed improvement in WUE because of improved soil water availability through reduced evaporation losses. However, in southern Australian red-brown soils the progressive tillage within four years reduced bulk density from 1.9 to 1.34 t m^{-3}. The progressive tillage regimes increased grain yield, grain quality, root length, plant biomass and WUE (Malinda and Darling, 2002). Hatfield et al.

(2001) reported that it is possible to increase WUE by 25–40% through soil management practices that involve tillage. Field scale experience show that the increase in WUE has a positive effect on crop yield.

12.5.2.2 Crop Residues

The residues of various crops are an important resource not only as a reservoir for large quantities of nutrients for crop production but also due to their help in improving the soil properties. Greb (1966) revealed that residues and mulches reduce soil evaporation by reducing soil temperature, impeding vapour diffusion, absorbing water vapour onto mulch tissue and reducing the wind speed gradient at the soil atmosphere interface. Hill (1990) did not observe any crop residue effect on bulk density of soil while Sidhu and Sur (1993) found low bulk density with residue incorporation. Valzano et al. (1997) recorded eightfold increases in hydraulic conductivity in zero-tillage stubble treatments relative to those where stubble was removed by burning. Hydraulic conductivity under straw retained, direct drilled, treatments was 4.1 times greater than that of straw burnt, conventional tillage, treatments (Chan and Heenan, 1993). Residues affect energy balance components and have a large impact on evaporation fluxes.

Crop residues affect the soil temperature substantially. Soils with surface residue are cooler than with no residue (Wilhelm et al., 1989). The cooler temperatures in winter season cause slower crop growth due to limited root function. Although there is an effect of crop residue on soil temperatures, the impact of the residue on the soil water content and the interactions with the soil thermal properties must be considered in interpreting the results of different experiments.

12.5.3 Agronomic Management

12.5.3.1 Time of Sowing

The optimum time of sowing plays a vital role in utilizing the inputs and natural resources efficiently and realizing the yield potential of an improved variety of the crop. Experiments conducted at ICARDA on chickpea showed the highest grain yield as well as WUE both for grain and dry matter when the sowing was done in mid-January. However, there was substantial reduction in both the characters in the case of late November and late February sowing (Oweis et al., 2004b). In another experiment on lentil they showed that mid-November sowing increased biomass productivity by 0.47 and 0.56 t ha^{-1} over late December and mid-January sowing. However, the highest grain yield of 1.60 t ha^{-1} was obtained in a mid-November sowing. Grain water productivity with supplementary irrigation increased significantly under mid-January sowing over the other dates of sowing. The biomass water productivity was 2.05, 1.97 and 1.79 kg m^{-3} under early, normal and late sowing, respectively.

Oweis et al. (2005) reported that the overall mean grain yield of fababean was 1.73, 1.60 and 1.38 t ha^{-1} under early-November, mid-December and late-January sowings, respectively. Correspondingly the overall mean grain WUE was 0.59, 0.61 and 0.52 kg m^{-3} in the three respective dates, indicating that the optimum sowing date was mid-December for high WUE but an earlier sowing used more water and achieved more yield.

12.5.3.2 Planting Method

Grain legumes are usually sown on light-textured soils using a flat sowing method. The growing of a chickpea crop sown after rice on heavy-textured soils has also started recently. In this case if during the reproductive phase a farmer applies irrigation to the crop, the crop fails badly as water stagnates in the root zone. Soon after the irrigation the crop turns pale yellow and plants start dying thereafter due to lack of oxygen. In on-farm trials, the application of irrigation to chickpea caused a drastic reduction in the grain yield when sown on flat beds (Table 12.3). However, crops sown on raised beds (67.5 cm wide) with one irrigation at pod initiation yielded 7.9% higher over that sown on flat beds without irrigation (Sekhon et al., 2004). Chandrakar et al. (1991) reported that on heavy soils excessive moisture under field conditions reduced the growth, nodulation and yield of chickpea drastically. At Hisar, chickpea sown on ridges recorded 30% saving of irrigation water and higher yield over flat sowing (Agarwal et al., 1997).

Table 12.3 Effect of planting methods and irrigation on the grain yield of chickpea after rice in on-farm trials

	Grain yield (t ha^{-1})			
	Locations			
Planting method	Kothe Rehlan	Sidhwan-bet	Kothe Rehlan	Mean
Flat bed, no irrigation	1.87	1.50	2.17	1.85
Flat bed, irrigation	0.36	0.64	0.49	0.49
Raised bed, irrigation	2.02	1.67	2.29	1.99

Source: Sekhon et al. (2004).

12.5.3.3 Criteria for Scheduling Irrigation/Supplemental Irrigation

Irrigation scheduling is the process of determining when to irrigate and how much water to apply to the crop. Proper scheduling is necessary for efficient use of irrigation water and production inputs, saving irrigation water and energy, and leading to higher crop yield and lower production cost. In a situation, where adequate irrigation water is available, the aim is to maximize crop yield with higher WUE. However, in a limited water situation, the emphasis is rationalizing the limited water distribution over the available land, applying water at moisture sensitive stages of crop growth and withholding irrigation at other stages. Though there are several approaches to decide when to irrigate the crop scheduling of irrigation based on crop phenology

Table 12.4 Grain yield and biomass productivity and water productivity as influenced by rainfed and supplemental irrigation in lentil and fababean

	Lentil[a]			Fababean[b]		
Irrigation	Grain yield (t ha^{-1})	Biomass yield (t ha^{-1})	Water productivity kg grain m^{-3}	Grain yield (t ha^{-1})	Biomass yield (t ha^{-1})	Water productivity kg grain m^{-3}
Rainfed	1.04	4.27	0.44	1.13	3.26	0.50
SI 1/3	1.42	5.35	0.54	1.49	4.00	0.57
SI 2/3	1.69	6.00	0.60	1.77	4.50	0.61
SI full	1.81	6.20	0.58	1.89	4.87	0.61

[a] Zhang et al. (2000).
[b] Oweis et al. (2005).

is the most simple and a reliable approach under situations where there is a limited supply of water. Among different stages, irrigation at the flowering stage increases the number of pods $plant^{-1}$, seeds pod^{-1} and seed size in legumes (Ahlawat and Rana, 2002). Singh and Pannu (1998) revealed that flower initiation and pod formation are the most appropriate and critical stages for irrigation of chickpea, lentil and fieldpea.

In dryland areas supplemental irrigation (SI) is a highly efficient practice with great potential for increasing grain legume production and improving livelihoods. Singh (2002) reported 200–300% increase in the grain yield of various crops with one supplemental irrigation under dry environments while a lesser increase in yield was observed in wet seasons. In the Mediterranean environments of Australia for chickpea the WUE for dry matter and seed yield was 8.7 and 3.2 kg ha^{-1} mm^{-3}, respectively and for lentil dry matter and seed yield was 13.7 and 3.8 kg ha^{-1} mm^{-3}, respectively. Supplemental irrigation increased grain yield of both the crops under moisture limited conditions (Zhang et al., 2000). Oweis et al. (2004a) carried out an experiment on lentil at the International Center for Agricultural Research in the Dry Areas (ICARDA) Syria, where mean annual rainfall was 230 mm and reported that the grain yield and biomass yield increased with SI (Table 12.4). The 2/3 SI gave maximum productivity both for grain and biomass. Similar increases in the grain yield and WUE of fababean were recorded by 2/3 SI by Oweis et al. (2005) (Table 12.4).

In northern India, under late sowing conditions particularly after cotton, chickpea benefits highly from irrigation. The highest consumptive use was recorded with two irrigations with highest WUE (7.75 kg ha^{-1} mm^{-1}) and minimum (7.01 kg ha^{-1} mm^{-1}) in the no irrigation treatment (Singh et al., 2004).

12.5.3.4 Crop Nutrition

A balanced fertilizer application is of paramount importance to increase WUE. Leaf stomatal regulation, water holding capacity, membrane permeability and photosynthesis are closely linked to nitrogen (N), phosphorus (P) and potassium (K)

Table 12.5 Effect of Zn application and water stress on total dry matter, grain yield, HI, water use and WUE in chickpea

Treatment		Total dry matter g plant^{-1}	Grain yield g plant^{-1}	HI (%)	Water use L plant^{-1}	WUE	
Zn (μg g^{-1})	Water (g g^{-1})					Dry matter (mg L^{-1})	Grain yield (mg L^{-1})
0.05	0.04	6.67*a*	2.98a	44.3b	2.077a	3.19ab	1.42b
0.1	0.04	6.88*a*	3.05a	43.7b	2.009a	3.43b	1.53b
2.5	0.04	8.36*b*	2.99a	35.6a	2.278b	3.69c	1.33a
0.05	0.12	7.24*a*	3.21a	44.3b	2.387c	3.10a	1.34a
0.1	0.12	8.33*b*	3.72b	44.3b	2.514d	3.32b	1.49ab
2.5	0.12	10.68*b*	4.19c	39.1a	2.843c	3.75c	1.47ab

Source: Khan et al. (2003).

application. Stomatal conductance and transpiration rate under good fertility conditions were lower than those at low fertility under water stress conditions (Wang et al., 2000). N application helped in increasing the leaf net photosynthesis rate under light or moderate water stress while no difference in the leaf net photosynthesis rate existed at severe water stress (Shen et al., 2000).

The application of organic matter (farmyard manure) not only improves physical properties of soil but also increases the water storage capacity and infiltration capacity of soil. Numerous studies show that WUE with high soil fertility are much higher than those with low soil fertility. The optimum water is necessary in fertile soil so as to gain the maximum efficiency for use of water resources.

Micronutrient application is also essential in grain legumes particularly when sown on poor fertility light-textured soils. Zn deficiency is common in many chickpea growing regions. Zn nutrition can influence the susceptibility of plants to drought stress. A reduction in C fixation due to water stress can cause an increase in activated O_2 in chloroplasts that can lead to membrane damage and reduced plant growth. Cakmak (2000) found that Zn has a protective role against photo-oxidative stress. In a pot experiment on chickpea, Khan et al. (2003) showed that 2.5 μg g^{-1} Zn application to soil prior to flowering significantly increased the water use and WUE under water stress conditions (Table 12.5).

12.5.3.5 Cropping Systems

Intercropping Effect

Water use is of great importance in determining resource utilization in intercropping systems. Numerous studies reported increased WUE in intercropping systems (Anders et al., 1996). Morris and Garrity (1993) reported no significant differences in total water uptake between intercrops and sole crops, buts WUE by intercrops ranged from 18 to 99% greater than in sole crops. Mechanisms they proposed for increased WUE include:

Table 12.6 Water use efficiency of grain yield and dry matter of sole and intercrop

Cropping system	WUE ($kg\ ha^{-1}\ mm^{-1}$) Grain	Biomass
Chickpea sole	9.4b	2.6b
Wheat sole	20.4a	8.6a
Chickpea + wheat	20.8a	10.3a

Source: Johansooz (1999)

(a) Capture of a large portion of ET as transpiration by intercrops.
(b) Interception of more light by intercrop.
(c) Greater efficiency of dominant species components.
(d) Higher transpiration efficiency by crop mixtures.
(e) Reduced boundary layers in the "rough" canopy of intercropping patterns (compared with uniform canopies of monoculture).

Johansooz (1999) reported higher WUE for sole wheat than sole chickpea under dryland conditions of Australia while it was similar for sole wheat and a mixture (Table 12.6).

There was a greater positive effect on the N pool of the soil in the case of following a mixture of wheat + chickpea when compared to following wheat alone. This increased soil N amount had a positive effect on the growth of subsequent crops. There was greater amount of residual water in intercropping plots.

Crop Rotation

The beneficial effect of grain legumes is well documented on succeeding cereals with respect to soil fertility, crop productivity, water use, higher economic returns and reducing disease build-up. Kacemi (1992) reported that grain yields of wheat

Table 12.7 Grain yield of wheat and WUE as influenced by previous crop at Morocco

Rotation	Wheat grain yield ($t\ ha^{-1}$)	ET (mm)	WUE ($kg\ ha^{-1}\ mm^{-1}$) Grain	Dry matter
Wheat-wheat	1.08	245	4.4	21.7
Wheat-fallow	2.48	244	10.2	27.1
Wheat-corn	1.81	244	7.4	25.5
Wheat-chickpea	1.95	247	7.9	24.7
Wheat-fababean	2.09	243	8.6	29.6
Wheat-lentil	1.43	238	6.0	26.3
LSD 5%	0.40	-	2.1	5.1

Source: Kacemi (1992).

were higher after legumes and WUE was also more. The ET did not vary but WUE after legumes was higher than wheat-wheat rotation (Table 12.7).

12.6 Radiation Use Efficiency

Under non-stressed environmental conditions, the amount of dry matter produced by a crop is linearly related to the amount of solar radiation, specifically photo-synthetically active radiation (PAR), intercepted by the crop (Health and Hebblethwaite, 1985). The slope of the regression between biomass and cumulative radiation intercepted by a crop has been used to determine the radiation use efficiency (RUE). Reductions in RUE due to water deficits have been reported by Hughes and Keatinge (1983) and Singh and Sri Rama (1989) in grain legumes. Tesfaye et al. (2006) in their studies indicated that dry matter production in grain legumes is highly associated with the fraction of PAR intercepted, which in turn is highly associated with green leaf area index (LAI). Seed yield production of chickpea, beans and cowpeas was strongly positively correlated with their RUE, indicating that RUE is a major component of seed yield. RUE was more sensitive to water stress during early than late stage reproductive water stress. The reduction in RUE due to water stress during the mid season reproductive phase (flowering and pod setting) was 39, 30 and 29%. When the stress was applied late season (pod filling) the reduction was 18, 19 and 17% for beans, chickpea and cowpea, respectively. It was concluded that attainment of high LAI reduces soil evaporation, intercepts and converts radiation into dry matter more efficiently and results in better partitioning of the dry matter to the seed which are the major requirements to attain a high seed yield in grain legumes in semi-arid environments. Beans and chickpea showed high K (extinction coefficient) values during early stage reproductive water stress and had low RUE, suggesting the importance of canopy modification in response to water deficits to maintain high RUE is dry environments. Favourable water supply during flowering and pod filling stages of grain legumes is required to maximize RUE by maintaining high LAI, reducing leaf shedding and flower drop (Tesfaye, 2004).

12.7 Rain Water Saving and Recycling

Rain water saving agriculture refers to integrated farming practices that are able to utilize rainfall water efficiently for life saving irrigation and improving WUE. In the rainy season, due to heavy rains, a lot of rain water is lost in the form of run off and causes soil erosion. Singh (2002) reported that in central India up to 60% of rain water is lost as run off in vertisols. At Hyderabad, India, on vertisols only 38% of the rainfall was utilized for evapotranspiration during the cropping season. About 29% of the precipitation was lost as run off, 24% evaporated from the bare fallow and 9% was lost by percolation. Therefore, there is a dire need for rain water management.which is possible through various scientific measures.

Grain crops are usually raised as a solo cropping system. In fields kept fallow during the monsoon, conservation of soil moisture ensures a successful rainfed chickpea crop (PAU, 1976). Adoption of the following practices helps to conserve the maximum amount of rain water in the soil:

(a) Leveling the field properly before the monsoon season set in.
(b) Dividing each field into small plots and making strong bunds so that the rain water does not run off.
(c) Not allowing weeds to grow as they rob field soil moisture and nutrients.
(d) Opening up the land with deep ploughing for better water absorption. Towards the end of monsoon season the ploughing should invariably be followed by planking.
(e) Ploughing the field only once preparatory to sowing. However, if the soil appears to be deficient in moisture running a roller before sowing facilitates bringing moisture near the soil surface for good germination of seed.

In case the land is sloppy, run off of rainy water can be reduced by maintaining stubbles and by adopting zero tillage. Contour terrancing also helps in better utilization of rain water. On vertisols maintenance of cracks is also essential (Zhang et al., 2002). They further suggested that in an area of less than 350 mm rainfall the rain water can be stored for life saving or supplementary irrigation.

A watershed-based water-harvesting and recycling system has been established at ICRISAT. The Govt. of India has also set up a model water-shed program in a number of villages and there has been considerable increase in the wells in areas of the water-shed program. The availability of water in the wells has enabled farmers to provide life – saving irrigation at the critical stage/s of the crop growth (Singh, 2002).

12.8 Methods of Irrigation

Water saving agriculture aims at more efficient use of irrigation water. The WUE is the basic indicator for measuring the effectiveness of water-saving agriculture. Traditional surface ditch irrigation (flood irrigation) is wasteful as a large quantity of water is applied to the crop. By this method the actual irrigation water supply by flood irrigation is 0.5–1.5 times more than the crop water requirement and the effective use coefficient of irrigation water is rather low at only 0.4–0.5 (Liu and Li, 1999).

Modern irrigation techniques like sprinkler or drip irrigation are very effective in saving water and improving grain yield but involve high monetary investment and energy and are only suitable for cash crops and on sloppy lands. In some experiments in China the ratio of consumed water use for surface irrigation, sprinkling and drip irrigation was 1:0.5:0.3. Besides the water saving effect, the use of sprinkling and drip irrigation increases the grain yield by about 10–30% (Fu, 1989). Sivanappan (1995) observed a 56% saving of water when sprinkler irrigation was used rather than surface irrigation. However, the use of these advanced techniques is not possible in grain legumes due to their poor yield. The improved technology such as land leveling using lasers, surge irrigation and pipe irrigation could successfully save water (Jia, 1999).

Surge irrigation or intermittent irrigation has been found to greatly improve the efficiency of surface ditch or border irrigation by raising water conveyance. It supplies water intermittently to field irrigation ditches or plots at specified time intervals. It can save up to 10–40% of water compared to ordinary gravity irrigation due to reduction in deep drainage and tail water loss (Jia et al., 1994).

Border check irrigation with small plots, 20 m long and 3 m wide could have maximum savings of irrigation water (Sun et al., 1992). Improved border check irrigation by using ridges from long to short, wide to narrow can help greatly in reducing irrigation volume and increasing irrigation uniformity. This technique can also control deep drainage to prevent the rise of ground water tables and soil salinization. From the measurement of soil water at 0–200 cm before and after irrigation, no deep drainage occurred when the ridge length was 30–50 m while deep drainage accounted for 30% of irrigation water when the ridge length was 200–300 m (Lin and Zhao, 1999). Si et al. (1992) showed that alternative ditch irrigation method saved 50% of the water, although yield reduction was only 14%.

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Chapter 13
Efficient Root System in Legume Crops to Stress Environments

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13.1 Introduction

Food grain legumes are very important as source of protein in many parts of the world in general, and developing countries in particular. However, their productivity is usually low, mainly since they are grown in stressfull soil environments. For example, important food grain legumes species, such as, soya bean (*Glycine max* L.), Common bean (*Phaseolus vulgaris* L.), Chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), cowpea (*Vigna unguiculata* L. Walp.), grasspea (*Lathyrus sativus* L.), lentil (*Lens culinaris* Medik.), black gram (*Vigna mungo* L. Hepper) and mung bean (*Vigna radiate* L. Wilczek) are usually grown in marginal areas under rainfed conditions and their yields are fairly low (Lawn and Ahn, 1985; Muehlbauer et al., 1985; Simithson et al., 1985; Steel et al., 1985; Silim et al., 1993; Campbell et al., 1994; Loss and Siddique, 1997; Frederick et al., 2001; Palta et al., 2004; Thomas et al., 2004; Munoz-Perea et al., 2006; Kashiwagi et al., 2006).

Crop performance under such stress conditions is closely related to root system development. For example, drought tolerance of the food legume species is closely associated with the distribution of root system, or rooting pattern in the soil (Kono et al., 1987; Itani et al., 1992; Pandey et al., 1984; Silim and Saxena, 1993a; Gaur et al., 2008), which is, in general, the consequence of root growth of plants in the early growth stage. In this regards, knowledge of root characteristics is required agronomically to select suitable crop species to be grown in a particular environment. Further, knowledge of genotypic variation within each species is also essential for agronomy as well as genetic improvement of crop species.

A crop root system consists of different types of component roots whose characteristics, such as length and number, determine the structure of root system (Yamauchi et al., 1987). However, in many cases, the root system structure in the field is so greatly affected by environmental conditions that identification of the root system structure of a particular species or genotype sometimes seems to be

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almost impossible. In spite of this fact, several attempt have been made, which found that rooting shape, size and root system structure vary greatly among the species (Brar et al., 1990; Newman and Mosser, 1988; Yamauchi et al., 1987; Abdelhamid et al., 2009). In addition, based on the extensive review on various root research, O'Toole and Bland (1987) concluded that genetic variation exists among different crop species.

Generally, it has been suggested that the total root length beneath cool-season food legume crops is about five to 10 times smaller than that below same area of cereal crops (Hamblin and Tennant, 1987; Gregory, 1988), and that the size of the root system of legumes appears to increase throughout the growth period although the rate of increase slows as seed filling commences (Gregory, 1988; Brown et al., 1989; Husain et al., 1990).

Moreover, for widely grown legume species such as soya bean (Kaspar et al., 1984), black bean (Stoffella et al., 1979), and pea (Ali-Khan, 1977) genotypic differences in rooting characteristics have been reported. Some root data for chickpea, cowpea, grasspea, lentil, black gram and mung bean are available (Kahn and Stoffella, 1987; Vincent and Gregory, 1986).

13.2 Root Development Under Stress Environments Under Warming Climates (Case Studies)

The soil stress factors include chemical, physical, and biological factors. One of the major chemical factors is pH (Foy, 1992). In addition to the direct effect of low soil pH, the majors problems are the toxicity of soluble aluminum ions and deficiency of phosphorus associated with soil acidification. In contrast, when the soil pH is high, there are alkalinity-salinity problems, which have been extensively studied in relation to dryland farming and desertification (Poljakoff-Mayber and Lerner, 1994). On the other hand, examples of the physical factors are soil moisture, soil air (Zobel, 1992; Jackson, 1985), soil temperature, and soil strength. The biological factor include soil microorganism, which are also known to affect root system morphology and function (Curl and Truelove, 1986; Peterson, 1992; Atkinson et al., 1994; Yano et al., 1996b).

Under field conditions, crop growth and yield are usually substantially lower than what is to be expected given adequate solar radiation, air temperature, and genetic potential. This fact is mainly due to environmental stresses, most of which are related to soil and seasonal weather factors.

The situation is complicated in the field, where these factors interact. Considering the large amount of research related to soil stress, little has dealt with the effects of such stress on the development of plant roots. Most cultural practices re targeted at reducing stress factors, hence, root responses are critical to improving crop production system and technology.

There was not a great deal of attention given to separating productivity under drought, which is important for agricultural plants, from survival mechanisms. Yet many adaptations to survival tend to reduce economic yield (Richards, 1997). As discussed by Mullet and Whitsitt (1997), one approach to improve crop performance in water-limited environments is to select for genotypes that have improved yield in these environments. This approach has proved partially successful, but difficult to accomplish due to the variability of rainfall and the polygenic nature of drought tolerance. A complementary approach to improve plant performance for drought-prone regions involves the identification and selection of traits that contribute to drought tolerance or water use efficiency (WUE). A partial list of potentially important traits might include water-extraction efficiency, WUE, hydraulic conductance, osmotic and elastic adjustments, and modulation of leaf area. Most of these traits are complex and their control and molecular basis are ill-understood.

In this section we will refer to some research on the effect of soil stress (drought) on root system development and structure. In the different studies, special attention has been given to show different component roots respond to water deficit stress in different ways, in order to ensure the survival and growth of plants under drought stress.

The condition of limited water supply in the soil to support plant growth is the most common form of stress that plant face. Droughted plants generally exhibit a small root system configuration and the reduction in root system size is directly proportional to the magnitude of water shortage in many cases. In cereals, for example, under severe water stress there is a much slower rate of root elongation than under well-watered conditions (Sharp et al., 1988; Pardales and Kono, 1990). Fraster et al. (1990) showed that the decreased root elongation that takes place under drought is due to the significant reduction in the rate of cell supply to the cortical layers a few millimeters behind the root apex. This information corroborates the earlier point raised by some researchers (e.g., Molyneux and Davies, 1983), that cell growth is the primary process affected by limited soil moisture supply.

However, as stated earlier, soil water stress does not exist in isolation, but is mutually interactive with soil structure, all of which integratedly affect the root growth. Previous studies have rarely paid attention to this fact, because it is extremely difficult to experimentally evaluate the effect of each factor separately as well as their integrated impact (Taylor and Gardner, 1963; Talyor and Ratcliff, 1969). Furthermore, there have been very few studies that quantitatively evaluate soil moisture stress effects on root growth (Kramer, 1983). This is mainly attributed to the unavailability of experimental techniques to precisely and simultaneously determine the elongation of roots and the water status of the soil.

Consequently, we can find research reports that show conflicting results, i.e., promoting and inhibiting effects of soil water stress on root growth. Taylor (1983) indicated that a soil moisture content of less than –1 MPa apparently retards root growth, whereas in wetter soil this effect is unclear. On the other hand, mild water stress does not affect root growth (Mia et al., 1996), or often increases the root/shoot (R/S) ratio, or promotes root growth itself (Weerathaworn et al., 1992). Main concerns of these studies are mostly the elongation of axile roots or root weight, but not the responses of root system structure to dry soil.

Drought-adapted plants are often characterized by deep and vigorous root systems. In robusta coffee, by growing four contrasting clones in large containers

(120 L), Pinheiro et al. (2004) observed that a deeper root system could be associated with better avoidance to soil water limitation in drought tolerant clones than in drought-sensitive ones. Another study has associated drought tolerance with a larger root dry mass, shown by Ramos and Carvalho (1997) working with 29 coffee genotypes. These authors did not find significant genotypic correlations between drought tolerance and production, hence suggesting that these traits were independent of each other. A great limitation of this work resides in assessing the root system using seedlings and, by contrast, assessing production in field-grown adult plants. Moreover, it is not known if the root behaviour at the seedling stage resembles that of the adult coffee tree. In any case, the difficulties in evaluating root systems, the large environmental influences and the complex inheritance of root characteristics hinder the use of these traits in selection programmes in spite of the obvious positive relationship between root depth, root growth and yield under drought conditions (Medrano et al., 1998).

13.3 Soya Bean

The effect of drought on soya bean (*Glycine max* L.) root system was studied by Kono et al. (1987) using the root-box method. This study examined all the components roots in the root system. Plants were grown under three different irrigation regimes for 38 days: control, well watered (approximately 43% to the maximum water-holding capacity of the soil); drought, irrigated from the top of the box (TI), and irrigated from the bottom of the box (BI) (36% of maximum soil water-holding capacity).

Shoot dry weight was inhibited to 60% of the control in TI plots and to 45% in BI plot, whereas inhibition of root growth was much less, i.e., to 96% in TI and to 82% in BI in terms of length. The drought treatment substantially increased the ratio in number and length of the third and fourth order lateral roots, which compensated for the inhibited growth of the lower order lateral roots. In addition, drought greatly altered the root system structure by promoting the production of long lateral roots that emerged from the basal portion of the taproot, thus making the direction of elongation of these lateral roots more downward (smaller rooting angle).

On the other hand, there were some root parameters that were rarely affected by soil moisture conditions. Examples of these are the branching order of lateral roots (the plants branched up to fourth order in the three plots) and the ratio of the number of L-type to S-type laterals.

The various components of the root system in some annual plants appear to have different responses to an on-going drought. In the case of sorghum, for example, Pardales and Kono (1990) reported that progressive drought that commenced 12 days after planting first caused a reduction in the number of lateral roots coming from the seminal root and nodal root axes, including the laterals on them. Increasing drought intensity eventually caused complete arrest in the growth of seminal root laterals while new nodal roots and first-order laterals continued to be formed although at a much depressed rate compared with that observed in well-watered plants.

Pardales and Kono (1990) also noted continued root growth in sorghum in terms of number and length of nodal roots under increasing drought intensity. This observation, and the report of Jupp and Newman (1987) that different parts of the root system of *Lolium perenne* tend to have different critical periods at which they succumb to the desiccation effect of drought, suggest that the different root system components in annuals may have different threshold levels at which they succumb to drought.

On the other hand, it may be that a certain level of drought intensity causes promotionof growth in some root system components. However, the increase in root growth under drought intensity is not well understood and thus needs to be clearly established because of the seemingly beneficial implication it will contribute to the general performance of plants growing under water stress conditions. The changes in the amount of available water with regard to soil layer are known, however, the cause of differentiation in root system components' distribution in the soil needs to be further investigated. Osonubi and Davies (1981) and Kono et al. (1987) mentioned that a water deficit in the upper soil layers promote deeper root penetration thereby allowing the plant to effectively use the available water stored deeper in the soil profile, provided that there is a moist soil link to the subsoil.

13.4 Faba Bean

Faba bean (*Vicia faba* L.) crops are generally regarded as sensitive to drought stress, and irrigation may strongly improve yield and yield stability of this species (Day and Legg, 1983). However, one of advantageous adaptations to drought stress shown by faba beans s increased root growth, particularly at depth (El Nadi et al., 1969; Husain et al., 1990). Studies on the effect of drought stress on faba bean root system growth revealed that water shortage, compared to frequent irrigation, leads to increased rooting depth and rooting density (El Nadi et al., 1969; Husain et al., 1990).

Faba bean has been shown to be relatively shallow rooting. The maximum rooting depth varies between 50 and 90 cm, depending on the genotype, water supply, and soil physical proper-ties (Rowse and Barnes, 1979; Hebblethwaite 1982; Day and Legg, 1983; Gregory, 1988; Husain et al., 1990). El-Shazly (1993) reported significant differences between 12 faba bean genotypes in total root length on the intact root system in pot and field experiments and found mass production of roots was mostly concentrated in the first 30 cm of the soil. Total root length values ranged from 21.9 to 28.4 m per faba bean plant grown for 11 weeks (Abdelhamid et al., 2009).

LiJuan et al. (1993) explained the characteristics of fab bean root system. The test materials were local Chinese small-seed varieties, which were sown in clay loam soil on 28 October. Observations of two successive years showed that radical emergence occurred when the seed germinated. The tap root elongated through the radical cap 5–7 days after sowing, and was more than 50 cm long at blooming stage. In sandy loam soil, Yu and Zhang (1979) had observed that the tap root could penetrate to a depth of 100–120 cm at the end of March. The growth of the tap root was fastest at seedling stage before winter, with an average daily growth of 7.35 cm. Faba bean has abundant lateral roots, which can emerge from the tap root and the plumule buried in the soil. The lateral root extrusions appear on the tap root when the seedling emerge and turns green. At the end of November, i.e., a month after sowing, the lateral roots occupy more than 60% of the total root mass, 80–90% of which were produced during 2nd and 3rd leaf stages (branching stage). The average daily transverse growth of laterals during these stages reaches 1.4–2.3 cm. On average, there are more than 85 primary laterals/plant during the blooming stage. Laterals can penetrate to a depth of 45 cm. However, 50–60% of the laterals are in the arable layer of 0–10 cm depth. The laterals expand transversely to more than 50 cm, which is nearly the length of the tap root. According to Yu and Zhang (1981) some laterals distribute horizontally near the soil surface around the tap root, when grow obliquely for 45–80 cm before they grow downward. These laterals can reach a depth of 75–100 cm. However, most of the root system distributes in the surface soil around the tap root within a depth of 30–40 cm. Secondary laterals are produced when the second complete leaves expand, forming a strong lateral system.

13.5 Chickpea

Chickpea (*Cicer arietinum* L.) under terminal drought (the soil moisture stress that occurs at the pod filling and seed development stage of the chickpea with increasing severity at the end of seasons) is a major constraint to chickpea production in over 80% of the global chickpea area, as the crop is largely grown rainfed in post-rainy season (Gaur et al., 2008). Efforts to breed drought tolerant varieties in the past have not been rewarding because of imperfect understanding of drought manifestation and using yield as an empirical selection criterion (Saxena, 2003). Several studies in recent years have focused on identification of morphological and physiological traits associated with drought tolerance. Root traits, such as root depth and root biomass, have been identified as the most promising plant traits in chickpea for terminal drought tolerance, as these help in greater extraction of available soil moisture. This section provides a brief review of the research progress and highlights future prospects of improving root traits for enhancing drought avoidance in chickpea as stated by Gaur et al. (2008).

13.5.1 Importance of Root Traits in Drought Avoidance

The yield of chickpea genotypes under rainfed and irrigated conditions were compared at ICRISAT to gather information on yield under drought conditions and potential yields (Saxena, 2003). More than 1,500 chickpea germplasms plus released varieties were subjected to field screening and some genotypes were identified to have higher drought tolerance indices, although each had a different trait or mechanism for coping with terminal drought (Saxena, 1987, 2003). Only one genotype, ICC 4958, that exhibited the best performance not only in field trials at ICISAT but also at several other locations in India and in the Mediterranean type climate at Syria, had higher root biomass (ICARDA, 1989; Krishnamurthy et al., 1996; Ali et al., 2005). Subsequently, in a field experiment at ICRISAT with 12 diverse chickpea germplasms, including ICC 4958, it was shown that a prolific root system, especially at the 15–30 cm soil depth, contributed positively to the seed yield under moderate terminal drought intensity and a deeper root system was shown to contribute to improved yield under severe terminal drought conditions (Kashiwagi et al., 2006).

Also, in a cool-temperate sub-humid climate of New Zealand, the importance of surface soil horizons (0–30 cm) in providing major water requirements of kabuli chickpeas and the ability of chickpea to draw water from depths below 60 cm have been clearly shown (Anwar et al., 2003). The advantage of a deep root system towards drought tolerance was also substantiated in soybeans (Kaspar et al., 1978), common beans (Sponchiado et al., 1989) and chickpea (Silim and Saxina, 1993b). Some major root attributes such as greater efficiency in water absorption per unit root length density, ability to change the rooting pattern across soil depths to efficiently access the available soil moisture and the ability to produce a larger root surface area per unit root biomass seem to make chickpea the best choice for the dryland cropping systems compared to other legumes or cereals (Thomas et al., 1995; Ali et al., 2002; Tilahun and Schubert, 2003; Benjamin and Nielsen, 2006).

Root length density of chickpea has been shown to be substantially lower than that of barley but, absorbed water more efficiently than barley plants (Thomas et al., 1995). The difference in water use between these species was a function of root hydraulic conductivity, which is governed by the diameter and the distribution of the meta-xylem vessels (Hamblin and Tennant, 1987). Chickpea have the ability to change their root distribution across soil depths depending on the soil moisture availability. The chickpea root system at the mid-pod fill stage has been shown to be two to three times greater in the surface soil layer (0–15 cm) alone when irrigated, matching the irrigation effect of two to three times greater shoot biomass productivity at maturity. Whereas the proportion of root length density distributed at deeper soil layers (115–120 cm) was shown to be higher under receding soil moisture conditions (Ali et al., 2002). In another comparison, chickpea and field pea pea have been found to have a greater proportion of their root system deeper in the soil profile under dryland conditions compared to irrigated conditions (Benjamin and Nielsen, 2006) while soybean was found to have a similar proportion of roots distributed across depth irrespective of irrigation treatments. Additionally chickpea was found to posses a higher root surface to root weight ratio compared to field pea or soybean (Benjamin and Nielsen, 2006). These results suggest that chickpea are better equipped towards tolerance to drought stress and further improvement of root traits would be one of the promising approaches to improve the drought avoidance of chickpea under the terminal drought environment.

13.6 Genetic Variability in Root Traits

A mini-core collection ($n = 211$) of chickpea germplasms was developed at ICRISAT (Upadhyaya and Ortiz, 2001), and it was evaluated for root traits using the cylinder culture system subsequently, Large and significant variation was found among the accessions of the mini-core collection for root length density (RLD), root dry weight (RDW), rooting depth (RDp) and root to total plant weight ratio (R/T) (Kashiwagi et al., 2005a, b). The significant genotype x season interaction that occurred for RLD and R/T in this study was found to be of non-crossover type. This was assessed by employing a rank correlation between the accession means of the two seasons. The accession ICC 4958, earlier identified to have a large root system, was among the crop ranking genotypes for a profilic root system. In addition, an accession, ICC 8261, was identified as the one with the most prolific and deep root system among the chickpea mini-core collection.

13.6.1 Molecular Mapping of QTLs for Drought Avoidance Root Traits

Molecular markers linked to major quantitative trait loci (QTLs) for root traits can greatly facilitate marker-assisted selection (MAS) for root traits in segregating generations. Over 500 simple sequence repeat (SSR) markers have been developed in chickpea (Hüttel et al., 1999; Winter et al., 1999; Lichenzveig et al., 2005) and the chickpea genome map is rapidly expanding (Millan et al., 2006).

A set of 257 recombinant inbred lines (RILs) from Annigeri x ICC 4958 cross was developed at ICRISAT and characterized for root traits (Serraj et al., 2004) and SSR markers. A SSR marker, TAA 170, was identified for a major QTL that accounted for 33.1% of the variation for root weight and root length (Chandra et al., 2004).

13.7 Techniques for Growing Plants for Saving Water

Water stress is one of the most common environmental stresses that may limit agricultural production worldwide. Many vegetable crops, have high water requirements and in most countries supplemental irrigation is necessary for successful production. However, in many countries as a consequence of global climate changes and environmental pollution, the availability of water for use in agriculture will be reduced. Therefore, great emphasis is placed on crop physiology and crop management for dry conditions, with the aim to make plants more efficient in water use.

Recent results demonstrated that regulated deficit irrigation (RDI) and partial root drying (PRD) are the irrigation methods that tend to decrease agricultural use of water. RDI is the method where the control and management of water stress was achieved by irrigating at less than the full requirement of the plants and, thus, maintaining soil moisture at a relatively dry level. RDI significantly limits leaf growth and this treatment generally results in yield reductions (Matthews and Anderson, 1988). Partial root drying (PRD) is an irrigation technique where half of the root zone is irrigated while the other half is allowed to dry out. The treatment is then reversed, allowing the previously well-watered side of the root system to dry down while fully irrigating the previously dry side. Compared to RDI, implementing the PRD technique is simpler, requiring only the adaptation of irrigation systems to allow alternate wetting and drying of part of the rootzone (Loveys et al., 2000). The PRD technique was developed on the basis of knowledge of root-to-shoot chemical signalling in drying soil and, therefore, understanding of this process is essential for successful application of the PRD technique.

In this regard, Abdelhamid et al. (2008), using soil columns in which the root system was divided into two equal layers, each 24 cm in diameter and 33 cm high, examined the influence of drying different proportions of the root system on the water relations, gas exchange, nodulation, nitrogen fixation and growth of faba bean (*Vicia faba* L.). The treatments were: (i) adequate water in both soil layers (Well-watered), and (ii) water withheld from the upper layer only (limited water). The two watering treatments were imposed from 61 to 81 days after sowing (DAS) when the plants were flowering. Drying the soil surface reduced the photosynthesis rate over the measurement period by 15% as a result of the reduction in stomatal conductance from 568 to 448 mmol/m^2/s. Drying the topsoil (0–30 cm) profile resulted in significant reduction in the length and width of leaflets. Total root biomass and root length density were reduced by 23 and 37%, respectively, when the topsoil was dry. Water restriction drastically affected nodulation, and N_2 fixation of faba bean plants.

13.8 Conclusions

Climate change may bring about increased aridity to extend areas of the world. Thus it is important to evaluate the effects of elevated CO_2 in association with other stress factors, namely high temperature and water deficit.

The recent reviews of methodologies for root studies and identification of the large variation in root characters of the germplasm have increased concern of researchers in exploiting root traits for improving drought tolerance in food legumes.

Molecular markers linked to major quantitative trait loci (QTLs) for root traits can greatly facilitate marker-assisted selection (MAS) for root traits in segregating generations. MAS for root characteristics is expected to greatly facilitate breeding for root characteristics, enabling the combining of different drought tolerance traits to develop cultivars adapted to a range of drought environments.

The effectiveness of root traits in improving drought avoidance would vary depending on growth environment, e.g. soil type, moisture status of the soil, soil compaction, etc. (Gaur et al., 2008). There is a need to characterize the drought environments and identify suitable mechanism(s) of drought tolerance for each specific environment.

Although the importance of root traits in drought avoidance is well-recognized, other plant mechanisms for coping with drought stress are not well understood in food legumes.

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Chapter 14
Weed Suppression in Legume Crops for Stress Management

Gudeta W. Sileshi and Taye Tessema

14.1 Introduction

In many cropping systems farmers spend more time and labour (up to 70% of family labour) in removing weeds from their crop than in any other farm operation (Chikoye et al., 2001). Worldwide, weeds constitute a major constraint to the production of legumes as many legume species are poor competitor to weeds because of slow growth rate and limited leaf area development at early stages of crop growth (Solh and Palk, 1990). Hence, losses could be substantial when optimum weed control is not achieved. In chickpea (*Cicer arietinum*) for instance, yield losses vary between 40 and 94% in the Indian subcontinent, between 40 and 75% in West Asia, 13–98% in North Africa, and 35% in Italy (Solh and Palk, 1990). In legumes such as chickpea, excessive weed competition may also adversely affect seed size, which is an important quality parameter in the Mediterranean region (Solh and Palk, 1990). Losses could vary from site to site or year to year depending on the legume species, the type of weed (parasitic vs. non-parasitic), the prevailing weed species, level of weed infestation, soil type, climate and management practices. Weed control becomes even more critical where moisture is limiting. When moisture is in short supply, weeds can reduce crop yields more than 50% through competition for moisture. In the past certain misconceptions about weeds have led in some cases to inappropriate use of control practices. Weeds have been assumed to exert only negative effects within cropping systems (Liebman and Dyck, 1993). However, weeds may enhance agro-ecosystem stability in terms of maintenance of ground cover, conservation of nutrients, and provision of habitat for beneficial organisms (Liebman and Dyck, 1993; Sileshi et al., 2008a). This calls for an ecosystem approach to weed management where the objective is weed management rather than control.

In the future, climate change, invasive weeds and herbicide resistance, are likely to pose challenges to weed management and water conservation. While rain-fed

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agriculture is likely to remain a feature of the subsistence and large-scale agricultural enterprises in the foreseeable future, climate change will be a major determinant of their productivity. Another emergent problem is the increase in invasive alien species of weeds, which is partly aggravated by increased global trade and climate change (Ziska and George, 2004). Many plant species have moved out of their natural geographic locations and have spread around the world with humans either as accidental or deliberate introductions. The weedy nature of these species often gives them an advantage over more desirable crop species because they often grow and reproduce quickly, have seeds that persist in the soil seed bank for many years, or have short life-spans with multiple generations in the same growing season. Some species when introduced into a new environment lack the competition and predation they evolved under in their native environments freeing them to proliferate quickly. The most serious problem that invasive weeds pose is their consumption of large quantities of water. For example, the invasive tree, slatcedar (*Tamarix ramosissima* Ledeb) uses more than twice as much water annually as all the cities in southern California (Johnson, 1986). The overall effects of climate change on weed invasions seem to bring bad news for farmers. Most of the important elements of global change are likely to increase the prevalence of invasive species (Dukes and Mooney, 1999). Thus invasive weeds could jeopardize legume production under climate change.

In this chapter we will synthesize the state-of-art knowledge on weed management in legume production systems with a major emphasis on climate change and alien invasive species. Although the focus of this book is on cool season legumes, we have also included warm season tropical legumes. Cool season legumes are more widely grown in Mediterranean climates, which are characterized by relatively scarce and erratic precipitation, with wet winter, and dry and hot summers. This is typical of the Mediterranean basin in south Europe, North Africa and West Asia as well as Western Australia and parts of South Africa. However, these legumes are also adapted to various tropical or subtropical climates. For example, most cool season legumes are widely grown at high elevations in subtropical countries such as Ethiopia. In fact, wild and primitive forms of field pea and faba bean (*Vicia faba*) are known to exist in the high elevations of Ethiopia, and hence some authorities consider Ethiopia as one of the primary centres of diversity (Keneni et al., 2007). With the increased interest in crop diversification in recent years, cool season crops are being promoted more and more in tropical and subtropical climates. For example, chickpea is being promoted in Malawi to make use of residual moisture after harvest of main crops. In such areas a substantial overlap is expected in the distribution of cool season legumes and tropical warm season legumes. We believe that limiting the discussion to cool season crops only will not be helpful to the increasing number of farmers who grow both types of legumes. Therefore, this chapter will use a broader framework in order to address the relevant issues in legume cropping systems not only in Mediterranean climates but also other climates especially in Sub-Saharan Africa and the Indian subcontinent. Because of the lack of economic development and institutional capacity, societies in these regions are likely to be among the most vulnerable to the impact of climate change (IPCC, 2001).

14.2 Types of Weeds and Weed Effects in Legume Cropping Systems

14.2.1 Parasitic Weeds

The economically important group of parasitic weeds in legumes belongs to the genera *Orobanche* (Family Orobanchaceae), *Striga* and the closely related genus *Alectra* (Family Scrophulariaceae). *Orobanche* species are holoparasites, i.e. lack chlorophyll and entirely depend on hosts for nutrition. On the other hand *Striga* and *Alectra* are hemiparasites, i.e. they have some chlorophyll and are capable of photosynthesis, but they still rely on hosts for water and minerals. All are obligate root parasites and connection with a host plant is fundamental in order to survive. Therefore, their seeds principally remain dormant until a chemical exuded by the host root indicates the vicinity of a host. Their seeds germinate and produce a germ tube that must create a contact with the host root or die. Once the parasite attaches to the host, materials are transferred from the source (crop) to the sink (parasite) through straw like penetrations, called oscula. Affected plants usually grow slowly and, dependent on the severity of infestation, biomass production is lowered. Crop damage is often very significant and depends on crop variety, soil fertility, rainfall pattern and level of infestation in the field. The loss caused by *Orobanche* spp. is often directly proportional to its biomass (Sauerborn et al., 2007). The loss inflicted by *Striga* infection may be even greater than the parasite's biomass, indicating the involvement of other than source/sink-based relations such as the reduction of photosynthesis in the host plant (Frost et al., 1997).

14.2.1.1 Orobanche Species

The genus *Orobanche* includes more than 100 species in both the eastern and western hemispheres. They attack mainly dicotyledonous crops in both rain-fed and irrigated production systems (Parker and Riches, 1993). *Orobanche* species are favoured by relatively low atmospheric humidity, which ensures a high rate of transpiration and hence enhanced transfer of water and solutes from the host (Parker and Riches, 1993). Most of the economically important species are native to the Mediterranean region (i.e. North Africa, the Middle East, and southern Europe), and western Asia (Mohamed et al., 2006). However, invasive *Orobanche* species extend to North America, South Asia, Southeast Asia, Southern Africa, and Australia (Mohamed et al., 2006; Parker and Riches, 1993; Rispail et al., 2007). With the anticipated climatic changes taking the form of higher temperatures and drought, most of the *Orobanche* species also pose potential invasive threats to much of the United States, southern and eastern South America, eastern Asia, southern Africa, and southern Australia (Mohamed et al., 2006). In the following sections we will discuss those species that affect legumes:

Orobanche crenata Forsk occurs exclusively in agricultural and disturbed habitats. It is an important pest in faba bean, pea (*Pisum sativum*), lentil (*Lens culinaris*), vetches (*Vicia* spp.), grass pea (*Lathyrus sativus*), chickpea (*Cicer arietinum*) and other grain and forage legumes in the Mediterranean and Middle East (Joel et al., 2007; Mohamed et al., 2006; Rubiales et al., 2006). It occurs mainly in rain-fed crops, and has been reported to be reduced under wet conditions (Parker and Riches, 1993). *O. crenata* has a limited range and has been known primarily from southern Europe and countries around the Mediterranean basin in North Africa and the Middle East. It also shows a more restricted invasive potential compared with other species (Mohamed et al., 2006). The limits of its distribution could be attributed to its low and narrow range of optimum temperature requirement for conditioning and germination, which was found to be around 18°C. Both lower and higher temperatures resulted in poor germination. As a result, for example, in Israel, *O. crenata* was found only in winter (Mohamed et al., 2006). At high infestations, this species could cause severe losses. In Israel it caused 100% loss in peas (Bernhard et al., 1999). In Morocco, the total infested area was estimated to be about 50% of the total faba bean area, causing 12–33% yield losses (Gressel et al., 2004). In Tunisia, losses in faba bean yield were estimated at 50–80%. In Egypt, *O. crenata* occurs in

Fig. 14.1 *Orobanche crenata* infestation showing 100% yield loss on faba bean in South Wello, Ethiopia (Photo Taye Tessema)

20% of the total area cropped with faba bean, causing 5–33% (Gressel et al., 2004). In Ethiopia the practice of harvesting green pods of faba bean is customary to prevent further yield loss by the weed. According to farmers crop loss could reach as high as 75–100% in some areas (Fig. 14.1).

Orobanche aegyptiaca Pers attacks a wide range of cops including tomato, potato, tobacco, eggplant, bell-pepper, pea, vetch, faba bean, carrot, celery, parsley, cumin, cabbage, cauliflower, rape, mustard, turnip, hemp, sunflower, spinach. In some areas, e.g. southern Russia, melon and water melon are also hosts. It also parasitizes ornamentals like Chrysanthemum and Gazania (CABI, 2003). It is an important pest of faba bean, common vetch, grass pea, chickpea and lentil in the Middle East and Asia. In addition, it also attack peanut (*Arachis hypogea*) (Parker and Riches, 1993).

Orobance foetida Poiret is widely distributed in natural habitats particularly in the western Mediterranean countries – Morocco, Algeria, Tunisia, Portugal and Spain (Vaz Patto et al., 2008). Until recently, it was known to attacks wild leguminous plants in the genera *Anthyllis, Astragalus, Ebenus, Lotus, Medicago*, *Ononis, Scorpiurus* and *Trifolium* (Pujadas-Salvá, 2002). It was considered an important agricultural parasite in faba bean and chickpea only in parts of Tunisia (Kharrat et al., 1992). In Tunisia, heavy infestation of faba bean fields by *O. foetida* is an emerging problem (Abbes et al., 2007). It has also been found in Morocco infecting common vetch (Rubiales et al., 2005). Recent studies show that *O. foetida* is evolving from parasitising wild hosts to crop plants, and this host shift is likely to pose a threat to agriculture (Vaz Patto et al., 2008).

Orobanche ramosa L. is mainly distribute in the Mediterranean but also extending to central Europe, the Middle East, northern Africa and Ethiopia. *O. ramosa* can infect several legumes including chickpea, clover, groundnut, faba bean, lentil and pea (Parker and Riches, 1993). Its host range outside the legumes is very wide, including some members of the families Alliaceae (onions), Cannabidaceae, Asteraceae (lettuce, niger seed, safflower and sunflower), Brassicaceae, Solanaceae (tomato, eggplant, tobacco), Cucurbitaceae (melon, watermelon, cucumbers), and Umbeliferae (carrot, parsley, celery, parsnip) (CABI, 2003; Parker and Riches, 1993).

Orobanche minor is found in native and disturbed habitats throughout the central and southern parts of Europe, and extends to the eastern coast of Africa and southwards (Parker and Riches, 1993). It has a wide host range among forage legumes in temperate climates. In addition, it was imported to various other parts of the world and is currently found as a garden weed. It is of economic importance on clover (*Trifolium* spp.) in the USA (Eizenberg et al., 2004). Although other *Orobanche* species can infect leguminous plants, they are generally of little economic importance.

14.2.1.2 *Striga* Species

Worldwide, more than 30 species of *Striga* are recognized, 22 of which are endemic to Africa, the centre of distribution and diversity (Mohamed et al., 2006). *Striga* species are a particular problem in sub-humid and semi-arid areas (Parker and

Riches, 1993; Rispail et al., 2007). So far, *Striga gesnerioides* (Willd.) is the only species known to parasitize legumes. This species also parasitizes members of the family Convolvulaceae, Agavaceae and Euphorbiaceae. It occurs in natural vegetation throughout the drier regions of Africa (Reiss and Bailey, 1998). *S. gesnerioides* is highly variable but host-specific (Musselman, 1980). To-date eight host-specific strains of *S. gesnerioides* have been described (Mohamed et al., 2006). Of these, the *Vigna* strain that attacks cowpea (*Vigna unguiculata* L.). Walp is the most important biotic constraint to cowpea production in the Sahel, the Sudan savannah and the northern Guinea savannahs of Mali, Burkina Faso, Niger, Senegal, Chad, Togo, Benin, Nigeria and Cameroon (Parker and Riches, 1993). Yield losses of 30% or more are common in these regions (Riches, 2002). Host-specific strains of *S. gesnerioides* also attack tobacco in localized areas in southern Africa, and sweet potato in East Africa. Interestingly the strain, that attacks tobacco in Zimbabwe and South Africa is unable to develop on cowpea roots, even though it is stimulated to germinate by root exudates from cowpea and other legume non-hosts including pigeon pea and velvet bean (*Mucuna pruriens*) (Riches, 2002). On the other hand, the American strain of *S. gesnerioides* has not been reported to attack cultivated crops (Mohamed et al., 2006).

The *Vigna* strain of *S. gesnerioides* devastates cowpea mostly in the Guinea and Sudan savannahs and the Sahel region of West and Central Africa (Parker and Riches, 1993). However, the Sudano-Sahel zone is generally more affected than the Guinea savannah zone (Singh and Emechebe, 1997). *S. gesnerioides* in southern Bénin has been characterized as a race that is different from those found in the dry savannah of West Africa (Carsky et al., 2003; Lane et al., 1994). With more cowpea monocropping and increasing population pressure, *S. gesnerioides* damage in cowpea has become more acute, particularly in areas with sandy, infertile soils and low rainfall (Singh and Emechebe, 1997). In Ethiopia, *S. gesneroides* has been reported to attack sweet potato (Fasil and Wogayehu, 2008). In areas of low precipitation it can cause severe damage because its hosts are already stressed. Its adaptation to drought has been-well established and, with the increasing drought frequency expected under climate change scenarios it could pose a major threat to cowpea production. Recent analysis shows that *S. gesnerioides* has a great invasive potential and, may expand its range further north in Africa (Mohamed et al., 2006).

14.2.1.3 *Alectra* Species

Alectra includes about 30 species occurring primarily in tropical and subtropical Africa (Mohamed et al., 2006; Parker and Riches, 1993). However, they also occur in parts of India and China (Parker and Riches, 1993; Sauerborn et al., 2007). So far *Alectra vogelii* Benth has been the major species known to attack leguminous species. *A. vogelii* replaces *S. gesnerioides* as an important constraint to cowpea production in East, Central and southern Africa (Parker and Riches, 1993). However, its range extends from the Northern Province of South Africa and Swaziland, through central Africa to Burkina Faso and Mali in the west, and through Tanzania and Kenya to Ethiopia in the east (Riches, 2002). Its climatic requirements are similar to those of *S. gesnerioides*, and in many cases the two are sympatric (Mohamed et al., 2006). However, deviation in temperature from the optimum significantly reduced germination and attachment showing sensitivity to extreme temperatures (Okonkwo and Raghavan, 1982). Some studies suggest sensitivity to drought (Dawoud and Sauerborn, 1994). This probably explains its restriction to savannahs and its absence in semiarid regions (Mohamed et al., 2006). This species attacks cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) in Africa, with high crop losses reported for Botswana, Ethiopia, and Mali (Mohamed et al., 2006). Bambara (*Vigna subterranea*), mung bean (*Vicia radiata*), common bean (*Phaseolus vulgaris*), chickpea and soybean (*Glycine max*) are also damaged in parts of eastern and southern Africa. Soybean, which is relatively free of pests in the dry savannas of Africa, is increasingly being threatened by *A. vogelii*. Pot trials also indicate that *Dolichos lablab*, siratro (*Macroptilium atropurpurium*), velvet bean (*Mucuna purpuriens*) and *Stilozobium deerinianum* can be attacked. It can also attack members of the family Compositae, Euphorbiacea, Labiatae, Malvacea and Pedaliacea (Parker and Riches, 1993). As with *S. gesnerioides*, host preference varies between regions. There is evidence suggesting that *A. vogelii* has developed host-specific strains, each attacking a narrow suite of hosts, but host specificity is more complex than that for *Striga*. Those from West Africa and Cameroon attack cowpea and groundnut. Populations from Botswana and northern parts of South Africa attack mung bean, while populations from Kenya, Malawi and Zimbabwe attack bambara nut in addition to the other crops which are susceptible elsewhere (Riches, 2002). This wide range of hosts poses a problem for the introduction of alternative pulses or legume cover crops into an arable rotation.

A. vogelii cause considerable yield reduction of grain legume crops throughout semi-arid areas of sub-Saharan Africa (Parker and Riches, 1993; Singh et al., 1993). Yield losses of 80–100% have, for example, been recorded on heavily infested cowpea fields in Botswana (Riches, 2002). Complete failure of some groundnut varieties and 30–50% reduction in Bambara nut yield occur in South Africa (Parker and Riches, 1993). In the northern Guinea savannah of Nigeria, it causes yield losses of 15% in groundnut. Late-sown soybean crops may be completely destroyed in northern Nigeria (Riches, 2002). Another minor species *Alectra pica* (Hiern) Hemsl has also been reported to attack cowpea and groundnut in Ethiopia and cowpea in Cameroon (Riches et al., 1992). *A. pica* has a similar host range to West African populations of *A. vogelii* parasitizing cowpea and groundnut but not bambara or mung bean (Parker and Riches, 1993).

14.2.2 Non-parasitic Weeds

All non-parasitic weeds possess chlorophyll and can have either C_3 or C_4 photosynthesis. Most grass weeds are C_4 plants, while many broad-leafed weeds and legume crops are C_3 plants. These differences have significant implications in terms of legume weed competition. In some instances, the legumes have shown stronger ability to compete with the grass weeds. For example, faba bean and soybean were stronger competitors to *Cynodon dactylon* (Juraimi et al., 2005). Among the C_4 plants, grasses are perhaps the most dominant weeds in cool season legume cropping systems. The abundance and composition of grass and broad-leafed weeds species varies with the region, climate and soil type.

Non-parasitic weeds can be classified as native and invasive species. Terms such as noxious weed are also used somewhat loosely to refer to weeds that infest large areas or cause economic and ecological damage to an area. It must be noted however that a clear distinction exists between invasive and noxious weeds. Irrespective of their origin, noxious weeds are those species if left unchecked that often dominate the environment where crop plants are to be grown. Among the invasive weeds, the parhenium weed (*Parthenium hysterophorus* L.) is probably the best known

Fig. 14.2 Close up of *Parthenium hysterophorus* (*top*) and infestation in beans at Instituto de Investigação Agrária de Moçambique (IIAM) near Maputo, Mozambique (Photo Gudeta Sileshi)

in legume production systems (Fig. 14.2). Introduced from Central America, this invasive weed is widely distributed throughout southern Africa and East Africa (Ethiopia, Kenya, Mozambique and South Africa), South and South-east Asia (India, China, Vietnam, the Pacific Islands, Nepal, Pakistan and Taiwan), Australia and many other countries of the world cutting across country-boundary and climate-barrier (Besufekad et al., 2005; Evans, 1997; Shabbir and Bajwa, 2006; Taye et al., 2004a, b; Taye, 2005). It is still spreading and may become more prominent in other parts of the World in the near future. Although it has not been reported from many parts of southern Africa, the first author have recently noted it in legume fields in Mozambique (Fig. 14.2). Because parthenium weed is an extremely prolific seed producer, with up to 25,000 seeds per plant, and with an enormous seed bank, estimated at 200,000 seeds/m^2, it has the potential to be an extremely aggressive colonizer of crops (Evans, 1997).

The spiny cocllebur (*Xanthium strumarium*) is another invasive species common in legume production areas of Australia, Africa and the Indian sub continent. However, it is less publicized weed. Mexican poppy (*Argemone mexicana*), native to tropical America, is now found in at least 30 countries with warm climates in the world (CABI, 2003). It is adapted to a wide range of habitats, including humid and semi-arid areas and a wide range of soil types. Legumes such as *Phaseolus vulgaris* (common bean), *Arachis hypogaea* (groundnut), and *Medicago sativa* (lucerne) are among the most affected (CABI, 2003).

Some of the existing problems in legume crops arise from the incidence of herbicide resistant weeds. Herbicide resistance is an induced inherent ability of some plant species to survive and reproduce after receiving a lethal dose of herbicide. Since the first report in 1970 there have been many reports of herbicide resistance (Chaudhry, 2008a; Heap, 2003). A global survey shows that there are over 323 resistant biotypes in 187 species (112 dicots and 75 monocots) (HRAC, 2009). Resistance to herbicides of various modes of action has been reported in over 60 countries worldwide (Chaudhry, 2008a). The evolution of herbicide resistance is already a serious problem in parts of the Mediterranean. The first report of herbicide resistance in Tunisia concerned ryegrass (*Lolium rigidum*) in cereals in 1996 (Heap, 2003). The total infested area with herbicide-resistant *Lolium* has been estimated to be 4,000–40,000 ha and is increasing (Gressel et al., 2004).

14.2.3 Weed Effects

Parasitic weeds inflict fitness costs by withdrawing water, minerals, and photosynthates directly from the host (Sauerborn et al., 2007). On the other hand, non-parasitic weeds cause losses through competition with legumes for moisture, light and soil nutrients. In any case, weeds consume large quantities of water, and most of it is lost by transpiration to the atmosphere. Some common annual weeds growing in association with cultivated crops use up to three times more water to produce a given amount of dry matter as do the crops.

The other direct weed effect is production of toxins and allelopathy. For example, parasitic weeds may produce phytotoxins that adversely affect the growth of their host. Many non-parasitic weeds also affect crops through allelopathy, a type of interaction in which one plant releases chemicals that are detrimental to the growth of other plants growing in its vicinity. The chemicals responsible for allelopathic activity are called allelochemicals, which are synthesized within plants as secondary metabolites and released through leachation from fresh and decaying plant parts or microbial decomposition of the fallen plant parts, or as root exudates or volatilization. A good example in legume cropping systems is the allelopathy by the invasive parthenium weed. Parthenium produces water soluble allelochemicals from roots, stems, leaves, inflorescences, pollen and seeds (Evans, 1997). Allelopathic effects of foliar leachates from parthenium weed have been demonstrated on cowpea, black gram, chickpea, green gram, mung bean, soybean, and French beans (Evans, 1997; Kohli and Batish, 1994; Oudhia et al., 1997; Singh et al., 2003). The germination and yields of traditional Indian pulse crops (guar, black and green gram) were also reduced when these were grown in soils previously infested by parthenium weed (Kohli and Batish, 1994). In addition, pollen allelopathy of parthenium weed has been demonstrated and, this may affect crops within the infested fields as well as in neighbouring weed-free crops (Evans, 1997). Some of the allelochemicals were also shown to have an inhibitory effect on nitrogen fixing and nitrifying bacteria (Kanchan and Jayachandra, 1981). These indirect and cryptic effects which can influence crop yields are even more difficult to quantify than direct competition.

Weeds may also act as alternative hosts of crop pests. For instance, in western Kenya *Striga hermonthica* is a good host for root-knot nematodes (Sileshi et al., 2008a). The parthenium weed has been shown to be an alternative host of bean aphid, *Aphis fabae* Scopoli in southern India (Evans, 1997). Weeds can also harbour and spread plant pathogens that infect and degrade the quality of crop. For example, the parthenium weed act as a secondary host of plant diseases. The bacterial pathogen, *Xanthomonas campestris* pv. *phaseoli*, could be transmitted from parthenium weed to beans (Evans, 1997). The parthenium weed also harbours the faba bean phyllody phytoplasma (Taye et al., 2004a, b). A host range study in India (Mathur and Muniyappa, 1993) has also shown that the phytoplasma disease was transmitted to field bean (25%), soybean (20%), lupin (20%), green gram (10%), horsegram (10%) blackgram (7%) and cowpea (5%). In some agro-ecosystems, complex interactions occur between weeds, insects and pathogens (Sileshi et al., 2008a).

The negative impact to a native species caused by an invasive species might trigger additional negative interactions for other associated native species. Invasive weed such as parthenium may out-compete and displace native grasses and broadleaf plants, which may have served as the sources of food and refuge to natural enemies of crop pests (Mulisa et al., 2008; Taye et al., 2004a, b). Invasive alien species can cause significant and sometimes irreversible environmental and socio-economic impact at the genetic, species and ecosystem levels. Their management costs include not only costs of prevention, control and mitigation, but also indirect costs due to impacts on ecological services.

14.3 Drought, Climate Change and Weed Effects

Among the number of abiotic and biotic factors curtailing crop productivity, drought ranks as one of the most important ones. Drought effects could be aggravated by weed competition as weeds often use moisture before crop requirements are met. Drought is considered relative to some long-term average condition of balance between precipitation and evapo-transpiration in a particular area, a condition often perceived as "normal". It is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with it and can significantly aggravate its severity. For the sake of clarity and to put weed management in the context of drought, we identify three types of drought: meteorological, agricultural and hydrological drought. Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" amount) and the duration of the dry period. Agricultural drought is said to exist when soil moisture is depleted so that the yields of plants are reduced considerably. Agricultural drought links various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapo-transpiration, soil water deficits, reduced ground water levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. Hydrological drought, on the other hand, is associated with the effects of periods of precipitation shortfalls on surface or subsurface water supply. The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although the three type of drought are interlinked, agricultural drought has direct influence on the interaction between weeds and crops.

With climate change, drought is predicted to occur 10 times more frequently in the future over a large part of the Mediterranean (Weiß et al., 2007). In the Sahel, droughts with varying degrees of severity occur in two out of every five years, making harvest of the major food and cash crops highly uncertain (Hengsdijk and van Kuelen, 2002). In the Sahel, 20–40% of annual rainfall is lost as runoff. This often results in agricultural drought, which cannot always be linked to low rainfall (meteorological drought). The loss of rain water through runoff, soil evaporation and drainage below the rooting zone is often considered as the major cause of moisture stress (Morison et al., 2008). Water transpired by weeds could exacerbate crop drought stress in dry periods through increasing soil moisture deficits, resulting in a decrease in crop water use efficiency (WUE). For example, in cluster bean (*Cyamopsis tetragonoloba*), water consumption was higher in unweeded plots. WUE decreased with the increase in time of weed removal beyond 20 days after crop sowing (Yadav, 1998). Thus weed control becomes even more important in drought conditions.

The effect of climate change such as rising temperature and changes in precipitation are already affecting agricultural production (Lobell et al., 2008; Long et al., 2006). Future impacts are projected to worsen as the temperature continues to rise and as precipitation becomes more unpredictable. Model projections suggest that increased temperature and decreased soil moisture will act to reduce global crop yield by 2050 (Long et al., 2006). There are also strong empirical reasons for expecting climate change to alter weed management (Chaudhry, 2008b; Patterson, 1995; Ziska and George, 2004; Ziska et al., 1999). Firstly, changes in precipitation, CO_2 concentration and temperature are likely to have significant direct (CO_2 stimulation of weed growth) and indirect effects (climatic variability) on weed biology and distribution (Zikas, 2002a; Ziska et al., 1999). In the following sections we will briefly describe the effects of elevated temperature, carbon dioxide and reduced precipitation.

14.3.1 Elevated Temperature

A common feature of many projections is a rise in temperature over much of the regions where legumes are traditionally grown. Some climate models suggest that temperatures could rise up to 4°C by 2,100 in many inland areas and by over half of this over the Mediterranean Sea. There has also been a warming trend in southern Africa over the last few decades. This is consistent with the global trend of temperature rise since 1970s. According to the IPCC (2001), temperatures in the region have risen by over 0.5°C over the last 100 years. Overall, Africa has warmed by 0.7°C over the 20th century and general circulation models project warming across Africa ranging from 0.2°C to more than 0.5°C per decade (Hulme et al., 2001; IPCC, 2001). Most cool season legumes have temperature optima for growth and development processes within the range of 15–25°C, with a base temperature of 0°C (Johansen et al., 2000). The optimum temperature for warm season tropical legumes is within the range of 25–35°C, with a base temperature of 10°C (Johansen et al., 2000). Increasing temperatures may mean increased stress on legumes and susceptibility to insects and diseases. It could also lead to an expansion of weeds into higher latitudes or altitudes. Global warming could extend the northern limits of parasitic weeds by several hundred miles (Mohamed et al., 2006). Studies on the effects of increasing temperatures on the germination and emergence of some invasive weeds suggest that such weeds could increase in distribution and importance (Ahmed and Wardle, 1991).

Increase in temperature can also pose a variety of direct and indirect effects on herbicides (Chaudhry, 2008b). For example extended heat reduces moisture in both soil and plant, limiting herbicide uptake either from the soil or foliage. Elevated temperature can also lead to structural degradation of herbicides and loss of potency. Herbicide volatility and carryover may also increase with increased temperature. This may harm susceptible crops that come into rotation. Phyto-toxicity caused by Triazines (e.g. simazine and atrazine) applied pre-emergence was reported to have increased with increase in temperature (Chaudhry, 2008b).

14.3.2 Carbon Dioxide (CO_2) Enrichment

Atmospheric CO_2 has risen from about 260 parts per million (ppm) 150 years ago to 380 ppm today (Houghton et al., 2001). The effect of increasing atmospheric CO_2 on climate change and agriculture has been a source of worry and mixed feelings for decades. The effect of rising carbon dioxide (CO_2) on crop yields is much more complicated and, more recent analyses cast doubts on earlier projections that suggested that CO_2 fertilization will increase crop yields (Long et al., 2006; Schimel, 2006). Hundreds of studies have shown that most major crops respond positively to CO_2 enrichment, because of the direct stimulatory effect of CO_2 on photosynthesis and the indirect effect of decreasing the water requirement of crops. The former effect should make crops more productive and the later more drought-tolerant (Schimel, 2006). Yet a new analysis of far more realistic studies based on the free-air concentration enrichment (FACE) technique casts doubts on projections (Long et al., 2006). The FACE results in food crops are different from earlier reports from laboratory and chamber studies in a consistent way (Schimel, 2006). Although the beneficial effects of elevated CO_2 on crop yields are well established for the experimental conditions tested, this knowledge is incomplete for numerous tropical crops and crops grown under suboptimal conditions (Schimel, 2006).

Results from various studies suggest that rising CO_2 could alter current yield losses associated with competition from weeds; and that weed control will be crucial in realizing any potential increase in economic yield of agronomic crops such as soybean as atmospheric CO_2 increases (Ziska, 2002a, b; Zikas et al., 1999). An important direct effect of high CO_2 on plants is a partial closure of stomata, which will restrict transpiration more than it restricts photosynthesis. The different effects of elevated atmospheric CO_2 have important implications for weed/crop interaction (Chaudhry, 2008b). It has been well known that the C_3 photosynthetic pathway is less efficient than the C_4 pathway. Because of this, CO_2 enrichment is more beneficial to plants with C_3 than those with C_4 photosynthetic pathway (Wolfe and Erickson, 1993). Recent studies and syntheses indicate that vegetative growth, competition, and potential yield of economically important C_4 crops could be reduced by co-occurring C_3 weeds as atmospheric carbon dioxide increases (Wolfe and Erickson, 1993; Ziska, 2002a, b). It can be argued that many weed species have the C_4 photosynthetic pathway and therefore will show a smaller response to atmospheric CO_2 relative to C_3 crops. However, this argument does not consider the range of available C_3 and C_4 weeds present in any agronomic environment. Hence, if a C_4 weed species does not respond, it is likely that a C_3 weed species will. To date, for all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favoured as CO_2 is increased. However, the interactive effect of temperature and water availability could influences the photosynthetic characteristics of the C_3 and C_4 species over the growing season (Niu et al., 2005). Many of the invasive weeds reproduce by vegetative means and may show a strong response to increases in atmospheric CO_2 (Ziska and George, 2004).

CO_2 enrichment may also stimulate vigorous weed growth, and induce physical or physiological resistance/tolerance to herbicides (Chaudhry, 2008b). These changes also could limit chemical weed control efficacy and increase weed–crop competition. In addition, elevated CO_2 could lead to further below ground carbon storage with subsequent increases in the growth of roots or rhizomes, particularly in perennial weeds. Consequently, mechanical tillage may lead to additional plant propagation in a higher CO_2 environment, with increased asexual reproduction from below ground structures and negative effects on weed control (Ziska and George, 2004).

14.3.3 Reduced Precipitation

Annual precipitation is projected to decline over much of the Mediterranean region south of 40–45° N (Palutikof and Wigley, 1996) where cool seasons legumes are traditionally grown. Even areas receiving more precipitation may get drier than today due to increased evaporation and changes in the seasonal distribution of rainfall and its intensity. Changes in large-scale atmospheric circulation, as represented by the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), would further affect the occurrence of extreme events (Lionello et al., 2006). The effects of climate change have also been dramatic in tropical and subtropical areas of Africa. While ENSO is a natural part of the Earth's climate, an important concern is whether its intensity or frequency may change as a result of global warming. The second half of the twentieth century has witnessed a dramatic reduction in mean annual precipitation and, severe droughts have occurred since the early 1970s (Giannini et al., 2003). East Africa, including Kenya, Tanzania and the Nile basin experiences, in the long rains from March to May, wetter than normal conditions due to ENSO. From 1996 to 2003, there has been a decline in rainfall of 50–150 mm per season across most of eastern Africa (Funk et al., 2008). Under intermediate warming scenarios, parts of equatorial East Africa will likely experience 5–20% increased rainfall from December to February and 5–10% decreased rainfall from June to August by 2050 (Hulme et al., 2001).

Similarly, southern Africa has experienced significant rainfall variability since the late 1960s. Below-normal rainfall years are becoming more and more frequent and the departure of these years from the long-term normal more severe. Between 1988 and 1992, over 15 drought events were reported in various areas of southern Africa. Rainfall variability in southern Africa has shown increased statistical association to the ENSO phenomenon (Faucherreau et al., 2003). Prior to the 1980s, strong El Niños occurred on average every 10–20 years. However, the early 1980s marked the beginning of a series of strong El Niño events. Climatic changes of this magnitude will have far-reaching negative impacts on the availability of water resources, and hence the competition between crops and weeds.

Precipitation (both amount and temporal variation) may play important roles in regulating the growth dynamics of C_3 and C_4 plants (Niu et al., 2005). Dry winters and wet summers promote C_4 expansion, while wet winters and dry summers increase the abundance of C_3 plants. At the global scale, increasing variability of seasonal rainfall accelerated the expansion of C_4 grassland in Northern America, China, and Africa (Pagani et al., 1999).

Drought also poses serious challenges to the use of herbicides. Many herbicides lose effectiveness during dry periods or drought conditions. Soil incorporated herbicides work best when soils have reasonable moisture levels after incorporation has been completed. Pre-emergence herbicides also depend totally upon rainfall after applications to activate the product. During drought stress weeds develop a thicker cuticular layer on their leaves or increased leaf pubescence to reduce moisture loss. This subsequently reduces herbicide entry into the leaf and decrease in herbicide efficacy.

14.4 Weed Control: The *Status Quo* and Future Needs

In parts of the Mediterranean, Sub-Saharan Africa and Asia, legumes are produced mostly by smallholder farmers on marginal soils and with traditional low-input technologies. Rain-fed agriculture also remains the dominant legume production system in these regions (Tuberosa et al., 2007). In dry land agriculture, intensity and type of weed pressure depend upon the rainfall pattern during the crop season. Clearly, water supply can limit crop yield and there are few management options to try and improve this. In future, water will also become increasingly scarce particularly in rain-fed semi-arid regions, thus limiting the option for irrigation (Shiklomanov, 2001). Research concerned with common annual weeds and with their water use requirements, compared with those of agricultural crops, shows that weed control must become an integral part of the farming operation. In the following sections we will briefly discuss the major approaches used for control of parasitic and non-parasitic weeds. There are a number of general and comprehensive reviews and books (Evans, 1997; Gressel et al., 2004; Parker and Riches, 1993; Rispail et al., 2007) on weed biology and management. The present work focuses on more recent developments in weed control specifically aimed at drought management in the context of anticipated climate change.

14.4.1 Manual Weed Control

Hand pulling, hoeing and tillage are the traditional methods practiced for a long time in West Asia, North Africa, the Indian-subcontinent and other parts of the world (Saad El-din, 2003; Sharara et al., 2005; Solh and Palk, 1990; Wortmann, 1993). For example in Egypt and Ethiopia, hoeing in faba bean fields is the most widespread method of weed control (Saad El-din, 2003; Sharara et al., 2005). The major advantage is that it usually requires no capital outlay when cash is not readily available and labour is provided from the farmer's immediate family or through non-cash exchange. It may also be the only feasible method for weeding broadcast legumes when herbicides are not available (Desta, 2000). Hand pulling and hoeing have become increasingly expensive because of scarcity of labour in rural areas. Where crops are not normally planted in rows, hand pulling is a time-consuming task. In Ethiopia it has been estimated to take up to 140 h to weed a hectare of land (Desta, 2000). This method is effective when carried out two to three times at early stages of weed development. When weeding is delayed, irreversible damage from weed competition occurs and removal of bigger weeds requires more man-power, with little economic return and serious physical damage to the crop (Solh and Palk, 1990). In addition, parasitic weeds exert their greatest damage prior to their emergence. Therefore, the majority of field loss may occur before diagnosis of infection (Sauerborn et al., 2007).

Preparatory tillage indirectly contributes to weed control as good seedbed preparation reduces the weed population and gives advantage to the crop to grow rapidly thus improving its competitiveness with weeds (Solh and Palk, 1990). Inter-row cultivation using implements drawn by animal or tractor power contributes to weed control directly. In the Ethiopian highlands, making three to six passes with a traditional ox-drawn plough before planting is a common practice aimed at reducing weed emergence (Desta, 2000). In some of the farming systems in the West Asia and North Africa region, however, the very wide row spacing (1.0–2.0 m) practiced to control weeds through inter-row cultivation is a major limitation to high yield in spring chickpea due to very low crop density. For example, in Algeria and Morocco, farmers increase row spacing up to 2.0 m to facilitate inter-row cultivation (Solh and Palk, 1990). To exploit fully the potential of winter sowing, the crop should be planted at high population density (Saxena, 1987) which makes inter-row cultivation impossible, except at very early stage of crop growth. Since weeds emerge with the winter sown crop and create sever competition, inter-row cultivation is not sufficient and intra-row hand weeding is necessary under most conditions (Solh and Palk, 1990). The limited effectiveness of manual weeding methods, particularly in winter sown chickpea, and the rising labour costs impose limitations on these methods. Under climate change scenarios, elevated temperature and CO_2 may result in faster growth of both weeds and crops. This may shorten the widow of opportunity for manual weeding as this increases labour requirement at critical times.

14.4.2 Resistant Genotypes

The legumes could be resistant to weed through different mechanisms: (1) chemically induced resistance, (2) transgenic resistance, (3) inherent genetic resistance; (4) weed suppressive ability; and (5) tolerance or the ability to maintain high yield despite weed competition.

14.4.2.1 Chemically-Induced Resistance

Recently, chemically induced resistance (CIR) has been identified as a tool for controlling plant pathogens, including fungi, bacteria and viruses, but only recently has this phenomenon started to be evaluated as a control strategy against parasitic weeds (Pérez-de-Luque et al., 2004). The phenomenon has been studied at the molecular level and has proven to be mediated by salicylic acid and associated with a number of defence responses and genes. CIR can be activated by exogenous application of salicylic acid or its synthetic functional analogue BTH. Recently, Pérez-de-Luque et al. (2004) demonstrated that foliar application BTH can reduced *O. crenata* infection by limiting the success in attachment and retarding the development of established tubercles. This method could be particularly useful for pea, which is highly sensitive to common herbicides and, in which little genetic resistance is available to *O. crenata* (Rubiales et al., 2003). However, using CIR strategies requires repeated applications of activators and its effect is transient (Pérez-de-Luque et al., 2004).

14.4.3 Transgenic Resistance

During the last decade, crops with resistance to broad-spectrum post-emergence herbicides such as glyphosate, have been developed through genetic engineering. This enables farmers to use a non-selective herbicide applied selectively over already emerged crops, and to easily implement zero tillage with subsequent soil protection. Herbicide-resistant crops offer the potential for simpler weed control, more effective management of problematic and resistant weeds, more timely weed control with potential to employ critical period, increased usage of minimum or zero tillage and avoidance of yield loss caused by current "selective" herbicides (FAO, 1998). However, there are several concerns with regard to deployment of transgenic crops. Objections to the use of these crops rest on several issues related to the associated risks, such as direct risks to human health, the potential transfer of genes from herbicide resistant crops to wild relatives (thus creating super weeds) and the possibility of volunteer crops becoming weeds in subsequent crops a (Ford Denison, 1999).

14.4.3.1 Inherent Genetic Resistance

Inherent genetic resistance is as one of the most desirable components in the integrated control of parasitic weeds (Pérez-de-Luque et al., 2007). Resistance to *Orobanche* has been found in lentil (Fernández-Aparicio et al., 2007a), species of *Pisum* (Pérez-de-Luque et al., 2005; Valderrama et al., 2004), *Cicer* (Fernández-Aparicio et al., 2007a; Rubiales et al., 2003, 2004), *Vicia* (Abbes et al., 2007; Sillero et al., 2005) and *Lathyrus* (Sillero et al., 2005). In the species of *Cicer* the resistance to *O. crenata* is a result of a combination of several mechanisms, including low induction of parasite seed germination, prevention of establishment, or reduced development of parasite tubercles (Rubiales et al., 2004). Similarly, resistance to *O. crenata* in lentils appears to have multiple components and a chain of escape and resistance mechanisms that either act alone or in combination and at different stages of the infection process (Fernández-Aparicio et al., 2007a). Abbes et al.

(2007) demonstrated resistance to *O. foetida* in faba bean genotypes selected for resistance to *O. crenata*, and some Tunisian breeding lines.

Resistance of cow pea varieties to *S. gesnerioides* has also been reported widely (Carsky et al., 2003; Moore et al., 1995; Singh et al., 2006). Cowpea cultivars with different susceptibility to *S. gesnerioides* infection were first observed in 1981 in Burkina Faso, and two lines (Suvita-2 and 58–57) were found to be completely resistant (Aggarwal, 1985). Further screening of new lines revealed that IT82D-849 (breeding line from IITA) and B301 (a landrace from Botswana) were completely resistant to *S. gesnerioides* populations in Burkina Faso, Mali, Nigeria and Cameroon (Aggarwal, 1991). A systematic breeding program for resistance to *S. gesnerioides* was started in 1987. From this program several lines were obtained that had complete resistance in several countries of West and Central Africa (Singh and Emechebe, 1997). For example, two cowpea landraces, APL-1 and 87-2, were completely resistant to *S. gesnerioides* from Burkina Faso, Mali and Cameroon and partially resistant to *S. gesnerioides* from Niger (Moore et al., 1995). Varieties APL-1 and 87-2 provided additional sources of resistance to most races of *S. gesnerioides*, including a newly discovered virulent race from Benin (Moore et al., 1995). Complete resistance was expressed either as a hypersensitive response of infected root tissues or as a severely retarded development of successful infections (Moore et al., 1995). However, neither of these cowpeas was resistant to *A. vogelii* (Moore et al., 1995). On the other hand, a landrace from Botswana (B 301) has shown complete resistance to both *Striga* and *Alectra* (Singh et al., 1993).

Resistance to *S. gesnerioides* is controlled by a single dominant gene, while resistance to *A. vogelii* is controlled by duplicate dominant genes which are different from the gene conferring *S. gesnerioides* resistance (Singh et al., 2006). Therefore, transfer of resistance is more straightforward. Recently, the International Institute of Tropical Agriculture (IITA) registered 6 improved cowpea germplasm lines with combined resistance to *S. gesnerioides* and *A. vogelii* (Singh et al., 2006). In addition, the first line (IT90K-59) is also resistant to major diseases including anthracnose, web blight, brown blotch, and scab, cowpea yellow mosaic virus and cowpea aphid-borne mosaic virus, nematodes, cowpea weevil, cowpea flower thrips, and cowpea aphid (Singh et al., 2006).

From the preceding discussion it is clear that in many cases resistance of simple inheritance has been identified and exploited in breeding. This has been particularly important allowing rapid progress to develop resistant cultivars of cowpea. However, breeding programs based on only a few dominant genes are in serious risk of breakdown of resistance. Although genetic resistance remains as one of the most important components in the integrated control of parasitic weeds, breeding for resistance is a difficult task and many aspects of the host/parasite interaction remain unknown (Pérez-de-Luque et al., 2007). Resistance against most parasitic weeds is of complex nature making breeding for resistance a difficult task. Precise and reliable screening techniques are required for an effective transfer of resistance into varieties better adapted to the target areas. Therefore, combining different escape and resistance mechanisms in a single cultivar may provide increased resistance that at the same time may be more difficult to lose through the evolution of the parasite, compared with resistance based on a single mechanism (Fernández-Aparicio et al., 2007a). In future, application of post-genomic technologies and the use of model plants should improve the understanding of the plant–parasite interaction and drive not only breeding programmes through either marker-assisted selection or transgenesis but also the development of alternative methods to control the parasite (Rispail et al., 2007). The integration of molecular marker selection techniques into resistance breeding is hoped to facilitated quicker transfer of desirable genes among varieties and novel genes from related wild species.

14.4.3.2 Weed-Suppressive Genotypes

This is the ability of a crop to reduce weed growth through competition. Interest in developing weed-suppressive varieties to enhance traditional herbicide and tillage-based approaches has increased recently (Jannink et al., 2000, 2001). Within the array of approaches available to implement integrated weed management, the competitive suppression of weeds by crops can make several small but cumulative contributions. Two arguments favour focussing breeding effort on weed-suppressive varieties over weed resistance/tolerance to aid weed management (Jordan, 1993). First, suppressing weeds reduces weed seed production and benefits weed management in future growing seasons while tolerating weeds only benefits the current growing season. Secondly, a weed suppressive genotype may prevent the risk of excessive weed pressure and thereby also confer within-season benefits. The literature documents relationships between several plant traits and competitive ability, in particular height, various measures of leaf area or light interception and maturity (Jannink et al., 2000). Wortmann (1993) assessed morphological characteristics of over 16 bean genotypes and, found that the ability to suppress weeds was found to be independent of bean growth habit, but was related to leaf size, leaf area index, and plant growth rate. His work also shows the feasibility of inclusion of large leaf size and high leaf area index as criteria for selecting high-yielding genotypes with improved ability to suppress weeds (Wortmann, 1993). Tall genotypes of pea generally suppressed *Lolium rigidum* and wheat more effectively than short genotypes (McDonald, 2003). While competitive suppression will rarely kill weeds outright, it will act reliably across environments. Moreover, competitive suppression can function independently of weather conditions that might hinder the application of other management practices (Jannink et al., 2000).

14.4.4 Crop Rotation and Fallowing

In the past crop rotation has often been considered in the context of facilitating rotation of herbicides in order to avoid major shifts in the weed flora and the build up of infestation of one or few noxious weeds (Liebman and Dyck, 1993). However, it forms the framework that allows one to keep weeds, insect pests and diseases off-balance in many agricultural ecosystems (Liebman and Dyck, 1993; Sileshi et al., 2008a). In a review of the literature involving 29 test crop and rotation combinations, Liebman and Dyck (1993) found that weed densities were less in 21 cases compared to the control (monoculture without rotation). Weed densities were more in the rotation in only one case, while no difference was found in the remaining five cases. In 12 cases where weed seed densities were reported, nine had lower weed seed densities than the control while the remaining three cases did not differ from the control (Liebman and Dyck, 1993). Crop yields were also higher in rotation than the control in 11 cases and equivalent in three cases. The success of rotation systems for weed suppression appears to be based on the use of crop sequences that create varying patterns of competition, allelopathic interference and soil disturbance to provide an unstable and frequently inhospitable environment that prevents the proliferation of a particular weed species (Liebman and Dyck, 1993). These results suggest that, in general, crop rotation results in better weed control than continuous monoculture. However, it does no guarantee that all rotations work to control weeds. Therefore, the use of rotations in legume cropping systems needs to be examined on a case by case basis.

Recently, crop rotation has received more attention in the framework of conservation agriculture. Legumes such as soybean are grown in some parts of the world under this system. Conservation agriculture is based on the principle of causing the least disturbance (with minimum or zero tillage), leaving plant residue on the soil surface, and crop rotation, including the use of legumes as green manure or cover crops. While this approach is beneficial to effectively protect and increase soil fertility, the switch to zero tillage or direct seeding practices may increase weed problems. For example, in one study conducted in Nigeria there were more weed species in plots under minimum tillage than in conventionally tilled plots (Ekeleme et al., 2005). The loss of tillage as a method of weed control means that producers must adjust crop rotations, herbicide use, and other cultural practices to compensate. Perennial weeds may become a serious problem to overcome, and there is a need to implement additional cultural methods, such as the use of cover crops. Under crop-livestock mixed production systems, this practice may also be limited because legume residues are used as livestock feed rather than for use as soil cover. In the Middle East, North Africa, Ethiopia, and India, residues of cool season legumes are important as a feed for livestock (Rao et al., 2005).

Rotation with non-host crops continues to be one of the most widely recommended practices for the control parasitic weeds. However, anecdotal evidence suggests that seeds of parasitic weeds (e.g. *A. vogelii*) may remain viable in the soil as long as 12 years (Parker and Riches, 1993). Rotations that make use of a small number of crops do not allow much flexibility for varying seeding dates, altering herbicide practices or using crops with different competitive abilities or life cycles. Diversified rotations that use many different crops provide more opportunities for varying weed control practices. For example, in the Ethiopian highlands, a weed-suppressing crop is often rotated with legumes such as field peas, faba bean and chick pea.

Fallowing has also been widely used for controlling weeds in traditional farming systems in the humid tropics of Africa (Banful et al., 2007; Ekeleme et al., 2005). For severely depleted soils, which are common in *Striga* infested areas, improved fallows, which include nitrogen fixing woody species that increase soil fertility concurrently with reducing the weed seed banks appear to be promising (Ekeleme et al., 2005; Sileshi et al., 2006). Improved fallows consist of deliberately planted species – usually legumes with the primary purpose of fixing nitrogen as part of a crop−fallow rotation (Banful et al., 2007; Sileshi et al., 2006, 2008a). Planted fallows reduce weed infestation by shading weeds surviving after crop harvest and by reducing the weed seed population in the soil (Banful et al., 2007; Chikoye et al., 2001; Sileshi et al., 2006).

14.4.5 Intercropping

The continuous production of legume crops often increases weed problems and also gives weeds a chance to adapt. In some areas parasitic weeds on cowpea have increased significantly as sparse stands of landraces inter-cropped with cereals have been replaced by sole crops of high yielding but susceptible varieties (Riches, 2002). Intercropping represents an option for spatially diversification of cropping systems (Baumann et al., 2002; Vandermeer, 1989) and weed management. Intercropping is widely practiced in Africa, Latin America and Asia as means of increasing crop production per unit area with limited capital investment and minimal risk of crop failure (Vandermeer, 1989). Legumes are traditionally intercropped with cereals. For example in Ethiopia, sorghum-faba bean, sorghum-chickpea, maize-faba bean intercrops are very common (Liben et al., 2001). Recent syntheses have demonstrated that intercropping is an ecologically sound method for management of weeds, insect pests and plant diseases in low external inputs farming systems (Baumann et al., 2002; Liebman and Dyck, 1993; Sileshi et al., 2008a). A global review of literature (Liebman and Dyck, 1993) showed that weed biomass in intercrops was lower in 47 (out of 54) cases compared to the respective sole crops. Weed biomass was higher than the sole crop in four cases and variable response was observed in the remaining three cases (Liebman and Dyck, 1993). The mechanisms by which intercrops suppress weeds have been explained in detail in Liebman and Dyck (1993). In the following sections, we will give specific examples relevant to legumes.

Intercropping is widely used in Africa as a low-cost method of controlling *Striga* (Oswald et al., 2002; Sileshi et al., 2006). Intercropping with broad-leaf crops which cover the inter-row also can help reduce *Striga* emergence and seed production, though the practice may not always result in increased cereal yield due to competitive effects. Intercropping legumes with cereals (Fernández-Aparicio et al., 2007a, b) or other legumes such as fenugreek (Fernández-Aparicio et al., 2007a, b, 2008a) has been shown to reduce infection of legumes by *O. crenata*. Fenugreek is frequently intercropped with vetches or faba bean in the Mediterranean (Evidente et al., 2007). This is an important cash crop in India, China, Near East, East Africa and Mediterranean countries, with market for its seeds for curry powder and for flavouring agent for ruminant and pig feed. It is also a popular forage and fodder crop. Some reports were inconclusive and conflicting, with some authors suggesting a beneficial effect of fenugreek when intercropped with faba bean for *O. crenata* or *O. foetida* (Kharrat et al., 1992). Fernández-Aparicio et al. (2007a, b, 2008a) showed a consistent control of *O. crenata* infection in faba bean, pea, lentil and chickpea when intercropped with fenugreek. The main mechanism for the reduction of *O. crenata* infection in legumes by the intercrop with fenugreek was suspected to be allelopathy (Fernández-Aparicio et al., 2007a, b, 2008a).

Weed suppression by intercrops has been reported in cool-season pulse and cereal crops. Specific examples include intercrops of lentil and wheat (Carr et al., 1995), barley and field pea (Mohler and Liebman, 1987), wheat and field beans (Bulson et al., 1997; Haymes and Lee, 1999), pea and barley (Hauggaard-Nielsen et al., 2001; Poggio, 2005). In an experiment comparing barley and pea intercrops with the sole crops, winter-emerging species were less abundant in intercrops (Poggio, 2005).

14.4.6 Trap and Catch Cropping

Trap-crops, also known as “false hosts”, produce *Alectra*- or *Striga*-germination stimulants but are not susceptible to attack. Cowpea, pigeon pea and velvet bean stimulate the germination of *S. gesnerioides* in southern Africa (Parker and Riches, 1993). There are some reports on potential trap crops that offer the advantage of stimulating germination of the root parasites without themselves being parasitized (Parker and Riches, 1993). Although the concept of using trap crops to reduce the *Striga* seed bank in the soil is not new, recent research has shown that the selection of variety within a species can increase the effectiveness of this practice.

14.4.7 Cover Cropping and Residue Management

Cover crops grown in the period between two main crops have potential as an important component of a system-oriented ecological weed management strategy. Residue-mediated weed suppression involves the management of residues from cover crops, green manure legumes and crops. Cover crops and green manure legumes fit very well in residue-mediated management of weeds (Kruidhof et al., 2009). Residues incorporated in the soil or applied as mulch on the soil surface can have inhibitory effect on weeds. For example, cover crop residues have been reported to negatively affect germination and establishment of weed seeds through allelopathic and phytotoxic effects (Kruidhof et al., 2009; Liebman and Davis, 2000). Weed species appear to be more susceptible to phytotoxic effects of crop residues and other organic soil amendments than crop species (Liebman and Davis, 2000). Cover crops that contain a high level of allelochemicals seem well-suited for residue-mediated weed suppression (Kruidhof et al., 2009).

In addition, crop residues can exert an effect on weed germination and establishment through other mechanisms. Release of nutrients from the residues can stimulate weed germination, whereas temporary immobilization of nutrients from the soil upon decomposition can inhibit it (Kruidhof et al., 2009). Residues left on the soil surface can lead to decreased soil temperature fluctuations and reduced light penetration, which both have been shown to inhibit weed germination (Liebman and Davis, 2000). Residue-amended soil may conserve moisture better than bare soil. Cover crops and green manure legumes provide many additional services to the agro-ecosystem, including improved soil quality, increased nutrient cycling and, in some cases, a contribution to pest management (Kruidhof et al., 2009; Sileshi et al., 2008b). Addition of organic materials can change the incidence and severity of soil-borne diseases affecting weeds and crops (Conklin et al., 2002; Liebman and Davis, 2000; Manici et al., 2004). However, optimal residue management strategy for weed suppression depends both on the cover crop species used and the target weed species (Kruidhof et al., 2009). Very few systematic studies exist on the effect of different residue management methods on weed suppression in legume crops. Therefore, this is an area for future research.

14.4.8 Soil Fertility Management

Incidence of *Striga* is known to be negatively correlated with soil fertility, particularly nitrogen availability (Cechin and Press, 1993; Sileshi et al., 2006). This also applies to *Alectra* to some degree (Parker and Riches, 1993). On the other hand, soil fertility appears to be a less critical factor for *Orobanche* spp. (Parker and Riches, 1993). *Striga* seed germination can be increased by improving fertility of the soil through the use of nitrogen fertilizers, compost or green manure. Although nitrogenous fertilizers can reduce *Striga* infection rates, they are rarely economical for resource poor farmers in the first year of application. Ammonium nitrogen impairs germination and attachment of *Striga* seedlings to roots of the host plant. It also reduces production of germination stimulant by the host. In Nigeria, application of N reduced and delayed *Alectra* emergence in soybean. In some crops fertilizer use can also reduce non-parasitic weeds. For example, in Egypt faba bean yield improved under interactive effects of fertilizer and weed control treatments as growth improved (El-Metwally and Abdelhamid, 2008). Using compost favored growth and yield of faba bean more than of weeds. Application of compost alone or combined with 50 or 100% of the recommended fertilizer rate improved faba bean growth in terms of specific leaf area, and leaf weight ratio (El-Metwally and Abdelhamid, 2008).

Soil fertility and organic matter can be improved through legume cover crops and improved fallows (see crop rotation). *Striga* species thrive on degraded soils, which are the majority of soils in tropical Africa. A more remarkable effect on *Striga* is expected from organic matter as compared to mineral fertilizers (Sileshi et al., 2006). In situ production of organic matter by growing short-rotation fallows and cover crop which improves soil fertility and crop yields have been widely studied (Banful et al., 2007; Sileshi et al., 2006, 2008b). Inducing *Striga* suppression in soils is probably manageable with the long-term application of principles that improve the biological health of the soil.

14.4.9 Biological Control

Biological control is used here in its broader sense; including natural control as well as classical biological control. Biological control is particularly attractive in suppressing parasitic weeds in annual crops because the intimate physiological relationship with their host plants makes it difficult to apply conventional weed control measures (Sauerborn et al., 2007). Both insects and fungi have been isolated that attack parasitic weeds. Most of the insects which have been reported to occur on *Orobanche* and *Striga* species are polyphagous and thus damage to these parasitic weeds is limited (Klein and Kroschel, 2002). However, the Agromyzid fly *Phytomyza orobanchia* is reported to be host-specific attacking only *Orobanche* species. Its distribution is related to the natural occurrence of *Orobanche* species (Sauerborn et al., 2007). *P. orobanchia* is particularly common throughout the Mediterranean area and is known in Bulgaria, Germany, England, Spain, Italy, Malta, Egypt, Israel and Ethiopia, the Balkans, the Ukraine, Central Asia, the Arabian Peninsula (Çikman and Doganlar, 2006). Larvae decrease the reproductive capacity of *Orobanche* spp., either directly through their feeding activity in seed capsules or indirectly through weakening the shoots (Klein and Kroschel, 2002). However, effectiveness of the fly could be reduced by parasitism by Eulophidae, Pteromalidae, Aphelinidae and Braconidae (Çikman and Doganlar, 2006).

Smicronyx spp., a gall-forming weevil, is described to be specialized on *Striga* species (Sauerborn et al., 2007). These insects prevent seed production through the development of larvae inside the seed capsules of their target hosts and thus contribute to reduce their reproductive capacity and spread. However, research with both insects has revealed that their effectiveness to prevent seed set is limited and will not be enough to lower the soil seed bank significantly (Smith et al., 1993; Sauerborn et al., 2007).

Approximately 30 fungal genera were reported to occur on *Orobanche* spp. and about 16 fungal genera were found on *Striga* species (Sauerborn et al., 2007). Results of surveys for fungal pathogens of *Orobanche* and *Striga* revealed that *Fusarium* species were the most prominent ones associated with diseased broomrapes and witch weeds. To date about 17 *Fusarium* species are reported to be associated with either *Orobanche* or *Striga*. Of these, six *Fusarium* species have shown significant disease development in selected species of *Orobanche* (Sauerborn et al., 2007). All growth stages from un-germinated seeds to inflorescences can be attacked (Sauerborn et al., 2007). Consequently, seeds of *Orobanche* and *Striga* may be infected by the application of *Fusarium* even if no host plant for the parasite is present in the field. That means that the parasite seed bank could be lowered every season. Fungal agents have also been developed as mycoherbicides (e.g. *Colletotrichum gloesporioides* trade name Lu bao) to control parasitic weeds such as *Cuscuta* spp (Auld, 1997).

Opportunities for biological control of non-parasitic weeds have also been explored and, significant progress has been made in some cases (Evans, 2002; Sileshi, 1997, 1998; Taye, 2007). Classical biological control – the introduction of natural enemies of exotic plants – is probably the only long-term solution for controlling invasive plant species. For example, several arthropods and fungi have been identified as bicontrol agents for the control of the parthenium weed (Evans, 1997, 2002). Searches for, and evaluation of coevolved natural enemies against parthenium weed have been conducted in the neotropics, and the leaf-feeding beetle, *Zygogramma bicolorata,* a seed-feeding weevil, *Simycronyx lutulentus*, a stem-galling moth, *Epiblema sternuana*, a leaf mining moth, *Bucculatrix parthenic*, and a sap-feeding plant hopper, *Stobaera concinna,* and a stem-boring curculionid weevil, *Listronotus setosipennis* from Mexico, Brazil and Argentina were introduced and successfully established in Australia. Two species of pathogenic rust fungi: *Puccinia abrupta* var. *parthenicola* and *Puccinia mealmpodii* were introduced and established. *Puccinia abrupta* and the phyllody caused by Faba Bean Phyllody (FBP) group were the two most important diseases infecting parthenium weed in Ethiopia. The rust was commonly found in mid altitude (1,500–2,500 m) with incidence from 5 to 100% (Taye et al., 2004a, b) while phyllody was observed in low to mid altitude regions (900–2,300 m) of Ethiopia with incidence of 5–75% (Taye et al., 2004a, b). In India, the mycoherbicide potential of plurivorous fungal pathogens belonging to the genera *Fusarium, Colletotrichum, Curvularia, Myrothecium* and *Sclerotium* has been evaluated (Mishra et al., 1995; Evans, 1997). Potential biological control agents also exist for indigenous problematic weeds such as the blue couch grass (*Digitaria abyssinica*) and Bermuda grass (*Cynodon* spp.) (Sileshi, 1997, 1998).

The strength of biological control is its environmental safety and sustainability. Because of their high host-specificity, pathogens can distinguish between a crop and associated weed where chemical herbicides may suffer from low margins of safety. However, the major constraint to the use of biological control agents may result from the regulatory authorities in the countries where the weeds are a problem. Since biocontrol agents are living organisms, regulators are fearful to introduce them from foreign countries. In such situations, biocontrol agents probably fail to be marketed internationally. This means that local strains have to be found in each country and need to be developed independently (Sauerborn et al., 2007).

A potential constraint in the future is climate change, which could alter the efficacy of biological control agents by potentially altering the development and reproduction of the target pest. Increased temperature, CO_2 enrichment and reduced precipitation will definitely affect dynamics and interaction among the biological control agent and the weed species. Drought or warming may benefit control in some cases but may be disruptive in others. Climate matching is important for selecting appropriate biological control agents (Myers and Bazely, 2003).

14.4.10 Chemical Control

Despite the many limitations of chemical control (see below), it will remain an integral part of weed management in the foreseeable future especially where conservation agriculture is practiced. The use of broad-spectrum herbicides make conservation agriculture easier, but it also runs the risk of bringing about new weed problems, either by a shift in the weed populations or the presence of species able to evolve resistance to the herbicides in use.

14.4.10.1 Types of Herbicides

Seed-Applied Herbicides (SAH)

Commercial seed treatment with herbicides is increasingly being used in the control of parasitic weeds of cereals and legumes (Jurado-Expósito et al., 1997). Herbicides applied to crop seed are very important especially in the control of parasitic weeds since parasite infection occur mainly in the root zone near the site of seed planting (Jurado-Expósito and García-Torres, 2000). Recent studies and reviews indicate that the attachment of haustoria to host crops can be delayed by seed-dressing using seed-applied herbicides (Jurado-Expósito and García-Torres, 2000; Kabambe et al., 2008). Jurado-Expósito et al. (1997) studied the feasibility of controlling broomrape (*Orobanche crenata*) in faba bean and lentil by treating seeds with imazethapyr and imazapyr in Spain. In faba bean, coating with imazethapyr resulted in 60–80% control of broomrape. Similarly, lentil seed treatments with imazapyr by coating seeds controlled 85–95% of broomrape (Jurado-Expósito et al., 1997). Seed dressing with imazapyr also suppressed *Striga* emergence in addition to depleting the soil seed bank in maize (Kabambe et al., 2008). Dicamba applied pre-emergent to *Striga* can control early parasite attachment under restricted circumstances. The attachment of haustoria of *Striga* to host crops can also be delayed using imazapyr for crop seed-dressing (Kabambe et al., 2008).

Germination Stimulants

Perhaps, the most effective germination stimulant available is ethylene gas. A number of other chemicals including cytokinins and sodium hypochlorite, which are not related to the natural stimulants, promote germination of parasitic weeds (Parker and Riches, 1993). However, the effectiveness of ethylene in some areas in Africa has been less than expected. For example, *Alectra vogelii* is unresponsive to ethylene (Parker and Riches, 1993). Recently, much attention has been focused on the isolation and identification of novel metabolites including those isolated from plant root exudates and fungal metabolite. The fungal metabolite cotylenins and fusicoccins have been reported to induce over 50% seed germination of *Striga hermonthica* and *Orobanche minor* even at very low concentrations (Yoneyama et al., 1998). Fernández-Aparicio et al. (2008b) screened several fungal metabolites to determine their capacity to stimulate the germination of several *Orobanche* species and found the highest stimulatory effect on *O. aegyptica*, and *O. minor* by ophiobolin A and derivatives of fusicoccin. The fusicoccin derivatives and ophiobolin A could represent a potential herbicide in view of their practical application in agriculture for the biocontrol of parasitic *Orobanche* species (Fernández-Aparicio et al., 2008b).

Pre-emergence Herbicides

Most of the pre-emergence herbicides used in legumes prevent the early establishment of crop seedling from germinating weed seeds. Several herbicides have been used for pre-emergence control of broomrape. For example, imazethapyr (75–100 g/ha) applied to faba bean and pea results in efficient control of broomrape (Jurado-Expósito and García-Torres, 2000). Those effective as pre-emergent herbicides for non-parasitic weed control in chick pea are alachlor, chlorobromuron, cyanazine, dinoseb amine, methabenzthiazuron, metribuzin, pronamide, prometryne and terbutryne (Solh and Palk, 1990). Among those used for controlling weeds in faba bean, Igran (terbutryn), Fusilade (fluazifopbutyl), Basagran (bentazon), Gezagard (prometryn), Amex (butralin) and Topstar (oxadiargyl) are the most prominent. Gezagard (prometryn) was used as pre-emergence herbicide in the control of a wide range of weeds in legumes (Singh and Wright, 2002). Some researchers have reported increased growth characters, yield and yield attributes of faba bean plants when prometryne was applied (Singh and Jolly, 2004). The selectivity and efficacy of these soil-acting herbicides is usually limited to specific agro-ecological conditions because of differences in soil type, moisture availability, temperature, and weed flora. Therefore, recommendations differ from one agro-climatic zone to another (Solh and Palk, 1990).

Post-emergent Herbicides

Post-emergent herbicides have limited effectiveness particularly for broad-leaf weeds. Post-emergent applications need great care with respect to stage of growth and air temperature to avoid phytotoxicity. Post-emergent herbicides such as glyphosate (60 g/ha) effectively control broomrape in faba bean (Jurado-Expósito and García-Torres, 2000). Imidazoline herbicides are generally well tolerated by legumes after emergence. For example, post-emergence applied imazethapyr is highly selective in pea and faba bean at 20–40 g/ha. Imazapyr (2.5–10 g/ha) and imazaquin (40–60 g/ha) have been reported to be effective in control of broomrape (Jurado-Expósito and García-Torres, 2000). For non-parasitic weed control in legumes, dinosebacetate, fluazifop-butyl and e fenoxprop-ethyl have been reported to be effective (Solh and Palk, 1990).

14.4.10.2 Limitations of Herbicides

Chemical control of weeds has several limitations. Undoubtedly, the top most under the anticipated climate change scenarios will be soil moisture deficit, which limits herbicide efficacy. Generally, the efficacy of herbicide treatments to control parasitic weeds such as broomrape depends heavily on rain fall and temperature and the parasite life cycle (Jurado-Expósito and García-Torres, 2000). In the case of non-parasitic weeds, drought may induce the development of a thicker cuticular layer or increased pubescence on weed leaves. This will reduce herbicide entry into the leaf and decrease in herbicide efficacy. Herbicide adjuvants can help increase the penetration of the herbicide into the leaf. However, adjuvants may reduce herbicide selectivity and increase crop injury. Increasing numbers of studies have also demonstrated decline in chemical efficacy with rising CO_2 (Ziska et al., 2004; Ziska and Teasdale, 2000; Ziska et al., 1999). Under the increased temperature and unpredictable precipitation scenarios, current recommendations of herbicides (dozes/rates) may not be effective. Therefore, selected herbicides may need to be subjected to re-testing for specific locations. There is also a need for matching modification of current herbicide recommendations (Chaudhry, 2008b).

The second major limitation of chemical control is their residual effect and phytotoxicity. In high elevation areas severe damage occurred on cereals following legume crops on which pronamide has been applied. In Algeria, use of trifluralin in chickpea resulted in damage to cereals in the following season (Haddad, 1988). Metribuzin showed a large degree of phytotoxicity to green gram, inhibiting its vegetative growth (Zaidi et al., 2005). Herbicides suitable for broomrape control such as imazethapyr have also been shown to cause phytotoxicity depending on the level of water stress and lentil cultivar (Hanson and Hill, 2001).

Development of herbicide resistant weeds is another major problem. Where herbicides have been used, weeds have evolved resistance, or new weed species have appeared that could not be selectively controlled by herbicides.

Another limitation of herbicides in legume production systems is their negative effect on nitrogen-fixation (Anderson et al., 2004; Khan et al., 2004; Singh and Wright, 1999; Zaidi et al., 2005). For example, chlorsulfuron adversely affected the formation and activity of symbiotic nitrogen-fixing nodules, even when only the rhizobial inoculant is exposed briefly to the herbicide (Anderson et al., 2004). Similarly soil applications of bentazone and 2, 4-D in chickpea decreased nodulation (Khan et al., 2004). Both production of late nodules and nodule growth were reduced particularly with simazine. Higher dozes of chlorobromuron and methabenzthiazuron also had adverse effect on number of nodules per plant (Malik et al., 1982). The presence of chlorsulfuron in the soil reduced the nodulation and nitrogen fixation of chickpea plants (Anderson et al., 2004). In pot experiments, the pre-emergence herbicides terbutryn/terbuthylazine, trietazine/simazine and prometryn decreased nodulation in pea (Singh and Wright, 1999). In green gram inoculated with *Bradyrhizobium* sp., pre-emergence application of metibuzin, glyphosate, fluchloralin and 2,4-D at the higher rates significantly reduced nodule number and dry mass (Zaidi et al., 2005). Many studies have concluded that herbicides affect nitrogen fixation largely via indirect effects on plant growth and consequent availability of photosynthates to the root nodules (Rennie and Dubetz, 1984; Bertholet and Clark, 1985; Sprout et al., 1992; Vidal et al., 1992; Abd-Alla et al., 2000). There is also evidence that some pesticides might impair the ability of the rhizobia to recognize appropriate host plants. Other herbicides, including glyphosate, can cause root hair deformations that apparently results in formation of fewer nodules (Mårtensson, 1992).

Other limitations of chemical control include unavailability, low persistence and lack of skills and equipment among subsistence farmers. There are no widely used chemicals for parasitic weeds especially in Africa (Parker and Riches, 1993). The intimate connection between host and parasite hinders efficient control of parasitic weeds by herbicides. Because of the close interconnection between the parasitic weed and its host, herbicidal control is difficult since herbicides cannot distinguish between the host and parasite (Sauerborn et al., 2007). Herbicides are applied at a certain growth stage of the crop when the root parasite is still underground. The herbicides concentrate in the parasites by translocation through the host-plant or through the soil solution until they die. However, often the timing and rate of herbicide application is critical because a proper concentration proportional to the parasite biomass has to be achieved without causing damage to the crop. Post-emergent herbicides that could effectively control broad leaf weeds satisfactorily are not available. The new post-emergent chemicals for grasses seem effective though the choice is limited. Most of the effective soil-acting herbicides have limited persistence in the soil and these are only effective at early stages of crop development. The narrow adaptation of these herbicides and the inconsistency of their effect from season to season are other limitations. Increasing price of some herbicides (especially with increase in fuel prices) and lack of credit facilities make herbicides inaccessible to such farmers (Gressel et al., 2004). Herbicide usage also requires skill, precision and suitable equipment which are not always present under subsistence agriculture. Development and spread of herbicide resistance (Heap, 2003) may also limit the use of those currently in use. The use of herbicides is also becoming more and more limited, due to changes in the regulatory environment.

14.4.11 Integrated Weed Management

Controlling weeds with one or a few techniques is only partially effective and sometimes inconsistent. This also gives the weeds a chance to adapt to those practices. Simply replacing herbicides by other control measures is also inadequate. Obviously, the most effective approach is the integration of different environmentally friendly control measures that are economically feasible to smallholder farmers. Integrated weed management combines different agronomic practices, so that the reliance on any one weed control technique is reduced. The objective of integrated weed management is to maintain weed densities at manageable levels while preventing shifts in weed populations to more difficult-to-control weeds. Integrated weed management using a variety of control techniques may also keep non-parasitic weeds off balance. Weeds are less able to adapt to a constantly changing system that uses many different control practices, unlike a program that relies on one or two control practices.

Three main types of practices can be used to develop integrated weed management in the framework of good agricultural practices. These practices are aimed at (1) preventing the introduction and spread of weeds, (2) giving the crop a competitive edge over weeds and, (3) making it difficult for weeds to adapt. The main principles of preventing introduction and spread of parasitic weeds are preventing seed set, reducing soil seed bank and inhibiting spread from infested to non-infested areas. Unlike normal weeds, most of the damage done by parasitic weed occurs before weed emerges above the soil (Sauerborn et al., 2007). Therefore, control methods have focused on reducing soil seed bank and interfere with the parasite's early developmental stages. Practices that reduce the soil seed bank of parasitic weeds include hand pulling stems before seed set or prompt destruction of crop residues after harvest to prevent continued parasite seed production. Other practices such as use of clean and certified seed and clean equipment can reduce chances of the introduction of new and/or noxious weeds in the fields. Composting livestock manure will reduce the viability of many weed seeds, although certain weeds can survive longer than others in composted manure. Patches of new invading weeds should be controlled to prevent them from spreading. Eradication of alien species such as the parthenium weed is mandatory.

Practices that help the plant to have a competitive edge over weeds include variety selection, high seeding rates, narrow row spacing, uniform seeding, appropriate land preparation, planting date and fertilizer application. Certain crop varieties can be more competitive than others. For example, yield losses caused by grassy weeds in tall pea varieties were less than half those suffered by shorter varieties (McDonald, 2003). High density can help give the crop an edge on weeds. Extra plants allow the crop to shade weeds and make it more difficult for weed to access nutrients and water. Narrow row spacing also allows the crop to be more competitive. There may be situations where wide row spacing is necessary, and higher seeding rates may offset the effect of wider row spacing. Shallow and uniform seeding is important for fast crop emergence and good establishment, which allows the crop to be more competitive with weeds. The closer is the seed to the soil surface, the faster the crop will emerge. Weeds that emerge after the crop cause less yield loss than those that emerge before the crop. Ensuring that the crop seed is placed in an ideal growing environment, and the weeds are not, is another way to give the crop the edge. Conservation farming practices leave crop residue in between the rows, which shades the soil and keeps it cool. Fewer weeds germinate under zero-tillage because of the reduction in soil disturbance.

Crop rotation and varying herbicide practices is important for keeping weeds off balance. Recent reviews suggest that crop rotations that involve alternation between host and non-host crops can be effective against plant pathogenic organisms and insect pests that are relatively host-specific, non-mobile, and that inhabit the soil for at least part of their life cycle. Rotating herbicides with different modes of action (from different herbicide groups) will help delay the development of herbicide resistance. Changing the planting date from year to year means that specific types of weeds cannot adapt. However, most of the cultivated area in legume producing regions relies on rainfall. In such conditions, conservation farming practices, in addition to other traditional practices such as crop rotation and fallow, plus traditional or new water harvest technique become a clear option to increase WUE and sustainability of agriculture.

14.5 Scaling-Up Weed Management Practices

From the review above it is clear that a wide array of weed management options is available, and many more are likely to be developed in the future. However, the major challenge is to scale-up the adoption of these options. Many of the technologies developed have not been effectively disseminated and there has been little adoption by farmers – who continue to use ineffective management practices that exacerbate the weed problem (Abang et al., 2007). The constraints to technology adoption are multiple and vary on a case-by-case basis (Tuberosa et al., 2007). The adoption and effectiveness of conventional control methods may be limited due to lack of appropriate agricultural extension services, increasing cost of agricultural inputs, and the complex nature of parasitic weeds. Future work must take into consideration the specific socio-economic characteristics of individual farming systems. Parasitic weeds are especially a community threat and effective control requires a community-based integrated management approach.

14.6 Conclusion

This work reviewed the *status quo* of weed control in legumes and suggests future developments aimed at weed management in the context of anticipated increases in drought intensity and climate change. In future, water will become increasingly scarce in rain-fed semi-arid regions where legumes are widely grown, thus severely limiting options for irrigation. The spread of invasive alien species of weeds and herbicide resistance, which are partly aggravated by increased global trade and climate change, are also posing more challenges to weed management. This may make conventional weed management practices ineffective. Cultural practices such as manual weeding and intercropping may also be affected by shorter growing seasons induced by climate change. Climate change may also disrupt the effectiveness of biological control as it will affect dynamics and interaction among the biological control agent and the weed species. Under the increased temperature and unpredictable precipitation scenarios, current recommendations of herbicides may not be effective. Increase in temperature and drought can reduce herbicide uptake, increase volatility, structural degradation and loss of potency. Therefore, selected herbicides may need to be subjected to re-testing for specific conditions reflecting climate change scenarios. This highlights the need for a well-planned weed management strategy to mitigate the effect of climate change and invasive alien weeds in legume cropping systems. Integrated weed management in the framework of good agricultural practices that (1) prevent the introduction and spread of invasive weeds, (2) give the crop a competitive edge over weeds and (3) make it difficult for weeds to adapt to cultural practices or herbicides need to be developed. Novel chemical control approaches, chemically induced resistance, and transgenic resistance will also play a crucial role in the integrated management of weeds in future. However, such developments must take into consideration the socio-economic and ecological conditions of individual farming systems.

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Chapter 15
Efficient Biological Nitrogen Fixation Under Warming Climates

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15.1 Introduction

Nitrogen fixation (NF) in legumes occurs in symbiosis with the prokaryotic genera *Rhizobium*, *Bradyrhizobium*, *Mesorhizobium*, *Sinorhizobium* (recently renamed as *Ensifer*), *Azorhizobium* and *Allorhizobium* (collectively termed as rhizobia). The reduction of atmospheric nitrogen (N_2) to ammonium by rhizobia is an important activity making N available for agricultural soils including those in arid regions. NF is affected by environmental constraints such as drought, cold, heat stress, salt stress and alkalinity. Although its severity depends on the amount of precipitation, temporal distribution, evaporation level, soil water-holding capacity and water requirements of crops, drought is one of the commonest stress factors affecting legume yields worldwide (Serraj et al., 2003). Given the climatic trends *viz* a *viz* global warming and desertification, drought stress is likely to remain a serious problem in major agricultural zones of the world. This chapter reviews the role of the symbiotic legume-r*hizobium* interaction for increased seed yield of legumes under drought conditions with special focus on chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medik.), field pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.*)* and grass-pea (*Lathyrus sativus* L.), the major cool season grain legume crops. Physiological, ecological, molecular and genetic aspects of NF in response to drought stress, together with inoculation and agronomic practices in order to increase yields in dry land conditions, are discussed.

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15.2 Legume Physiology Under Drought

15.2.1 Host Plants Under Drought

Legumes are more sensitive to osmotic stress than their microsymbiont rhizobia (Zahran, 1999). Water potential and hydraulic conductivity decrease in a drying soil, resulting in difficulty for plants to absorb water, thus leading to a decrease of plant water potential and affecting a number of physiological processes. The effects of drought stress on plant performance depend on the plant species and cultivars under study, its tolerance to stress, the magnitude of the water shortage, and how fast plants experience this drought stress. The differential drought tolerance within most plant species can be related to their differential net CO_2 assimilation rates under drought stress (Ashraf and Afia, 2005). Both decreased leaf expansion and stomatal closure restrict photosynthesis and dry matter accumulation and this reduction in assimilate supply affects many physiological processes, including root growth and, as a consequence, roots may be less able to utilize the soil water reserves. When leaves are subjected to drought stress, net photosynthesis decreases, whereas the calculated intercellular CO_2 concentration remains relatively stable (Tenhunen et al., 1984; Wong et al., 1985). This response is due to a combination of increased stomatal resistance (stomatal limitation) and limitation of the mesophyll photosynthetic capacity (non-stomatal limitation).

A number of grain legumes show significant reduction in NF during soil dehydration (Sinclair et al., 1987). When exposed to dry conditions, nodules show retarded growth resulting in a partially developed root cortex-embedded organ. Drought stress reduces both NF and nodule respiration proportionally to the degree of water deficit. Water transport across nodules is likely to occur through the cell walls, which have a high affinity for water, since structural changes occur when exposed to water stress (Sprent, 1972). Due to reduced nodule oxygen permeability, nodules have limited ability to carry out oxidative phosphorylation, in spite of maintaining relatively high photosynthetic rates (Aguirreolea and Sánchez-Díaz, 1989).

The response to drought and recovery also depends on the type of nodule structure, i.e. determinate or indeterminate (Venkateswarlu et al., 1990). Indeterminate nodules such as those in alfalfa (*Medicago sativa* L.), faba bean and clover, having prolonged meristematic activity, show resistance to low soil moisture contents (Swaraj, 1987) and are more drought tolerant than determinate nodules, such as those in soybean and common bean (Sprent and Zahran, 1988). Recovery of nodule activity has been reported to involve both the rehydration of the existing N_2-fixing nodule tissue and a renewed growth of nodule meristem (Engine and Sprent, 1973), and nodules show a progressive increase in size and a more open structure (Gallacher and Sprent, 1978).

Depending on the legume species, a number of organic solutes are intracellularly accumulated at different levels under drought stress. Proline accumulation may also be considered as an indicator in the selection of drought stress tolerant legumes. In addition, several other free amino acids and low molecular weight solutes have been reported to accumulate in different legumes (Labanauskas et al., 1981; Ford, 1984), which presents a range of possible variation in legume species and selection for drought tolerance. Tropical legumes, e.g. soybean and cowpea (*Vigna unguiculata* [L.] Walp.), which export ureides, appear to be more sensitive to soil drying, although they have been suggested as drought tolerant and adapted in terms of plant survival (Serraj et al., 1999). *Lablab purpureus* has been also reported as a drought tolerant grain and forage legume, and could be adapted to arid and semi-arid regions (Abdel-Wahab et al., 2002). The existence of variation among cultivars within species differing in NF sensitivity to water deficit indicates that tolerance traits found in some genotypes may be useful in breeding programme for NF drought tolerance in legumes (Serraj and Sinclair, 1997). Another possibility is the genetic alteration of commercial legumes for improved NF under drought.

15.2.2 Regulation of Nodule NF Under Drought

In nodules, NF is carried out by prokaryotes within specialized structures called symbiosomes. As such, the main metabolic factors that regulate NF should not be largely different from those widely studied in the nitrogenase of free-living diazotrophs: (a) an adequate oxygen balance, (b) the occurrence of an energy-yielding substrate, and (c) the maintenance of an adequate N status, since nitrogenase activity is a highly energy demanding process.

15.2.2.1 The Role of Oxygen

Oxygen is critical for NF since most nitrogenases are very sensitive to its presence, being irreversibly inhibited within a very short-time (Hill, 1988). However, NF requires a large energy supply and, although the plant shoot may provide carbon in excess via the phloem, an anaerobic metabolism would not provide enough energy to support NF. This situation is resolved by the presence of leghaemoglobin, which maintains a very low oxygen concentration within the infected region of the nodule (~50–100 nM), while providing high delivery fluxes. These microaerobic conditions are also possible because of the synthesis of high affinity cytochromes in bacteroids. In addition, a variable oxygen diffusion barrier (ODB) has been described in nodules (Tjepkema and Yocum, 1974). The responses of nodule functioning to most environmental constraints, including defoliation, darkness, heat stress, phosphate deficiency, nitrate supply, salt and drought, have been related to the operation of the ODB: a closure of the ODB represents a decrease of oxygen availability for bacteroids and, therefore, a lack of energy to support the highly demanding NF. Indeed, the decreased oxygen permeability is probably a universal stress response in legume root nodules, being the key factor for the inhibition of NF (Denison, 1998). However, most of the reduction in NF under drought could not be restored by raising the external oxygen concentration (Hunt and Layzell, 1993; Diaz del Castillo et al., 1994), which implies that, in addition to O_2-flux shortage, other factors are involved in nodules of water-stressed plants.

15.2.2.2 The Involvement of Carbon Metabolism in Nodules

Nodule NF depends on the supply of sucrose delivered from the phloem, as with other sink tissues in many plants (Avigad, 1982; Hawker, 1985). Sucrose may be hydrolyzed by either sucrose synthase (SS) or alkaline invertase (AI), and follow the glycolytic pathway to provide energy and carbon skeletons for bacteroid respiration and ammonia assimilation. A strong decline in SS activity following drought, which would have further effects of collapsing the glycolytic flux, has been described in soybean (Gonzalez et al., 1995) and pea (González et al., 1998) nodules. This finding was supported by other studies using a pea mutant containing only 10% of wild-type SS activity, which showed that SS is essential for normal nodule development and function, since plants with this low level of SS were unable to fix N_2 (Craig et al., 1999; Gordon et al., 1999). Now, it has been clearly shown that there is a strong correlation between drought, nodule SS activity and NF for a number of grain legumes (Arrese-Igor et al., 1999). Furthermore, SS decline in content and activity has led to a dramatic decrease in nodule malate content, which would provoke an impairment of bacteroid functioning, including NF (Gonzalez et al., 2001; Gálvez et al., 2005).

Additional evidence for the involvement of nodule carbon metabolism in the response of nodulated legumes to drought comes from the fact that lines showing contrasting tolerance to drought also displayed different responses in their nodule SS behaviour, both in soybean (Ladrera et al., 2007a) and in common bean (Sassi et al., 2008). Finally, new proteomic approaches have further confirmed the crucial role of SS in N_2 fixation of other legumes such as *Medicago truncatula* (Larrainzar et al., 2007).

15.2.2.3 Nitrogen Status and Feed-Back Inhibition of NF

The N status of the plant may theoretically be regulating nodule NF (Oti-Boateng and Silsbury, 1993; Parsons et al., 1993; Hartwig, 1998). Several N molecules have been suggested to be involved, including ureides (Atkins et al., 1992), glutamine (Neo and Layzell, 1997), asparagine (Bacanamwo and Harper, 1997; Vadez et al., 2000), and the glutamate/glutamine (Curioni et al., 1999) or aspartate/asparagine (Lima and Sodek, 2003) ratios.

In ureide-exporter legumes, where allantoin and allantoate are the main nitrogenous compounds exported from nodules and where most of our knowledge on the effects of drought on NF comes from, NF is a more drought-sensitive process than in the temperate legumes which are amide-exporters (Sinclair and Serraj, 1995) though some species such as chickpea exported and maintained both and uriede during drought (Thavarajah and Ball, 2006). It is still under discussion whether N status is based upon ureide (or N content) in shoots (systemic regulation of NF; Serraj and Sinclair, 1996; Purcell et al., 1998), or directly in nodules (local regulation; King and Purcell, 2005; Ladrera et al., 2007). The latter is supported by experiments using split-root system, where only the half-root system under drought showed an inhibition in NF (Marino et al., 2007a).

15.2.2.4 Other Aspects Involved in NF Regulation Under Drought

Carbon/nitrogen (C/N) interactions are of importance for plant performance, particularly under non-optimal conditions and hence an integrated approach to analyse C/N interactions is needed. There is recent evidence of cytosolic isocitrate dehydrogenase, a major component in the C/N balance, as playing a major role in nodules in response to carbon shortage (Galvez et al., 2005) or oxidative stress (Marino et al., 2007b). Also, statistical analysis of the various components involved in the response of nodules to drought showed that the malate/ureides ratio shows a better correlation to NF than malate or ureides alone (Marino et al., 2007a). How this C/N balance might control NF has not been addressed yet.

A neglected area of research in the regulation of NF to drought has been the transduction and transmission of stress signals. How stress signals affect gene transcription and how the gene products function in stress tolerance is very important to elucidate the molecular responses of plant genes to water deficit. Plants counter drought stress through many physiological and developmental changes. Many genes that respond to drought stress at the transcriptional level have been described (Skriver and Mundy, 1990; Bray, 1993). The majority has been shown to be induced by both drought and cold stress, but some are responsive only to drought. Abscisic acid (ABA) is produced under such environmental stresses, and it is important in the tolerance of plants to drought, high salinity, and cold (Davies and Jones, 1991). Many genes that respond to drought and/or cold stress are also induced by the exogenous application of ABA (Bray, 1993; Chandler and Robertson, 1994; Wasilewska et al., 2008). Dehydration may also trigger the production of ABA, which, in turn, induces various genes. Experimental evidences have shown the existence of both ABA-independent and ABA-dependent signal-transduction cascades between the initial signal of drought or cold stress and the expression of specific genes. Analyses of the promoters of drought-inducible genes have revealed a novel *cis*-acting element that is involved in the ABA-independent response to conditions of dehydration, low temperature, or high salt (Yamaguchi-Shinozaki and Shinozaki, 1994).

Several genes encoding factors involved in signal transduction cascades, such as protein kinases, transcription factors, and phospholipase C, are induced by drought in bacteria and plants. This suggests that these factors may function in the signal transduction pathways between initial water stress signals and gene expression.

On the other hand, direct oxidative damage provoked by environmental constraints has been described in nodules (Gogorcena et al., 1995, 1997; Matamoros et al., 1999), being of major importance in alfalfa nodules (Naya et al., 2007). Recent reports suggest that nodules having more enzyme antioxidant defenses might display a higher tolerance to osmotic/salt stress in common bean (Sassi et al., 2008) and chickpea (Kaur et al., 2009). Up-regulation of a number of genes involved in antioxidant protection, e.g. *CuZnSODc* (superoxide dismutase C), plastid *FeSOD*, *APXc*, *GRc*, *sodA*, *katB* (catalase B) and *katC* (catalase C), explicitly indicate that both the host cells and bacteroids experience oxidative stress under drought. In alfalfa nodules moderate and severe drought stress has been shown not to have a significant effect on the mRNA levels of *nifH*, although it decreased the content of MoFe-protein and Fe-proteins to different extents (Naya et al., 2007). This suggests that loss of nitrogenase activity is partly caused by protein degradation in addition to a decrease in ATP and reducing power. Re-watering of plants decreased the *nifH* mRNA level but allowed the partial MoFe-protein or total Fe-protein recovery of nitrogenase protein (Naya et al., 2007). Furthermore, the physiological nodule responses to drought can be mimicked using a local application of a Reactive Oxygen Species (ROS)-generator, such as paraquat (Marino et al., 2006), and it is now evident that ROS affect SS expression both at the transcriptional and post-translational levels (Marino et al., 2008).

There have been some recent, isolated reports of an increased tolerance to drought in nodulated legumes. Suárez et al. (2008) reported improvement of drought tolerance and grain yield in common bean by overexpressing trehalose-6-phosphate synthase in rhizobia. Trehalose and its closely related metabolites are known to be involved in some kind of osmoprotection conferring drought tolerance (Garg et al., 2002). Also, Verdoy et al. (2006) have reported increased tolerance to osmotic stress in *M. truncatula* by overexpression of Δ-pyrroline-5-carboxylate synthetase, which leads to the accumulation of high levels of proline. The same research group has shown that overexpression of flavodoxin in bacteroids induces changes in antioxidant metabolism leading to delayed senescence in alfalfa root nodules (Redondo et al., 2009).

15.3 *Rhizobium* Tolerance to Drought and Other Associated Stresses

15.3.1 Natural Occurrence, Diversity and Survival in Drought Conditions

Drought stress affects the soil microbial community in two ways: first, reducing the number of water-filled pores and the thickness of water films around soil particles; second, increasing salt concentration in the soil solution. Water film characteristics influence the movement of motile bacteria, like rhizobia, and in general, the distribution of soil biota (Hamdi, 1970; Tate, 2000). All these factors are altered by drought, affecting not only rhizobial activity and distribution in the soil, but also diversity of rhizobia populations (Orchard and Cook, 1983; Postma et al., 1989; Wadisirisuk et al., 1989; Mnasri et al., 2007). Distribution of *R. leguminosarum* in loamy sand and silt loam is influenced by the initial soil water potential (Postma et al., 1989), and while moderate water tension slows the movement of *R. trifolii* (Hamdi, 1970), the movement of bacteria cease when water-filled pores in soil becomes discontinuous as a result of water stress. Rhizobial mortality has been reported in sterile soils that were rapidly dried after inoculation. Furthermore, under drought conditions reduced viability of almost all the rhizobia species able to establish symbiosis with crop legumes has been reported (Miller and Pepper, 1988; Boonkerd and Weaver, 1982; Danso and Alexander, 1974). As a consequence, the size of the rhizobial population is much lower under extreme desiccated conditions (Tate, 1995), with fast growing rhizobia being more susceptible to soil dehydration than slow growing rhizobia (Sprent, 1971).

However, based on different studies, it has been suggested that there is genetic potential to improve drought tolerance in several rhizobial species, such as *R. leguminosarum* (Athar, 1998) and *E. meliloti* (Athar and Johnson, 1997). Recently, a drought-tolerant strain of *E. meliloti* has been reported (Mnasri et al., 2007). The natural occurrence of *Rhizobium* species in arid conditions (Waldon et al., 1989) emphasizes the drought tolerance of some species. Among them, rhizobia nodulating *Prosopis* species have been shown to have a high drought tolerance and capacity to adapt to arid environments. Both the type of soil and the differential rates of desiccation affect the growth and survival of rhizobia (Fuhrmann et al., 1986). Free-living indigenous rhizobia may survive under low water potential conditions for a month (Fuhrmann et al., 1986), whereas commercial strains often fail to survive under these conditions (Shoushtari and Pepper, 1985). Loss of viability of rhizobial inoculum suggests that the nature of the suspending medium, pH, and temperature are important factors in the survival of the inoculum in the dry state (Fred et al., 1932). Lower water potential of the peat carrier results in a significant decrease in the growth and survival of rhizobia (Griffth and Roughly, 1992).

Plant survival under drought is sometimes conditioned by the possibility of establishing a symbiotic interaction, even if it is not a highly effective symbiosis (Sprent, 2001). Also, plant roots excrete organic compounds, which have been shown to induce *Rhizobium* growth (van Egaraat, 1975; Phillips et al., 1998), ensuring its survival under water-limiting conditions. However, under stress conditions bacteria tend to lose their DNA, especially those containing plasmids, as in the case of fast-growing rhizobia species (Stouthamer and Kooijman, 1993). Indeed, some studies have found that certain *R. leguminosarum* populations can be dominated by non-symbiotic forms of this species (Segovia et al., 1991). In addition, drought stress has been shown to induce morphological changes in different rhizobia such as *E. meliloti* (Busse and Bottomley, 1989) and *B. japonicum* (Hunt et al., 1981), leading to a reduction in infection and nodulation rates.

15.3.2 Response to Other Concomitant Factors

15.3.2.1 Increased CO_2 Levels

It has been projected that atmospheric concentration of CO_2, currently at about 360–385 μmol mol^{-1}, may surpass 700 μmol mol^{-1} before the end of this century (Vu and Allen, 2009). In C3 plants, the photosynthetic carbon assimilation carried out in the Calvin cycle is not saturated at current CO_2 atmospheric concentrations. A rise in CO_2 availability could stimulate photosynthesis and, therefore, productivity of most agricultural crops (Long et al., 2004). It has been suggested that within C3 plants, those which posses large sinks are good candidates for higher growth stimulation in high CO_2 conditions (Poorter, 1993). Thus, N_2-fixing plants could obtain greater growth benefits from more efficient photosynthetic rates under elevated CO_2, than nitrate-grown leguminous plants (Cabrerizo et al., 2000) or grasses (Lüscher et al., 2000). Atmospheric CO_2 enrichment leads to increased nodule mass, because of a larger availability of carbohydrates via the phloem, and, therefore, a higher NF activity on a plant basis (Cabrerizo et al., 2001).

In summary, higher atmospheric CO_2 levels will probably stimulate NF and enhance N availability in soils, increasing the importance of the role of legumes in agricultural systems. However, under these high CO_2 conditions, symbiotic NF will be limited by the relative low availability of phosphorus in soils, thus, leading to a higher demand for P fertilisers. To benefit from higher levels of atmospheric CO_2, strategies which provide an adequate supply of P in legume-based rotation systems should be developed. Lastly, higher P fertilisation requirements under elevated atmospheric CO_2 levels need to be met taking into consideration the higher irrigation demand due to the combination of increased evapotranspiration rates under these conditions (see Chapter 16).

15.3.2.2 High Temperature

Rhizobia are mesophilic microorganisms exhibiting an optimum growth temperature in the range of 25–30ºC. For successful symbiosis the temperature requirement of both partners should be fulfilled. In general, root hair infection and nodule structure and function are negatively affected by high temperature (Michiels et al., 1994). As an exception, some rhizobial strains isolated from nodules in arid environments are able to grow at 40ºC or even higher (Englesham et al., 1981). Although strain adaptation to high temperature has been reported, it has been associated with decreased effectiveness in establishing symbiosis, mostly due to plasmid loss (Hungria and Franco, 1993). Additionally, heat stress has been shown to induce the synthesis of heat shock proteins in *Rhizobium* (Michiels et al., 1994) and to modify lipopolysaccharide patterns and bacterial mobility (Zahran et al., 1994).

15.3.2.3 Salt Stress

In general rhizobia are more salt tolerant than their respective plant host (Zahran, 1999), with some bacterial strains of various species able to grow within the range of 300–700 mM NaCl (Mpepereki et al., 1997). Osmoregulation is the main strategy employed by rhizobia to cope with salt stress (Ghittoni and Bueno, 1996), including altered polysaccharide production upon salt treatment (Lloret et al., 1998). In some cases bacteria that are highly salt tolerant as free-living cells produce ineffective nodules, showing reduced symbiotic efficiency and/or low rates of NF (Chien et al., 1992).

The process of nodule formation is particularly sensitive to salt stress (Zahran, 1991). Under salinity conditions root hair curling is inhibited, and bacterial colonization and infection thread formation are highly reduced (Zahran and Sprent, 1986). Application of salt stress to N_2-fixing nodules also provokes the rapid inhibition of NF (Tejera et al., 2006). Some variability in salt tolerance among crop legumes has been described, with faba bean, common bean and soybean being more tolerant than pea (Cordovilla et al., 1995a). Cultivar-dependent tolerance has been also shown in faba bean (Cordovilla et al., 1995b), common bean (Drevon et al., 2001), chickpea (Singh et al., 2005) and several *Medicago* species (Zahran et al., 2007).

15.3.2.4 Soil Acidity

Soil acidity reduces NF in legumes, particularly affecting *Rhizobium* survival in soil and reducing nodulation (Ibekwe et al., 1997). Certain species like *Mesorhizobium loti* and *R. tropici*, however, have been described as highly tolerant to soil acidity (Cooper et al., 1985; Graham et al., 1994). Differential sensitivity to soil acidity has been shown for *Rhizobium* strains nodulating common bean (Anyango et al., 1995) and cowpea (Mpepereki et al., 1997). Soil acidity tolerance has been related to pH homeostasis maintenance and, in several species, associated with potassium and/or glutamate accumulation (Priefer et al., 2001). In a similar manner to drought-tolerant rhizobia, some acid-tolerant strains isolated from acidic soils have been reported to form ineffective or low-effective nodules (Del Papa et al., 1999). Regarding the influence of the plant host, legume tolerance to acid soils has been suggested to be the most limiting soil-related factor to determine a successful symbiosis (Tang and Thomson, 1996). In this sense, several species of the genera *Medicago* and *Trifolium* have been described as acid tolerant (Evans et al., 1990).

15.3.2.5 Biotic Stresses

Legumes are very sensitive to weed competition. To control weeds during the early development of grain legumes, the application of herbicides at pre-sowing and pre-emergence is usually recommended (Vencill, 2002). Glyphosate-tolerant soybean (Padgette et al., 1995) has been reported to have an important impact on production (Dill et al., 2008). Other total herbicides, such as linuron and prometryn, have been shown to be effective for weed control on lentil (Elkoca et al., 2005). Additionally, there are a number of pathogens able to cause significant yield losses in grain legume fields (reviewed by Porta-Puglia and Aragona, 1997). Furthermore, parasitic plants, such as broomrapes, pose also important limitations for some legume species (Cubero et al., 1988). Although in general any biotic stress affecting host physiology has a negative effect on the establishment and functioning of the symbiotic interaction, in arid ecosystems the symbiosis can be advantageous (Marulanda et al., 2006; Requena et al., 2001).

15.3.2.6 Effect of Other Associated Organisms

The mutualistic association between plants and fungi of the phylum Glomeromycota, known as arbuscular mycorrhiza (AM), has been reported to provide benefits to the plant, including increased resistance to abiotic stresses and root pathogens (Liu et al., 2007). Although the potential advantages of AM symbiosis in terms of improved growth and crop yield are often highlighted (Sinclair and Vadez, 2002), the actual benefits of the interaction largely depend on the environmental conditions and the combination of plant and fungal species (Gazey et al., 2004). The legume-AM interaction does not exclude other types of symbiosis such as the association with N_2-fixing bacteria. The dual symbiosis with AM fungi and rhizobia is considered important for legume growth in natural ecosystems. For instance, the simultaneous inoculation with AM fungi and rhizobial bacteria has been shown to increase water uptake in Retama plants (Marulanda et al., 2006), to improve both plant establishment and soil fertility in desertified ecosystems (Requena et al., 2001), and to enhance NF by improving P supply (Mortimer et al., 2008).

15.4 Improving NF and Yield Under Drought Conditions

15.4.1 Agronomic Practices

For a successful symbiosis establishment, the conditions necessary for an optimal host plant growth should be first fulfilled. Agronomic practices have profound influence on the soil as well as the crop conditions. Tillage practices, crop selection, cropping systems, method of sowing, time of sowing, life saving irrigation, use of agro-chemicals, use of *rhizobium* culture and its frequency, method of inoculation, greatly affect not only the crop but also the microbial activity in the rhizosphere. Some of the important agronomic practices affecting NF under drought conditions are briefly discussed below.

15.4.1.1 Optimizing Seed Inoculation and Sowing

It is important to sow seeds as soon as possible after inoculation. If inoculated seeds remain on or near the soil surface, exposed to hot drying winds for several weeks, supplemental inoculation is advisable. Although planting inoculated seeds in dry soil is usually not recommended, when adhesive-like syrup is used for the inoculation, bacterial growth can sometimes be maintained for 2–3 weeks. If the water-shortage period is prolonged, it is advisable to re-inoculate the soil.

When soil and climatic conditions are unfavorable for the survival of rhizobia, or when germination is delayed due to environmental conditions, soil inoculation results in better nodulation and often better plant growth and yield than seed-applied inoculants, as shown for chickpea (Brockwell et al., 1980) and faba bean (Dean and Clark, 1977). The depth of inoculum placement is an important factor that can influence the benefits of soil inoculation (Kyei-Boahen et al., 2002). For instance, inoculation strategies aimed at positioning the inoculant rhizobia to intercept lateral roots may improve nodulation of the lower part of the root system and consequently improve NF. For inoculation in heavy clay soils, granular soil-applied inoculants are preferred to seed-applied inoculants.

15.4.1.2 Improving Soil Conditions

Drought alters the physicochemical soil properties in several ways. The lack of soil moisture results in reduced microbial mobility. Soil type, origin of the isolate and host variety specificity also influence the establishment of the inoculant. The movement of rhizobia is lower in clay soils compared to light-textured soils, possibly due to adsorption to clay particles (Issa et al., 1993). Different soil types were shown to have variable effect on the survival and multiplication of chickpea *Rhizobium* strains under moisture stress (Issa and Wood, 1995). Therefore, factors such as soil water-holding capacity, moisture-receding pattern, etc., have a profound influence on the survival and longevity of the *Rhizobium* bacteria.

Organic matter has several positive influences on soil fertility, moisture-holding capacity and microbial activity. Under drought conditions, the organic content declines because less dry matter is produced, which ultimately affects both soil buffering capacity and microbial activity.

The content of organic matter can be increased by adding crop residues and green manure, which leads to an increase in soil moisture-retaining capacity, while decreasing soil temperature, having a positive influence on *Rhizobium* activity, however if there is an associated increase in soil N the NF is inhibited (Gaur, 1979).

Other soil characteristics, including the depth of soil profile, the parent material, soil pH, ground water table, previous crops, soil fertility status, and tillage practices also affect NF under drought. Due to clean and repeated cultivation, the oxidation of organic matter is accelerated, resulting in higher levels of NO_3 in the soil profile, which may inhibit NF (George et al., 1992). Appropriate soil management practices, e.g. no-tillage, minimum tillage or other approaches, may decrease soil temperatures and preserve moisture, and, thereby, increase NF (Hungaria and Vargas, 2000). It is therefore suggested to practice minimum or no tillage for enhancing NF activity.

Moisture is an important input in dry land agriculture having great influence on both *Rhizobium* activity as well as crop performance. Increased moisture content is translated into larger nodule number and nodule dry weight. Precipitation during the rainy season can be conserved through adequate agronomic practices during the crop growing period. The soil moisture levels which are adequate for the seed germination are usually also adequate for optimal bacterial movement, growth and nodule formation. Seedbeds should be conducive to moisture conservation. In vertisols, chickpea sown on flat beds have been shown to nodulate better than those sown on ridges with the same sowing density (Rupela and Saxena, 1987). This was attributed to greater evaporation losses due to increased surface area in ridges, which may be critical when moisture is limited. A well-levelled and open field seedbed reduces runoff and ensures conservation of rain water. Contour bunding, compartmental bunding, conservation furrows, vegetative barriers, vertical mulching, sub-soiling, among others, have been also found effective for in-situ moisture conservation in different areas. Furthermore, mulches reduce evaporation losses besides suppressing weed growth, improving water intake in the soil and reducing fluctuation of soil temperature.

15.4.1.3 Nutrient Availability

A soil deficient in plant nutrients negatively affects plant growth and inhibits NF. N availability can be a limiting factor for plant establishment during the initial stages of growth, i.e. before the onset of NF. A starter fertiliser dose of about 10–20 kg N/ha is usually employed to boost host plant growth during this initial stage. However, later application of N fertilisers leads to an inhibition of NF, affecting also rhizobia growth, nodule formation and development, since plants will employ the readily available source of N, thus limiting the energy-demanding NF process.

On the other hand, legumes need P (Kumar et al., 1993) and K for proper plant growth and root establishment. Application of fertilisers containing N, P, K and S (Sharma, 2001) and micronutrients (Singh et al., 1999) has been shown to increase the number of nodules per plant, enhance NF and boost grain yields of chickpea under rainfed conditions. Application of other mineral fertilisers such as 1 kg/ha cobalt chloride, 1 kg/ha sodium molybdate and 25 kg/ha $ZnSO_4$ along with inoculation has been found to increase chickpea yields by 41, 39 and 28%, respectively, over control plants (Namdeo and Gupta, 1992). Since the availability of these nutrients is also limited under dry conditions, their supplementation at the root zone improves their availability for the plant. Under drought, exogenous application of Mo together with the *Rhizobium* inoculant has been shown to produce positive responses in legumes such as faba bean, pea and chickpea (Carranca et al., 1999) and grasspea (Sarkar et al., 2003).

In general nutrient deficiency affects NF by reducing the host plant shoot growth, and, as a consequence, the lower photosynthetic rates limit the C supply to nodules. In particular, P deficiency has been shown to lead to the formation of smaller nodules (Schulze and Drevon, 2005) and to have direct effects on nodule performance. Thus, there is evidence that low P induces N-feedback inhibition of NF (Almeida et al., 2000), which results in nodules having a higher O_2 consumption per amount of fixed N_2 (Ribet and Drevon, 1995; Schulze and Drevon, 2005).

15.4.1.4 Intercropping

Intercropping legumes with non legumes is a common cropping system in the tropics. The non-legume crop improves the effectiveness of NF in the legume. Under field conditions, NF in faba bean was shown to be positively affected by plant population density in monocrop or intercropped system with barley (Danso et al., 1987). In mixed cultures, up to 96% of the N in the faba bean crop was derived from the air, as compared to 65% when no such competition occurred. Obviously, the main advantage of the legume–cereal intercrop is the input of N to the system by the fixation of atmospheric N_2 by the legume, which may contribute to increased quality of the intercrop components.

15.4.2 Rhizobium Management

The identification of legumes able to carry out NF in different ecosystems with a range of water levels suggests that rhizobial strains with different sensitivity to soil moisture may also be selected. It can be assumed that rhizobial strains can be selected with moisture stress tolerance within the range of their legume host. Optimization of soil moisture for plant growth results in maximal development of NF inputs into the soil system by the *Rhizobium*-legume symbiosis (Tate, 1995).

NF under drought conditions can be affected by several factors. One of them is the variation in the capability of the *Rhizobium* strains. Strains which are capable of withstanding severe conditions of moisture stress will be able to fix more N_2 as compared to others which are less able to survive and carry out all physiological process normally. However, the strain variability to fix N_2 under drought conditions has not been studied in depth. There are several reports to indicate variable response of *Rhizobium* strains in different pulses. Differential effect of *Rhizobium* strains with significant differences in the survival rate were observed under rainfed and dry land situations exhibiting variable moisture stress conditions in chickpea (Kantar et al., 2003; Raghuwanshi et al., 2003), in lentil (Athar, 1998), in faba bean (Lisova et al., 1997) and in grass pea (*Lathyrus sativus* L.) (Keshry et al., 2004).

There is limited data indicating a superiority of specific rhizobial strains in improving crop performance in water limited environments (Serraj et al., 1999). However, the fresh *Rhizobium* inoculation has been observed to be one of the ways of replenishing the declining source of *Rhizobium* in the rhizosphere. As the population of *Rhizobium* declines with drying of soil and lack of moisture in drought conditions, this fresh replenishment will definitely be helpful to the process of NF. Selection and use of strains on their capability to withstand the harsher conditions is found to enhance NF in many legumes, due to simple reason that the freshly added *Rhizobium* will readily colonize and increase the rate of nodule formation. On set of drought at the vegetative phase will adversely affect the plant response in comparison with drought at the reproductive phase. Furthermore, recovery from a drought phase to normal moisture conditions also varies with *Rhizobium* strains and crops. Identification of efficient strains of *Rhizobium* and compatible host plants will be helpful in increasing the response to inoculation (Athar, 1998).

Strain selection can be an effective tool for increasing NF when the legume of interest is an uncommon species for which there is no recommended strain. The important criteria for selection of effective strains of *Rhizobium* include: effective NF over a range of environmental conditions, competitive ability against other strains, ability to multiply in broth and survive in peat, survival in seed pellets, persistence in soil, ability to migrate in soil and colonize, ability to survive adverse moisture stress conditions, strain stability during storage, nodule formation and NF in the presence of soil N. Hungria and Vargas (2000) observed a good response by such selection of naturally occurring rhizobia from acid tropical soils affected by water stress.

Through the recent advance in molecular biology methods, it is possible to produce the genetic map of *Rhizobium*, develop genetically engineered rhizobia and identify rhizobial strains based on DNA probes and/or marker genes. These techniques can be used to screen, identify and develop *Rhizobium* strains which are effective under water-limiting conditions, eventually leading to enhanced NF during drought.

15.4.3 Legume Breeding Programmes

There are great differences among the grain legume species regarding the amount of fixed N_2 (Peoples and Crasswell, 1992). Legumes differ in nodulation and NF in response to inoculation with the same strain of *Rhizobium* under controlled conditions (Kush and Dadarwal, 1980). In chickpea considerable variability has been also reported for all NF traits, which can be employed for various mapping and breeding programmes (Rupela, 1992, 1994). In this legume, an important effort has been made leading to the development of a series of genomic tools to accelerate molecular breeding (Mantri et al., 2007). Around 7,000 chickpea ESTs are currently annotated at the NCBI database and most of them were originated from a drought-stressed chickpea population. Mantri et al. (2007) profiled the transcriptional response of tolerant and susceptible genotypes to different abiotic stress in chickpea microarrays. As a result, a large number of transcripts were categorized on drought, salt and cold stresses. More recently, super serial analysis of gene expression (Matsumura et al., 2003) has been used to investigate abiotic stress response in ckickpea (Kahl et al., 2007).

In the last four years, the Grain Legume Integrated project (GLIP), a European initiative, has produced an important advance in grain legume research. In this context, abiotic stress tolerance has been focused on species such as *M. truncatula*, pea and chickpea, for which several works have been published (de Lorenzo et al., 2007; Merchan et al., 2007; Gálvez et al., 2005; Larrainzar et al., 2007; Marino et al., 2008). The identified genes will be used for the generation of a Legume Stress Chip (GeneXPro, Frankfurt, Germany), a diagnostic tool to easily screen for stress tolerance.

Several genes of interest have been targeted and transgenic plants have been generated to show the relevance of these genes under abiotic stress. For instance, alfalfa plants over-expressing chloroplastic MnSOD showed lower cold-induced membrane injury (McKersie et al., 1996), although these transgenic lines did not present better tolerance to drought stress (Rubio et al., 2002). Also, the transcriptional regulator, Alfin1, over-expressed in alfalfa plants was shown to regulate endogenous NaCl-inducible gene expression, resulting in salinity tolerance (Winicov and Bastola, 1999). Similarly, a drought-responsive AP2-type transcription factor (WXP1) induced several wax-related genes resulting in increased drought tolerance when over-expressed in alfalfa (Aharoni et al., 2004; Zhang et al., 2005). In addition, stress-inducible expression of AtDREB1A increases transpiration efficiency in peanut under water-limiting conditions (Bhatnagar-Mathur et al., 2007).

Another interesting approach to determine gene function is TILLING (Targeted Induced Local Lesions in Genomes), which was first developed in *L. japonicus*

(Perry et al., 2003) and it is being developed for pea (Dalmais et al., 2008), soybean (Cooper et al., 2008) and *M. truncatula* (GLIP, 2004–2008). Comparative genomics studies have been carried out using model legumes and cultivated species, including faba bean. The genome of *M. truncatula* is closely related to that of pea (Doyle et al., 1996; Gualtieri et al., 2002), suggesting that the *Viceae* are likely to share extended co-linearity. The knowledge of the syntenic regions of the relevant legumes will facilitate cross legume mapping of genes and agronomic traits, which can be helpful in increasing NF by selection of high nodulating host plants under drought conditions and transfer of those traits to different crops.

15.5 Conclusion

Rhizobia are in competition for nutrients with other soil microorganisms and, at the same time, exposed to biotic and abiotic factors. Among the latter, drought represents one of the most harmful constraints due to its effect on soil physical and biological characteristics. Drought reduces not only the growth and diversity of free-living rhizobacteria, but also negatively influences plant development. Both factors determine the establishment and activity of an effective N_2-fixing symbiotic interaction. Although in general free-living bacteria are more tolerant than their corresponding host legume, the success of the symbiotic system largely depends on the plant tolerance to drought. Genetic potential to improve drought tolerance in both rhizobia and legumes has been shown for different species. This improvement, together with a better knowledge of the regulation of the symbiotic NF process, will hopefully contribute to the selection of drought-tolerant effective symbiosis and to improve crop production in water-limiting agro-systems. Advances in molecular techniques such as DNA probes or marker genes may prove to be effective tools for the breeding of super nodulating legumes. On the other hand, agronomic practices such as appropriate method of seed inoculation, improvement of soil organic matter content, soil evaporation mitigation/prevention measures, application of starter doses of N, conservation/minimum/no tillage, inter/mixed copping and proper soil nutrition may be readily employed in order to boost NF under dry conditions. Higher atmospheric CO_2 levels will probably stimulate NF and enhance N availability in soils, although it may be associated to a higher demand for P fertilisers. The progress of our knowledge on the effects of drought on NF, which is a must for improving legume yield and quality under limiting conditions, may require the scientific will of integrating data at very different levels, with interdisciplinary approaches. Nevertheless, this can be only achieved with the extended commitment from funding agencies at the national and international levels, providing the suitable context for this research to progress and produce some hopeful results in this critical field for food, feed and sustainability.

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Chapter 16
Microbes and Agrochemicals to Stress Tolerance

Asghari Bano and Noshin Ilyas

16.1 Introduction

Increase in global air and ocean temperature due to greenhouse gas emission, widespread melting of snow and ice and rising global mean sea level, are expected to induce many changes in the global climate system during the twenty-first century. Climate changes increase irrigation demand in majority of world's regions due to combination of increased evaporation from soil surface and increased transpiration from plant surface as a consequence of global warming. Combination of these along with decreased precipitation poses significant challenge to future food security. Reduced or lowering of CO_2 fertilization affect subsequently in reduced grain number, size and quality, shortening of growing cycles, volatilization losses of surface applied fertilizer nutrient. Drought affected area will likely increase under climatic change. The effect of stress is mainly perceived as a decrease in photosynthesis and growth and is associated with attenuation in carbon and nitrogen metabolism. The global warming is expected to modulate the plant metabolism, change in root exudation ability is one of the important factors determining plant microbe association, the survival and tolerance of rhizobia will also get changed.

16.1.1 Effects of Drought on Biological Nitrogen Fixation

Symbiotic nitrogen fixation is highly sensitive to drought, which results in decreased N accumulation and yield of legume crops (Kots et al., 2002). About 75% of N_2-fixing activity and 50% of the respiratory activity of detached soybean root nodules were lost when water potential of nodules was lowered from approximately turgid nodules to moderately stressed nodules (Pankhurst and Sprent, 1975).

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The effect of drought on biological nitrogen fixation has been reviewed earlier by Zahran (1999). Under drought significant reduction in nodule carbon flux occurs because of decline in nodule sucrose synthase (SS), Isocitrate dehdrogenase and nodule malate content (Marino et al., 2007) which has been demonstrated as one of the important controlling factor for nodule senescence and decline in nitrogenase activity for nitrogen fixation (Marino et al., 2007)

The effect of drought stress in legumes can be divided into 2 broad categories.

Survival & tolerance of symbionts (e.g. rhizobia) under water stress.

Tolerance of host legumes under water stress.

16.1.2 Alteration in CO_2 Concentration and Its Impact on Biological Nitrogen Fixation

N_2 fixation depends on an adequate combination of carbon, nitrogen, and oxygen fluxes within nodules. Strong interactions among different pathways involved in C and N metabolism take place at early stages of drought in legume nodules affecting N_2 fixation. A carbon flux shortage takes place in nodules experiencing a range of mild drought conditions as a result of down-regulation of activity of sucrose synthase (Lvez et al., 2005).

Atmospheric CO_2 enrichment and N deposition, each a major ecological concern, are likely to have opposing effects in natural ecosystems. Hardy and Havelka (1976) showed enhanced N_2 fixation under CO_2 enrichment, and both legume biomass and frequency were enhanced in free-air CO_2 enrichment studies (Teyssonneyre et al., 2002). Total N in *Lespedeza capitata* and *Lupinus perrenis* were increased by 58.3 and 32.0%, respectively at 560 μmol mol^{-1} CO_2 (Reich et al., 2001). In contrast, C3 and C4 grasses were responsive to N deposition, whereas legumes showing little response. Influence of N on legume/grass balance in pastures is well documented. In a model developed by Thornley et al. (1995), the legume fraction in pasture declined from 18 to 1% as N supply was increased.

Growth under elevated CO_2 generally increases carbon (C) allocation to root biomass and other below ground processes (Rogers et al., 1996), Higher C inputs to the soil (Xiao et al., 2007) might be expected to increase competition for nitrogen (N) between soil microbial community and plant roots, and in low N status soils there is some evidence for a decrease in plant available forms of N (Gill et al., 2002).However, changes in the structure and composition of soil microbial populations under elevated CO_2 may, in the long run, increase plant available N (Luscher et al., 2004).

The consequences of elevated CO_2 in terms of the increased inputs of nutrients and water required to support the increased yield potential. A number of general trends under elevated CO_2 are discernible. Negative effects are likely to include (a) reductions in crude protein content, given the observed declines in plant N concentrations, increased concentrations of total nonstructural carbohydrates and C:N ratios of litter (Körner, 2000), particularly under conditions of low soil N availability (Bowler and Press, 1996); (b) increased fibre content (hence reduced intake), and (c) increases in a range of plant secondary compounds with toxic and/or antinutritional properties (i.e. phyto-oestrogens, cyanogenic glycosides, coumarin, hypercin, condensed tannins). Positive effects may include (a) increased non-structural carbohydrates at elevated CO_2 (Read et al., 1997) and (b) increases in crude protein levels under conditions of reduced rainfall.

16.1.3 Effects of Minerals on Biological Nitrogen Fixation

16.1.3.1 Phosphorous

Mineral nutrients may influence symbiotic dinitrogen fixation of leguminous plants at any of four phases of the overall process: (a) host plant growth, (b) growth and survival of rhizobia, (c) infection and nodule development, and (d) nodule function (Robson, 1978). Phosphorus (as phosphate) is an essential macronutrient for plant growth and development and is normally applied to soil in the form of phosphatic fertilizer. Phosphate in soil mostly exists in insoluble (bound) forms and the concentration of soluble phosphate in soil solution is very low (400–1,200 mg kg^{-1} of soil) (Rodriguez and Fraga, 1999). Plants are able to utilize only a small proportion of phosphatic fertilizers that are applied, as much is rapidly converted into insoluble complexes in soil (Hilda and Fraga, 1999; Cisse and Amar, 2000*)*.

Phosphate (P) levels are regarded as the major soil fertility factor most limiting to legume growth (Edmeades et al., 1991). Compared with grasses, legumes have a higher requirement for P (Caradus, 1981), are less tolerant of low P availability (Jackman and Mouat, 1972), and are less competitive for soil P (Evans, 1977).

Plants dependent on symbiotic N_2 fixation have ATP requirements for nodule development and function (Ribet and Drevon, 1996) and need additional P for signal transduction and membrane biosynthesis. Phosphorus concentrations in the nodule are often significantly higher than those in shoot or root tissue (Israel, 1987). Al-Niemi et al. (1997) suggest that bacteroids can be P limited even when plants have received otherwise adequate P levels. Phosphorus has specific roles in nodule initiation, growth, and functioning in addition to its role in host plant growth (Jacobson, 1985). Phosphorus increases symbiotic dinitrogen fixation in subterranean clover by stimulating host plant growth rather than by exerting specific effects on rhizobial growth and survival or on nodule formation and function (Robson et al., 1981; Isreal, 1987).

Phosphate nutrition is intimately related to nitrate uptake and symbiotic nitrogen fixation in plants. Nitrate assimilation was markedly restricted in inorganic phosphate (Pi) -limited soybean plants (Rufty et al., 1993). Pi deficiency is a major limiting factor in N_2 fixing crops. Ribet and Drevon (1995) reported that Pi deficient soybean plants were significantly smaller and had smaller and fewer nodules and also suggested that N_2 fixing machinery in soyabean nodules was capable of acclimatizing to Pi deficit conditions.

A lower tissue Pi content of legumes can aggravate the damage caused by water deficit to photosynthesis especially at the pollination stage (Santos et al., 2004). Rao and Terry (1994) showed reduction both in assimitaltion rate and Ribulose 1,5- bis phosphate (RuBP) content under phosphorous deficiency, with a leaf accumulation of non-phosphorylated carbohydrates. Low leaf phosphate status seems to limit Calvin cycle somewhere in the sequence of reactions between triose phosphate and RuBP formation. Phosphate induced changes in the leaf gas exchange might also be considered as a metabolic response to photosynthesis to wild stress as stated by Tang et al. (2001).

Disturbances in Pi nutrition appear to be partially responsible for the reduced growth of plants under moderate water deficit (Green way et al., 1969). Therefore, drought stressed plants appear to induce enzymes, such as ATPases, that are characteristic to inorganic phosphorous (Pi) starvation response (Duff et al., 1994). Phosphorous deficiency also effects water relations of plants. Stomatal conductance can greatly be reduced (Saneoka and Fugita, 1990). This may be, because phosphorous deficiency increases sensitivity of stomata to ABA (Radin, 1984). Addition of Phosphorous (P) alleviates the effect of drought stress on plant growth, P accumulation, and grain yield which suggest that application of P fertilizers could mitigate drought stress in legumes at the reproductive stage, resulting in less yield and improvement of grain quality of legumes grown in P-deficient soils (Jin et al., 2005).

Plants have evolved sophisticated metabolic and developmental changes to conserve inorganic phosphate (Pi) and to maximize its acquisition from the rhizosphere when Pi is limiting (Ticconi et al., 2004). Remodeling of root system architecture and increased root hair formation affecting surface, density and lengths of roots to accelerate soil exploration are typical developmental responses to low Pi, because of low P mobility in soil (Lopez-Bucio et al., 2002).

16.1.3.2 Potassium (K^+)

Fertilizer potassium (K^+) influences plant water status and helps overcome soil moisture stress (Marschner, 1995). Studies by Sangakkara et al. (1996) and Nandwal et al. (1998) revealed the beneficial impact of fertilizer K^+ in reducing plant water stress in beans and mungbean, respectively. Potassium increased shoot dry weights of both species, confirming its benefit in promoting growth of legumes (Bailey and Laidlaw, 1999). The impact of K^+ was greater at suboptimal soil moisture, which showed the beneficial effect of this nutrient in mitigating moisture stress, as shown in *Phaseolus* (Sangakkara et al., 1996). In mungbean, K^+ was found to play a major role in promoting vegetative growth and optimizing physiological parameters in optimal and suboptimal soil moisture regimes, thus validating its use in all soil moisture regimes to optimize yields.

16.1.3.3 Silicon

Silicon is found as a component of cell walls. Plants with supplies of soluble silicon produce stronger and tougher cell walls making them a mechanical barrier for production of sucking insects. This significantly enhances ability of plants to heat and drought tolerance.Application of metasilicic acid (0, 0.04, 0.08, 0.20, 0.40 or 0.80 g L^{-1}) to hydroponically-grown, *Bradyrhizobium*-infected cowpea [*Vigna unguiculata* (L.) Walp.] plants showed that silicon nutrition in symbiotic cowpea promotes an increase in mechanical strength of stems, which, in turn, support reproductive structures.

16.1.4 Effects of Higher CO_2 Counteracting Drought Under Adequate P Nutrition

The effects of elevated concentrations of atmospheric CO_2 on plant productivity are of great concern in agricultural systems. In soybean, increased concentrations of CO_2 have been shown to increase photosynthesis and carbon allocation to developing organs, including roots. Increased carbon transport may increase crop production by stimulating symbiotic N_2 fixation in legumes. Conversely, drought has been shown to reduce N_2 fixation in soybean. Climate models combining elevated CO_2 with regional weather conditions suggest that some soybean growing areas will experience increased drought along with higher CO_2 concentrations, thus drought may counteract beneficial aspects of increased CO_2. Elevated carbon dioxide increases the amount of nitrogen fixation in soybean which leads to greater plant biomass and higher nitrogen contents. Increases in N_2 fixation are brought about by increases in nodule biomass, not by increased fixation rates. Due to elevated CO_2, drought effects were less distinct (Serraj, 2003).

Among several mechanisms reported to be involved in the physiological response of symbiotic nitrogen fixation to drought stress, carbon shortage hypothesis is of great significance. Serraj (2003) investigated the combined effects of CO_2 enrichment and water deficits on nodulation and N_2 fixation in soybean. Under drought, in a genotype with drought tolerant N_2 fixation, approximately four times the amount of 14C was allocated to nodules compared to a drought sensitive genotype. It was found that an important effect of CO_2 enrichment of soybean under drought was an enhancement of photo assimilation, an increased partitioning of carbon to nodules, whose main effect was to sustain nodule growth, which helped sustain N_2 rates under soil water deficits.

From current knowledge of ways in which plants respond to elevated CO_2 (increased photosynthesis, reduced sromatal conductance and increased water use efficiency), it might be expected that yield responses to elevated CO_2 will be proportionally larger when growth is limited by soil moisture (Morison, 1993) and there is experimental evidence to support this view from a wide range of plant types (Idso and Idso, 1994; Samarkoon et al., 1996). Elevated CO_2 leads to a decrease in stomatal conductance (Field et al., 1995) which has been shown to increase soybean yield and productivity (Ferris et al., 1999).

A positive effect of CO_2 enrichment occurs on recruitment of drought in tolerant woody legumes. The association between photosynthesis and transpiration is thought to impose physiological and morphological constraints effects of atmospheric CO_2 enrichment on relative growth rate and survival of drought in seedlings of five woody legumes, atmospheric CO_2 enrichment increases survival more in drought-tolerant species than in drought-sensitive species. Prolongation of survival has been noted in most drought-tolerant at ambient CO_2 (Polley et al., 1999).

Doubling CO_2 increased the maximum period of drought survival by a mean of 10–11 days and increased the mean duration of drought required to reduce survival to 50% by 4 days across the species studied. This benefit of high CO_2 on drought-treated plants apparently derived from changes that improved seedling water status. Elevated CO_2 may have prolonged survival by reducing transpiration rates or by improving seedling tolerance of low water potentials, (Miao et al., 1992; Morse et al., 1993; Polley et al., 1999).

16.2 Effect of Inoculation with Benefical Microbes in Biological Nitrogen Fixation

16.2.1 Under Drought Stress

Rehman and Nautiyal (2002) reported differences between *Rhizobium* sp. NBRI2505 S*esbania* and a mutant form in their tolerance to drought. Others have reported differences in the tolerance of rhizobial strains to drought in *Gliricidia sepium* (Melchior-Marroquin et al., 1999) and in *Acacia mangium* (Galiana et al., 1998). Athar (1998a, b) examined the effect of drought on ten strains of *Rhizobium leguminosarum* in soil. The growth of rhizobia at low osmotic potentials requires the production of many polyols or amino compounds which demand considerable amounts of energy, leading to increased specific respiration rates and enhanced heat production. A positive correlation was found between the relative water content of leaves of plant and the amount of IAA produced by the strain isolated from its root and rhizosphere.

Results of Athar and Johnson (1996) suggest that nodulation, growth, and N_2 fixation in alfalfa can be improved by inoculation with competitive and drought-tolerant rhizobia and may be economically feasible way to increase alfalfa production in water-limited environments. The effectivity of the nitrogen-fixing wild herb legumes and their significance to soil fertility in arid regions, were previously reported (Zahran, 1998). Wild legumes (herb or tree) are mainly distributed in arid regions and actively contribute to soil fertility in these environments. These bacteria are very important from both economic and environmental points of view (Zahran, 2001). The N_2-fixing activity and tolerance to drastic conditions may be higher in wild legumes than in crop legumes. The wild legumes in arid zones harbor diverse and promiscuous rhizobia in their root-nodules. Specificity existed only in few rhizobia from wild legumes, however, the majority of them are with wide host range The rhizobia of wild legumes in arid zones, exhibit higher tolerance to the prevailing adverse conditions, e.g. salt stress, elevated temperatures and desiccation. These rhizobia may be used to inoculate wild, as well as, crop legumes, cultivated in reclaimed desert lands. Recent reports indicated that the wild-legume rhizobia formed successful symbioses with some grain legumes. Moreover, intercropping of some N_2-fixing tree legumes (e.g. *Lablab, Leucaena*, *Sesbania,* etc.) to pasture grasses improved biomass yield and herb quality.

Most rhizobial strains, which nodulate important crops, are also sensitive to desiccation in soils (OsangAlfiana and Alexander, 1982) and on seeds (Vincent et al., 1979). Therefore, for the good growth of legumes in semiarid and arid regions of the world where fertilizers are unavailable or expensive, it is necessary that the plant, being nodulated by an effective strain of *Rhizobium.* The tolerance of strains to these adverse environmental conditions is associated with reduced growth efficiency of rhizobia at low matric potential. With limiting moisture levels; however, population densities tend to be lowest under the most desiccated conditions and to increase as the moisture stress is relieved.

Growth and survival of 10 strains of *Rhizobium meliloti* Dang. from Pakistan and Nepal were evaluated for their survival under drought in vials filled with sterile soil maintained at –0·03, –1·0 and –1·5 MPa. Rhizobia in the soil-filled vials were enumerated at 0, 4, 8, 14, 21 and 28 days after inoculation. The highest numbers of rhizobia per g of soil were observed at –0·03 MPa followed by soil maintained at –1·0 and –1·5 MPa. Strains UL 136 and UL 222 survived the best under drought and should be considered for commercial inoculant production in Pakistan (Athar and Johnson, 1997).

Ten strains of lentil rhizobia *(Rhizobium leguminosarum*) were evaluated for drought tolerance by exposing them to soil moisture potentials of –0·03, –1·0 and –1·5 MPa. Water availability, rhizobial strain and time of exposure to drought had a significant ($P \leq 0{\cdot}001$) effect on the number of surviving rhizobia g^{-1} of soil. Highest cell counts were observed at –0·03 MPa, followed by soil maintained at –1·0 and –1·5 MPa. Some of these strains could probably be used successfully as inoculants for lentil production in arid and semi-arid environments (Athar, 1998a, b).

Majeed (2001) investigated the effect of inoculation with *Rhizobium leguminosarum* strain TAL 377 in two cultivars of soybean (*Glycine max* L.) i.e. NARC 2000 and NARC 2001 under drought and rewatering. After 10 days of sowing, drought stress was imposed for five days by withholding water supply. The stressed treatments were rewatered after 5 days and the plants were harvested after 48 h of rewatering. The inoculated plants were found to be more drought tolerant and showed early recovery following rewatering. Ilyas (2008) observed that inoculation with *Rhizobium* isolates obtained from plants suffering from water stress resulted in better performance of *Cicer arietinum* L. plants grown under induced water stress conditions as compared to plants inoculated with isolates obtained from well watered conditions.

Bacteria of the genus *Azospirillum* are associative nitrogen (N_2)-fixing rhizobacteria that are found in close association with plant roots. *Azospirillum* is considered the most important rhizobacterial genus for improvement of plant growth or crop yield worldwide (Bashan et al., 2004). Bacteria of the genus *Azospirillum* are. Genus *Azospirillum* (K-subclass of proteobacteria) is known for many years as plant growth promoting rhizobacteria (Okon, 1985; Okon and Vanderleyden, 1997).They are able to exert beneficial effects on plant growth and yield of many agronomic crops under a variety of environmental and soil conditions. The effect of the inoculation of legumes with *Azospirillum* has received increasing attention in recent years, and positive effects of combined inoculation with this bacterium and *Rhizobium* have been reported for several legumes (Burdman et al., 1998). The main mechanism by which *Azospirillum* promotes plant growth is the improvement of root development and the consequent enhancement of water and mineral uptake by the plant (Okon and Vanderleyden, 1997).

Plants inoculated with *Azospirillum brasilense* are characterized by changes in root growth and morphology, such as enhancement of root elongation, larger root surface area and root dry weight, promotion of root hair growth and root branching (Hadas and Okon, 1987). *Azospirillum* effects depend on inoculum concentration, plant species, timing of inoculation and environment. Combined inoculation of greenhouse-grown common bean plants was shown to increase nodulation and N fixation, and when *Azospirillum* was applied at an optimal concentration, positive effects on plant growth were also observed (Burdman et al., 1997). The effects of *Azospirillum* on root morphology (longer and thinner roots and abundant root hairs) are probably related to its ability to produce phytohormones, mainly auxins (Bottini et al., 1989; Dobbelaere et al., 1999).

German et al. (2000) studied the effect of inoculation with *Azospirillum brasilense* cd.on root morphology and growth of common bean (*Phaseolus vulgaris* L.) under different moisture regimes. The optimum concentration of *Azospirillum* for root growth is 10^7 colony forming unit (cfu) seed^{-1} or plant (Okon and Vanderleyden, 1997). *Azospirillum* appears to act synergistically with *Rhizobium* to stimulate plant growth, nodulation and nitrogen fixation in common bean (Burdman et al., 1997). Inoculation with *Azospirillum* isolates obtained from water stressed conditions and low soil moisture conditions resulted in better performance of *Triticum aestivum* L. plants under induced water stress conditions as compared to inoculation with isolates obtained from well watered conditions and irrigated conditions (Ilyas, 2008).

Pereyra et al. (2006) studied the effect of inoculation with *Azospirillum brasilense* Sp245 under water stress. The results showed that *Azospirillum*-plant association is accompanied by biochemical changes in roots which, in turn, promote plant-growth and tolerance to water stress (Fig. 16.1).

Soil microorganisms, such as plant growth-promoting rhizobacteria (PGPR), play crucial roles in plant growth. Inoculation with *Pseudomonas* increases plant

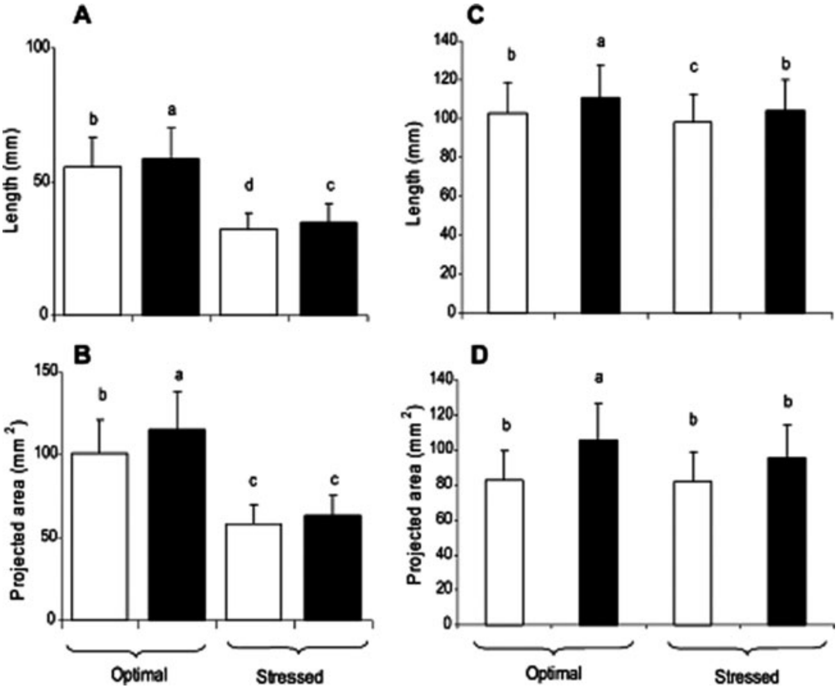

Fig. 16.1 Length (**a**) and projected area (**b**) in coleoptiles, length (**c**) and projected area (**d**) in roots of *Azospirillum*-inoculated wheat seedlings grown under normal and water stress conditions. Figure adapted from Pereyra et al. (2006)

growth and yield during a period of water stress. Arshad et al. (2008) evaluated the effect of inoculation of *Pseudomonas* spp on partial elimination of the effects of drought stress on growth, yield, and ripening of pea (*Pisum sativum* L.). Two preselected plant growth promoting rhizobacteria (PGPR) containing 1-aminocyclopropane-1-carboxylate (ACC)-deaminase (EC 4.1.99.4) were used to investigate their potential to ameliorate the effects of drought stress on growth, yield, and ripening of pea (*Pisum sativum* L.). Inoculated and uninoculated (control) seeds of pea cultivar 2,000 were sown in pots (4 seeds pot^{-1}) and placed in a wire house. The plants were exposed to drought stress at different stages of growth (vegetative, flowering, and pod formation) by skipping the respective irrigation. Results revealed that inoculation of peas with PGPR containing ACC-deaminase significantly decreased the "drought stress imposed effects" on the growth and yield of peas. Exposure of plants to drought stress at vegetative growth stage significantly decreased shoot growth by 41% in the case of uninoculated plants, whereas, by only 18% in the case of inoculated plants compared to nonstressed uninoculated control.

Positive correlation was observed between proline content and drought tolerance of legumes (Ford, 1984). Straub et al. (1995) reported that bacteria used to inoculate soybean that were unable to catabolize proline was not effective to provide drought tolerance and suffered 2X more decrease in seed yield as compared to the plants inoculated with bacteria that were able to catabolize protein. It may be possible to obtain significant increase in yield by enhancing the oxidative flux of proline in bacterial used to inoculate legumes (Zahran, 1999). There are recent reports of desiccation tolerance in *Frankia* spp.; these species also survive and form effective symbiosis at high temperature and low soil moisture (Sayed et al., 1997).

Vesicular-arbuscular mycorrhizal (VAM) symbiosis often results in altered rates of water movement into, through and out of host plants, with consequent effects on tissue hydration and leaf physiology. VAM symbiosis probably affected the water relations of soybean plants indirectly through improved P nutrition (Auge, 2001). VAM effects stomatal conductance, water potential, etc. of host plants. Mycorrhizal mechanisms of effects can be encountered in hormonal involvement (e.g. Allen et al., 1980, 1982; Levy and Krikun, 1980), more effective scavenging of soil water (e.g. Hardie and Leyton, 1981; Sieverding, 1981), possibly through improved soil/root contact (e.g. Reid, 1979), stimulation of gas exchange through increased sink strength (e.g. Allen et al., 1981; Johnson et al., 1982; Kucey and Paul, 1982; Snellgrove et al., 1982) with possible effects on osmotic adjustment (Allen and Boosalis, 1983), and contributions of soil hyphae to water absorption (Hardie and Leyton, 1981; Allen, 1982).

16.2.2 VAM and CO_2 Concentration

The importance of Vesicular arbuscular mycorrhizae (AM) in plant and ecosystem responses to global changes, e.g. elevated atmospheric CO_2, is widely acknowledged. According to Niel (1999) total plant mycorrhization increases with elevated CO_2. VAM fungi increase proportionately with fine root length/mass increase and exhiibit greater colonization per unit root length/mass at elevated CO_2 than at current atmospheric levels. However, there is increasing evidence that elevated CO_2 has little effect on mycorrhizae development (Staddon and Fitter, 1998) and functioning (Staddon et al., 1998), although there may be some fungal interspecific differences to consider (Klironomos et al., 1998). Frequently, increases in AM root colonization occur in response to increased CO_2, but also the lack of significant changes has been reported (Rilling and Field, 2003).

16.2.3 Application of Microbes and Phosphorous Content

Some soil microorganism have previously been shown to be effective in releasing phosphate from bound inorganic soil phosphate through solubilization and mineralization. Microorganisms that convert insoluble phosphates into soluble forms are termed phosphate-solubilizing microorganism (PSMs). A large number of phosphorous soulbilizing bacteria have been isolated from the rhizosphere of several crops and these constitute about 20–40% of the culturable population of soil microorganisms.Two main mechanisms are responsible for the beneficial effects of PSB. One is due to the modification of the microbial balance at the rhizosphere level, the other is due to the modification of the metabolism and the physiology of the inoculated plant. The use of phosphate solubilizing bacteria as inoculants increases P uptake by the plant and crop yield. The important genera of PSB include *Achromobacter*, *Aerobacter*, *Alkaligenes*, *Bacillus*, *Pseudomonas*, *Serratia* and *Xanthomonas*. In addition, certain fungi known as phosphate solubilizing fungi (PSF) have also been shown to solubilize insoluble phosphate.These organisms have been in use as biofertilizers and are gaining importance in the recent years due to their vital role in maintaining the soil nutrient status and structure.

The principal mechanism for mineral phosphate solubilization is the production of organic acids, and acid phosphatases play a major role in the mineralization of organic phosphorous in soil (Rodríguez and Fraga, 1999).

16.3 Strategic Role for Grain Legumes with Climate Change (CO_2 Concentration)

Over the past 60 year, accumulating evidence suggests that human activities have contributed significantly to simulate global climate change (Schneider, 1994; Skinner and Majorowicz, 1999; Intergovernmental Panel on Climate Change, 2001; Smith and Almaraz, 2004), and will continue to do so well into the twenty-first century (Karl et al., 1997). “The Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change, 2001) projects that atmospheric concentrations of CO_2 will increase from 368 mmol in 2000 to between 540 and 970 mmol in 2100. Over the same period, the IPCC estimates that accumulation of atmospheric greenhouse gases will increase air temperatures by 1.4–5.8°C.

Pulse crops may be categorized into cool-season (dry pea, lentil, and chickpea) and warm-season (common bean and soybean) crops based primarily on their ability to emerge at low soil temperatures and exhibit frost tolerance (Miller et al., 2002). Legumes increase production diversification due to differential responses to growing season, rainfall and temperature patterns (Johnston et al., 2002; Miller et al., 2002).

Symbiotic nitrogen fixation, have been shown to be sensitive to global change in a number of experimental studies (Bai et al., 1996). In particular, biomass of root nodules of legume plants, an indicator of symbiotic nitrogen fixation intensity, increased significantly with atmospheric CO_2 concentration.

The mutual promotion of nitrogen fixation and CO_2 enrichment might be related to the capability of the plants to keep a relatively constant C to N ratio in order to maintain their physiological and structural functions. With more assimilation under an enriched CO_2 environment, plants need more nutrients from root systems in order to convert assimilation products into other functional and structural materials. In general, increases in atmospheric CO_2 concentration, precipitation, and nitrogen-fixing capability all have positive effects, while increasing temperature has a negative effect, on plant biomass production for semi-arid climate conditions. The effects of climate change become more significant for plants with symbiotic nitrogen fixation, the effect of nitrogen fixation tends to be stronger with a lower temperature and at larger precipitation. A higher atmospheric CO_2 concentration inhibits the effects of climatic change. Under doubled CO_2 concentration, an increase in temperature causes less reduction in plant biomass, and an increase in precipitation causes a smaller increase in plant biomass, than those at the present CO_2 concentration. On the other hand, when temperature is higher and precipitation is less, the increases in plant biomass brought about by CO_2 enrichment are greater than those with lower temperature and more precipitation (Gao and Shaffer, 2002).

In their study of the potential changes of productivity of cool-season legumes, Grashoff et al. (1994) concluded that for rainfed Faba bean crops in the cold climate of Netherlands, Syria and Israel productivity would increase, especially under water limitation. A small increase in temperature (1.7°C) would decrease yield, but the lower water requirement at higher [CO_2] (1.7°C and 460 μ l/l for the climate in 2030) more than compensates, raising yields from 2.8 to 4.7 t/ha (Syria), 3.9–5.0 t/ha (Israel) and 5.1–5.7 t/ha (Netherlands). In fully irrigated conditions yields would be higher, but the relative CO_2 effect would be lower. Interestingly the standard deviation of the predicted yield (>10 year simulated average) shows a tendency to decrease in the changed climate scenario.

Low temperature has a profound effect on growth and development of legumes (Thomas et al., 1981; Bakht, 1995) Imposition of low temperature can result in reduction in the photosynthetic rates. Low temperature appears to exert a direct inhibitory effect on the calvin cycle enzymes. During the reduction in the rate of photosynthesis by cold stress, it is thought that the light reduced photo-inhibition of photosystem II is a secondary response following the low temperature inhibition of the calvin cycle (Ottander and Oquist, 1991).

Studies of low root zone temperature effects on nitrogen fixation by soybean and other subtropical legumes have indicated that low root zone temperature decreases both nodulation and nodule function (Zhang et al., 1996). Soil temperature affects symbiosis. In legumes, low soil or root temperature decreases both nodulation and rates of N_2 fixation. Higher incidence of nodulation may be observed in mid-range temperatures. High and low ranges of soil temperature may be unfavorable to nodulation. High root temperatures have inhibitory effects on nodule development. Nodules on plant specimens showed a positive correlation with soil moisture and temperature, and occur in a specific range of moderate moisture and temperature (Wolf, 2001).

The basis for the sensitivity of legumes to soil drying has been shown to be associated with transport of N as ureides from nodules to the shoot. Those species that transport N as amides have N_2 fixation that is much less sensitive to soil drying than those that transport ureides (Sinclair and Serraj, 1995). The importance of ureides being involved in the high sensitivity of ureide-transporting legumes to water deficits may result from decreased phloem flow after water deficit and a resulting increase in ureide concentrations in the plant. Warm season N_2-fixing legumes move fixed N from the nodules to the aerial portions of the plant primarily in the form of ureides, allantoin and allantoate, oxidation products of purines synthesized de novo in the nodule.

16.4 Conclusion

Symbiotic nitrogen fixation is sensitive to global climatic change. Increase in atmospheric CO_2 concentration, precipitation, and nitrogen-fixing capability have positive effects on nitrogen fixation particularly at low temperature. The mutual promotion of nitrogen fixation and CO_2 enrichment might be related to the capability of the plants to keep a relatively constant C to N ratio in order to maintain their physiological and structural functions.

The wide range of moisture levels characteristic of ecosystems where legumes have been shown to fix nitrogen suggests that microbial strains with different sensitivity to soil moisture can be selected. Both *Rhizobium* spp. with the genetic potential for increased tolerance to these adverse environmental stresses could enhance production of food and forage legumes in semiarid and arid regions of the world. *Azospirillum* inoculation induces longer and thicker roots and abundant root hairs and helps in adapting legumes to water stress by enhancing mineral and water uptake. Some soil microorganism have previously been shown to be effective in releasing phosphate from bound inorganic soil phosphate through solubilization and mineralization and assist nodule functioning through the process of Biological Nitrogen Fixation.

16.5 Future Strategies

Microbial isolation from plants grown under different stress conditions should be characterized and evaluated for the performance under induced stress.

Their mechanism of stress tolerance needs to be investigated to implicate them for imparting tolerance to host plant

Strategies viz. Simulation modeling involved in stress tolerance both by legume host and symbionts should be further be sorted out in relation to changing climate.

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Chapter 17
Integrated Legume Crops Production and Management Technology

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17.1 Introduction

The cool season legume crops are high value crops and play a vital role in crop diversification and economic viability of legume farming systems in dry ecologies. These annual legumes are grown in more than 120 countries across all the continents. A small group of countries; India, Turkey, Pakistan, Bangladesh, Nepal, Iran, Mexico, Myanmar, Ethiopia, Australia, Spain, Canada, Syria, Morocco, Egypt, USA contribute more than 90% to the global production. Pulse crops are grown over an area of 72 million hectars (2007) with a production of 56 million tonnes (FAOSTAT, 2009). However, the average production of these crops per hectar is quite low. Pulses are major food crops for nutritional security among countries of the developing world. It is important to mention that these crops are very hardy and can be grown in marginal lands where high input crops fail to give economic returns. Even on marginal lands higher economic returns from these crops are possible by the use of integrated crop production management (ICPM) systems. Canada, Australia, Mexico, USA, etc. have obtained an average yield of more than 1.4 t/ha for many years. Similar gains in these crops are possible in other countries with improved crop management. The demand for pulses in years to come (2050) is expected to rise to three and fourfold higher than the present global level. Achieving this increase will be the major challenge to the legume scientific community, policy makers, extension agencies, traders and consumers in 2050. A combination of productivity enhancement and area expansion may help in achieving this target. Thus in future under warming climates, it will be a big challenge for all the stakeholders to sustain the production of these crops internationally.

Internationally, most of the legume crops grown under water limiting environments in rainfed agro ecosystem and more than 70% area under different legume crops is rainfed. Globally, limited inputs are applied by the farming communities for legume crop production during the cropping season. Interestingly, improved

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and integrated management for cultivation of these crops in developing counties is beyond the imagination of many of those involved. Thus most of the time pulses are cultivated on marginal lands, poor soils, stressed environments, neglected cropping systems and without appropriate technologies. It is quite possible that high yielding genes might have been eroded from these crops during the course of production and growing area expansion using limited numbers of introductions. The seed replacement ration is poor in legume crops around the world. The high quality seed of high yielding, newly developed cultivars are thus not reaching many farmers. Under such environmental conditions the realization of the potential yield for pulses is very difficult. Under these situations, it is very important that scientific and farming communities should maintain close interactions and that the needed inputs and technologies may be provided in the cultivation of legume crops. Otherwise it will not be possible to sustain the legume production system under changing climates which will create international crises in legume production, trade, supply and consumption around the world in years to come.

As an example legume production in semi-arid Mediterranean regions is often variable and may be limited in alkaline and calcareous soils, which predominate in northern Jordan and Syria. Other limiting factors include moisture stress and low soil P levels (Kassam, 1981). As a consequence, most countries in the region are net importers of pulse crops. Apart from edaphic conditions, several other factors will affect legume yields, the most critical being seeding management. Choice of seeding date, rate and depth will ultimately, greatly affect crop yields, especially in areas presenting environmental stresses (Gane, 1985). Row spacing and plant density have been developed to reduce soil temperatures and soil evaporation losses. Jettner et al. (1999) reported that the optimum plant population density is usually high in favorable growing conditions, because of increased resource availability. Satorr (1999) reported that seeding rate is one of the major factors determining the ability of the crop to capture resources. It is of particular importance in legume production because it is under the farmer's control in most cropping systems. Optimum plant densities vary greatly between areas according to climatic conditions, soil, sowing time, and varieties (Gate, 1995). Seeding rate may be one of the most influential factors, with seeding rates of 50–75 seeds m^2 maximizing pea yields in Western Canada (Johnston et al., 2002).

In semi-arid environments, increased seeding depth may be required to ensure adequate moisture for germination and seedling emergence. Johnston and Stevenson (2001) reported that optimal seeding depth in the Canadian prairies will vary depending on prevailing climatic conditions, but seeding at depths >76 mm may reduce stand density and seed yields. Seeding date is another important factor that will affect legume seed production. In arid and semi-arid environments, early planting might reduce high evapo-transpiration stress faced by plants and consequently increase seed yields (Ludlow and Muchow, 1990); this is especially important in legume, which is a cool-season crop (Gane, 1985). On the other hand, a delay in sowing increases the risk of the seedbed becoming too dry for successful germination. Late planting might also reduce rooting depth, and can result in less extraction of stored water from deep in the soil. Previous studies conducted with other legumes grown under similar conditions, suggested that early seeding benefits both seed yield and seed weight (Tawaha and Turk, 2001; Turk et al., 2003).

If we consider the average yield production of these legume crops in developed countries like USA, European countries and Australia then the seed yield are very low in comparison to cereal crops. This is due to generally less inputs going towards legume crops. The situation in African countries is very bad and most of the legume crops are poor yielders. Thus it is important that to meet the future production targets and demand of legume crops in the different societies in both the developed and developing world under warming and changing climates, important decisions have to be implemented at various levels including national governments, national and international research organizations, interested stakeholders, farming communities, etc. Though there are many options to combat or to mitigate the low production and productivity of these crops under changing climates at an international level, the authors will limit this chapter only to the components of integrated production management technologies.

The most important components of integrated crop production and management technologies are high yielding cultivars, agronomic practices like soil operations, tillage, weed, irrigation and nutrient management, diseases, insects and pest's management, post harvest and processing, storage, marketing, etc. All concerned stakeholders like breeders, agronomists, extensionists, food technologists, traders, farmers, etc. have to work in close association with each other in legume crop production systems for sustainability in food and nutritional security at a global level.

17.2 Production Constraints

In the post green revolution period per capita availability of legumes declined due to the increased demand-supply gap caused by miss match in population and production growth. The major constraints that limit production include non-availability of quality seeds of improved varieties, poor crop management, biotic and abiotic stresses prevalent in the legumes growing areas. There is a need for a major breakthrough in the new technology front to increase yield levels through morph-physiological changes in plant type and successful hybrid technology, development of multiple disease–resistant varieties and tolerance to abiotic stresses and insect pests. The potential of existing technologies in raising the production level has not been realized in the farmer's fields because of non-availability, poor management practices and low priority given to these crops by governments and farmers at an international level (Pandey et al., 2007).

To achieve sustained production of these crops there is a need to understand and address the following productivity constraints (i) lack of high – yielding varieties adopted to diverse growing environments (ii) cultivation of these crops under resource constraints particularly under rainfed, marginal and low input environments (iii) biotic and abiotic stresses affecting these crops (iv) poor response to high inputs (v) emerging deficiencies of micro nutrients (vi) non- adoption of improved production technology and (vii) administrative machinery for replacement of low yielding – varieties with high-yielding, pest – and disease- resistant varieties. The present important abiotic stresses affecting these crop's productivity are drought, heat, cold and salinity around the world. It is also important to mention that such stresses will also dominate in the years to come under changing climates.

17.2.1 Drought

Terminal drought is the most important abiotic stress for these crops as they are usually grown under rainfed conditions on residual soil moisture in the post-rainy season. The crops often experience increasing drought stress during the reproductive growth stage, resulting in early senescence, and reduction in pods and seed development. Two strategies that are employed in legume crops for drought management are escape and tolerance. Developing early maturing cultivars to escape terminal drought is the most effective strategy as it enables the crop to complete its life cycle before the onset of severe drought.

17.2.2 Cold

These legume crops have been traditionally grown in spring in the WANA region and during the winter season in most of the countries around the world. As the crop grows on residual moisture under rainfed conditions, it is often exposed to high temperature and moisture stress during the pod –filling stage. Advancement of sowing to winter can help escape these stresses and prolong crop duration. Cold tolerance at the seedling stage and flowering stages are needed in cultivars for winter planting in many countries. Generally these crops are sensitive to chilling temperatures during reproductive growth as these adversely effect the pollen germination, fertilization and pod setting. Considerable yield losses in these crops can occur due to cold stress in many countries.

17.2.3 Diseases

Diseases and insect-pests are two important biotic stresses affecting the productivity of these crops. For various diseases see chapter six on diseases.

17.2.4 Salinity

All the legume crops are very sensitive to salinity and the extent of yield losses depends on the level of soil salinity. Yield losses occur due to reduction in germination, plant growth/biomass and seed size. In legume growing areas, saline soils are common in West and Central Asia and Australia. For more details see chapter on salinity.

17.2.5 Insect Pests

Major insects causing damage include pod borer (*H. armigera* Hubner) and leaf miner (*Liriomyza cicerianan).* These are important insect pest for many legume crops in production areas. Bruchid beetles (*Bruchus rufimanus* (Coleoptera: Bruchidae)) is the most problematic storage pest of legume crops. All legume workers must include insect – pest management in their integrated crop management strategies and practices for sustainable productivity.

It is important to mention that in the years to come as the predicted temperatures increase and rainfall patterns change, insect-pests incidences will be different Atmospheric CO_2 concentration will be of a different level and other abiotic conditions of planting environments will be different. Therefore, the present level of production of these legume crops will not be same, human population will increase and demand for these crops will be more. Thus the management of legume crops has to be intensified in the future.

17.3 New Cultivars Development and Management

The importance of legume crop cultivars has been mentioned in the chapter on cultivars of this book and the breeding strategies are also not the part of integrated management production system. Thus only limited background information is provided on breeding aspects of cultivar development and importance of these crops. For detailed information on cultivars Chapter 20 may be consulted.

Plant breeding has played a significant role in developing legume cultivars that can survive and grow well in a range of environments. For many years, the development of drought-tolerant cultivars has been a major concern of crop scientists (Clarke et al., 1992; Fischer, 1979). This can be achieved through development of phenological and morphological traits that can play role in the adaptation of legumes to drought areas. Previous studies (Nachit and Jarrah, 1986; Hadjichristodoulou, 1987) show that it is possible to modify crop plants to fit into drought environments. According to Dedio (1975), improving crop plant performance in the presence of drought has been a slow process. Clarke et al. (1992) reported that grain yield under drought conditions is influenced by environmental factors and the effects of genetic yield potential. Growth under different conditions of environmental stress requires physiological or biochemical adaptations.

Selection of short-duration varieties is an important strategy to combat drought (Gupta et al., 1983). It avoids late season drought and high water demand associated with warm temperatures and high evaporative demand in the mid- to late-grain fill period. Adapted early maturity varieties consequently have higher water use efficiency than do later maturing varieties. Progress has been made in selecting short-duration varieties for this purpose (Van Rheenen et al., 1990). Previous reports mentioned that drought resistance may include greater rooting capacity, osmo-regulation, accumulation of amino acids, control of leaf water potential and increased seed size (Singh et al., 1985; Morgan et al., 1991; Jones and Corlett, 1992; Singh, 1993). Recent advances in genomic technologies have led to the identification of a vast number of potentially helpful water-stress-related genes, plus technologies for gene over-expression. Furthermore, these can be introduced into transgenic plants under the control of suitable promoters and are transmitted to subsequent generations (Delmer, 2005).

Thus, comprehensive efforts are being made by national and international research organizations like ICARDA, ICRISAT, CIAT, IITA to incorporate resistance against biotic and abiotic stresses, to improve genetic yield potential of new cultivars, development of transgenic varieties, wide adaptation, etc. In the integrated crop production management system, there is a role of improved high yielding, resistant, widely adapted quality cultivars of these crops developed by breeders around the world. In the integrated management system only new high yielding cultivars should be promoted by scientists and extensionists and the same may be adopted by farming communities in cultivation system to sustain the production, consumers demand, international and national marketing system at global level.

17.4 Agronomic Management

The agronomic management of legume crops has been described at length in chapter seven separately. Only practical considerations of integrated management system will be taken-up in this chapter. Tillage has been and continues to play a major role in terms of soil preparation, improved infiltration, crust breaking and weed control (Gupta et al., 1983). Previous studies using five year's experiments showed that minimum tillage for soil preparation with mulching enhanced soil moisture status by decreasing evaporative loss and diminished thermal regimes of soil, thus minimizing the effects of drought on crops. The effects of tillage systems on the chickpea crop have been studied extensively by Rathore et al. (1998). He mentioned that these benefits are directly related to soil moisture conservation and available moisture during the growing season (Table 17.1).

On the other hand, Truman et al. (2005) reported that conservation tillage joined with residue management and para- tilling are associated with abridged runoff and erosion, enhanced infiltration, and increased soil water holding capacity. Such research has shown that in a no-tillage system, surface residue play an important role to improve the overall precipitation storage efficiency (Ma et al., 1999). Crop residues also play an important role in providing physical protection for soils to control wind and water erosion, increasing precipitation infiltration by protecting the soil surface from raindrop impact and subsequent crusting, and reducing evaporation by decreasing air movement immediately above the soil (Anderson et al., 1986;

Table 17.1 Influence of various operations of tillage components on the different agronomic traits of chickpea during 1991–1992

Treatments	Plant height (cm)		Number of plants per square meter		Number of pods per plant	
Tillage	1991/1992	1992–1993	1991/1992	1992–1993	1991/1992	1992–1993
ZT	60.9	49.3	44.7	35.8	47.7	57.1
ZTIRT	59.2	–	41.3	–	46.0	–
MT	61.5	52.8	40.7	34.6	49.8	59.8
CT	53.6	50.8	33.8	31.8	41.2	43.0
LSD (P=0.05)	2.5	1.7	9.0	1.3	5.4	9.2
Mulching						
M0	57.6	49.5	38.5	30.2	42.3	54.5
M1	59.9	52.4	41.8	33.7	49.1	63.4
LSD (P=0.05)	1.8	1.4	6.4	1.1	3.8	7.5

ZT= zero tillage, ZTIRT= zero tillage followed by inter row tilling, MT= minimum tillage, CT= conventional tillage, M0= no mulch, M1= mulched. Adapted from Rathore et al. (1998).

Shanahan et al., 1988; Halvorson, 1990; Horton et al., 1996; Peterson et al., 1993; Corbeels et al., 1998; Nielsen et al., 2005; Tanaka et al., 2005). Conversley Potter et al. (1995) illustrate the importance of tillage on increasing the macro porosity of soil and the ability of soil to rapidly absorb water when rain begins when compared to no-tillage systems.

Thus many agronomic considerations are important to increased productivity of these legume crops globally. However, the most important agronomic approaches which need to be included in the integrated management for higher productivity of legume crops are field ploughing, planting methods, weed, irrigation and nutrient management, harvesting and threshing operations to increase the legume crops productivity and production around the world. For more details see the chapter on weed management, efficient water utilization in irrigation, nutrient management and biological nitrogen fixation and use of agrochemicals.

17.5 Introduction of New Approaches

The importance of natural elicitors and their use in legume production systems is a new conceptual approach. The present limited information on their role will need to be increased to provide an understanding about their utilization in the integrated management system of legume crops. Being involved in plant defense response and plant-microbe interactions, flavonoid production by plants (including isoflavones) may be increased when plants recognize certain molecules or structures that characterize a pathogen or a symbiont; such compounds are known as inducers or elicitors. Consequently the use of biotic or abiotic elicitors of plant defence responses has been evaluated for a number of years as a pest biocontrol strategy (Tahvonen, 1988; Lafontaine and Benhamou, 1996; Benhamou et al., 1998; Duzan, 2004), and more recently as a means of increasing the production of compounds of value to the nutraceutical industry.

Kneer et al. (1999) demonstrated that the exogenous application of natural elicitors to roots of *Lupinus luteus* L, including lipochito-oligosaccharide (LCOs) produced by rhizobia, chitosans (i.e., deacylated chitin), and salicyclic acid (i.e., a compound involved in plants' systemic response to pathogens), resulted in an increase in the synthesis and root concentration of the isoflavone genistein. The response was dose dependant but was observed in all cases at very low concentrations varying with the elicitor but being as low as 100 μM. Injections of purified yeast cell wall (which contain chitin polymers) increased flavonoid content in the foliage of *Lupinus albus* L. (Bednarek et al., 2001). Gagnon and Ibrahim (1997) also reported a marked increase in isoflavone content of *Lupinus albus* L. seedlings upon treatment of seeds with yeast extract and chitosan. Actinomycetes are organisms that have been reported to have antagonist effects on some pathogens and have been successfully used as biocontrol agents; it has been suggested that some of their properties may be associated with an induction of plant defence responses, although such properties remain to be demonstrated (Beausejour et al., 2003). A study conducted by Bitteli et al. (2001) investigated the potential of chitosan, a natural beta-1-4-linked glucosamine polymer, to reduce plant transpiration. Chitosan was applied foliarly to pepper plants and water use was monitored Scanning electron microscopy (SEM) and histochemical analyses demonstrated that chitosan induced closure of the plant's stomata, resulting in decreased transpiration. Bittelli et al. (2001) reported a reduction in transpiration of pepper plants upon the foliar application of chitosan. This translated to 26–43% reduction in water use, while maintaining fruit yield and biomass accumulation. In contrast, in certain situations the impacts elicitors have on plant physiology and defence response may translate into yield increases, as observed by Hirano et al. (2000); with 20% seed yield increase in soybean following treatment of seeds with chitosan. We suggest that chitosan might be an effective antitranspirant to conserve water use in agriculture.

Plants accumulate a variety of organic osmoprotectant solutes through a biochemical mechanism which improves their ability to withstand drought stress. One of these solutes, is Glycinebetaine (GB) (N,N,N-trimethyl glycine). Betaine stabilizes the structures and activities of enzymes and protein complexes and maintains the integrity of membranes against the damaging effects of several abiotic stresses. Previous research has shown that exogenous application of GB to non-accumulators of GB is an alternative to improve the stress tolerance (Gorham et al., 1985; Delauney and Verma 1993; Rhodes and Hanson, 1993; Bohnert et al., 1995). Reports have emerged recently indicating that GB-treated plants maintained a higher net photosynthetic rate during drought stress than non-GB treated (Ma et al. (1999). In another study, Ma et al. (2007) reported that GB improved photosystem II (PSII) activity and increased antioxidant activities under water deficit conditions. Thus it is important to consider such options to include in the integrated management of legume crops under climate change.

17.6 Moisture Conservation Through Tephra Covers

In recent decades, many studies have discussed the role of tephra covers on soil moisture conservation. Detailed reviews are found in Díaz et al. (2005), Tejedor et al., 2002b, 2003b. For centuries, farmers in many arid and semi arid areas have used coverings of clastic fragments to lower water loss from soils underneath. Agricultural stone covers are known by various names, including gravel, rock, volcanic ash or lithic-mulches (Lightfoot, 1994; Doolittle, 2000), gravelage in Switzerland (Nachtergaele et al., 1998), arenados in the Canaries (Araña and López, 1974; Hernández-Moreno et al., 2007), and sandy fields in China (Gale et al., 1993). Li et al. (2007) reported that amount of available water in soil can be enhanced by surface mulching and other soil management practices. Recent studies have shown that some realistic techniques of rainwater harvesting (Li et al., 2000; Li and Gong, 2002; Tian et al., 2003; Li et al., 2007) and supplementary irrigation (SI), can be used to get better crop yields and production constancy of farmland ecosystem (Zhao et al., 2005; Xiao et al., 2007; Zhang et al., 2007). Tephra covers have been used for dry farming in Argentina, the Canary Islands, China, Greece, Israel, Italy, Peru, New Zealand, peninsular Spain, Switzerland, and USA (Groenevelt et al., 1989; Pérez, 2000; Tejedor et al., 2002a, b, 2003a; Zhang et al., 2005). Recent studies emphasize the importance of tephra covers to conserve soil moisture, but efficiency varies widely (Díaz et al., 2005).

In Spain in a 31 day experiment Díaz et al. (2005) reported that a 10-cm layer of tephra resulted in a 92% reduction of evaporation compared to uncovered soil; all grain sizes ($\leq$4 mm diameter) and cover thicknesses (2–10 cm) reduced evaporation sharply, 81–85%. Pérez (2000) reported that significant influence of surface volcaniclastic layers from Haleakala (Maui, Hawaii) on soil water conservation. In a 22-day experiment Pérez (2000) note that, bare soils lost 50% water after 9–14 h, but soils under tephra took 112–191 h. Also he found that exposed soils were dry in 3–6 days, but covered soils retained moisture for 10–21 days. The tephra acts as mulch and was found to decrease soil moisture losses by dropping soil temperature and evaporation, enhancing soil biotic activities, reducing hard soil setting and contributing plant nutrients (Valentin and Casenave, 1992; Pal et al., 1994; Poesen and Lavee, 1994; Nachtergaele et al., 1998; Tejedor et al., 2003a, b).

17.7 Plant Hormone

Many of the plant responses to soil water deficit occur via chemical signals such as the phytohormone abscisic acid (ABA) (Wilkinson and Davies, 2002). Most reports have demonstrated that the endogenous levels of ABA in vegetative plant tissues rise in response to stresses that cause a plant water deficit (Taylor et al., 2000; Bray, 2002; Zhang et al., 2006). ABA plays a central role in many aspects of plant development, in the regulation of stomatal aperture, and in the initiation of adaptive responses to various environmental conditions. Previous research has shown that ABA is formed under both drought and low temperature stress. Furthermore, plants grown under water stress show a higher tolerance to low temperature stress than do well-watered plants (Thomashaw, 1994). Shinozaki et al. (1996) reported that a number of genes have been described that respond to drought and low temperature stress at the transcription level. The functions of some gene products have been predicted from sequence homology with identified proteins and are thought to play a role in protecting cells from water deficits and low temperatures (Thomashaw, 1994). Many drought-inducible genes with various functions have been identified such as late embryogenesis abundant (LEA) proteins (Moons et al., 1995), the enzymes betaine aldehyde dehydrogenase (Ishitani et al., 1995) and 1-pyrroline-5 carboxylate synthetase (Yoshiba et al., 1995). However, it has been demonstrated that ABA was produced under such environmental stresses and thus additional ABA may not be of benefit.

Researchers have long known that the application of exogenous ABA provides tolerance to various stress conditions (Thomashaw, 1994; Shinozaki et al., 1996; Shinozaki et al., 2003; Shinozaki and Yamaguchi-Shinozaki, 2007). The obvious relationship between plant ABA content and plant tolerance to water deficit has been described (Kulkarni et al., 2000; Liu et al., 2005). Furthermore it has been shown that exogenous application of ABA directly induces many stress responsive gene products (Bray, 1988; Rouse et al., 1996; Gupta et al., 1998). Zhang et al. (2006) reported that the protective effect of ABA is based on the fact that ABA primarily promotes stomatal closure to minimize transpirational water loss and then it mitigates stress damage through the activation of many stress-responsive genes, which collectively increase the plant stress tolerance. Thus under climatic changes such options can also be employed to increase productivity of these crops if situation demanded.

17.8 Fertilizers

Chemical fertilizers have played a big role in twentieth century to bring forth the green revolution globally. The production of cereals has been increased 3–4 times higher due to change in plant types and fertilizers applications. The major fertilizers viz. nitrogen, phosphorus, potash, etc. have played an important role in most of the irrigated crops. However, these fertilizers at nominal rates are recommended as basal application only in these legume crops, even then the farming communities are reluctant to apply the recommended doses of NPK under dry ecologies. It is predicted that under climate change both temperature and drought may increased in the near future. Under that situation the judicious and appropriate use of these fertilizers will play an important role as basal applications to legume crops to increase productivity. Therefore, experience of some important past research will form the basis of future strategies for the application of major fertilizers. For more details the chapter on agronomic approaches of this book is recommended.

Researchers in the last decade have found that nutrient uptake in plants under drought stress may have an important role in drought tolerance (Abu Assar et al., 2002; Baligar et al., 2001; Samarah et al., 2004). The nutrient-use efficiency of legume cropping systems must be improved by selection of improved genotypes adaptable to drought conditions which will have a major contribution to the overall gain in crop productivity (Baligar et al., 2001).

Samarah et al. (2004) reported that drought stress may involve the uptake of mineral elements in plant tissues by affecting root growth and nutrient mobility in soil and nutrient uptake. Bloom et al. (1985) found that decreases in water availability generally decreases the nutrient availability. On the other hand, plant species and genotypes within species differ in their response to nutrient element uptake under water stress (Garg, 2003). In a study conducted by Ali et al. (2002) genotypic variations in response to application of Fe, B and Zn were found among chickpea genotypes.

Several studies have demonstrated that application of large amounts of K has been associated with resistance to many stress conditions including those imposed by diseases, drought, and high and low temperatures (Jonathan et al., 2001). Also they reported that K may increase stress resistance by enhancing rooting, producing thickened cell walls, with an associated higher cellulose content, and decreases in tissues hydration, resulting in hardy tissue. Experiments were conducted by Abu Assar et al. (2002) to study of trace element correlations with drought tolerance in different sorghum genotypes using energy-dispersive X-ray fluorescence techniques. He found that in the majority of the genotypes (seeds), K and Fe contents were more in the tolerant genotype as compared to the susceptible type. Later he found that the concentration of Fe decreased with maturity in the tolerant group and it increased with maturity in the susceptible group.

Thus in integrated production management under climatic changes the appropriate levels of major fertilizers like NPK have to be applied judiciously before planting of these crops to sustain the productivity of cool season crops around the world.

17.9 Enhanced Nitrogen Fixation

It is a natural gift of the legume crops that they are capable of fixing atmospheric nitrogen for their use during the cropping period. However, this biological nitrogen fixation greatly varies from variety to variety, planting environment to environment, location to location, etc. It is also certain that different rhizobial strains are playing a major role in the efficiency of this phenomenon. For detailed information, the chapter on biological nitrogen fixation of this book is recommended. Only limited references are being included below for better understanding.

Productivity in drought prone environments may be increased by the introduction of N2-fixing legumes along with corresponding effective rhizobial strains. Many factors such as legume species, genotypes, pests, soil acidity, soil salinity, drought, soil fertility, pesticides, flooding and inoculant strains are the major factors affecting nitrogen fixation in legume farming systems (Banu et al., 1993; Heshem et al., 1995; Heshem, 1997; Heshem, 1998; Biswas et al., 2000). Drought is the major environmental factor that can affect rhizobial competition and N2 fixation.

Biological nitrogen fixation in legume cropping systems is thought to have several beneficial effects including:

17.9.1 Agronomic Benefits

Biological nitrogen fixation in legume cropping systems can improve the rate of seedling emergence, radical elongation, height and dry matter, plumule length, cumulative leaf and root areas, and grain yield and straw yields, single-leaf net photosynthetic and nutrient uptake(Banu et al., 1993; Heshem et al., 1995; Heshem, 1997; Heshem, 1998).

17.9.2 Environmental Benefits

The use of biological nitrogen fixation has been documented to improve the environment through decrease level of ground water pollution by nitrate and reduce outputs of greenhouse gas production (Vance, 1997; Van Kammen, 1997).

17.10 Arbuscular – Mycorrhizal

Arbuscular-mycorrhizal (AM) fungi are important in sustainable agriculture.They play a crucial role in plant nutrient uptake, water relations, ecosystem establishment, plant diversity, and the productivity of plants (Maronek et al., 1981; Nelsen, 1987; Linderman, 1994). Several studies demonstrated that the donation of the AM symbiosis to plant drought tolerance results from a combination of physical, nutritional, physiological, and cellular effects (Ruiz-Lozano, 2003). Allen and Allen, 1986 reported that Arbuscular-mycorrhizal improve plant water relations and thus increase the drought resistance of host plants. Previous studies have shown that the inoculation with AM fungi could affect the water metabolism of hosts and consequently increase their drought tolerance (Davies et al., 1992).

Smith et al. (1986) reported that mycorrhiza play a role in improved plant water status and changes in water relations have been attributed to a wide variety of mechanisms, including some mechanisms not directly related to phosphorus nutrition or water uptake. Levy and Krikun (1980) stated that most effects of the mycorrhizal association were on stomatal regulation rather than on root resistance. Previous studies shown that AM symbiosis might increase the drought resistance of higher plants by promoting antioxidant enzymes in bean (Lambais et al., 2003), red clover and some shrub species (Alguacil et al., 2003). According to Wu and Xia (2006) the inoculation of *Glomus mosseae* promoted active absorbing areas of trifoliate *P. trifoliata* roots and increased plant water use efficiency when the soil water contents were 20, 16, and 12%. Kubikova et al. (2001) found a greater osmotic adjustment in leaves of mycorrhizal basil plants than in non-mycorrhizal ones during a lethal drought period. Porcel et al. (2003) found that when AM soybean plants subjected to drought they had lower oxidative damage to lipids and proteins in nodules than non-AM plants, and this was linked to protection against nodule senescence. Previous studies have shown that the inoculation of *G. mosseae* reduced the production rate of $O_2{}^-$, improved the contents of superoxide dismutase (SOD) and catalase (CAT) in sugarcane leaves, and enhanced the removing ability of reactive oxygen, consequently reducing the peroxidation of membrane lipids and improving drought tolerance during water stress (Wang et al., 1989).

According to Augé (2001, 2004) there is a role played by AM fungi in alleviating drought stress of higher plants as it appears that drought resistance is enhanced. Fidelibus et al. (2001) found that four *Glomus* species isolated from arid, semiarid and mesic areas stimulated root growth (dry weight and length) and that leaf phosphorus concentrations were 12–56% higher in arbuscular mycorrhizal (AM) plants than in non-AM plants under well-watered conditions.

17.11 Integrated Diseases Management

In legume crops incidences of biotic stresses frequently occur in different countries during their cropping season. Some diseases are simple and some are complex in genetic inheritance and overall their mode of inheritance is not as well and systematically understood as for cereals. In most of the legume growing areas more than 2–3 diseases prevail and damage this crop substantially. Thus resistance breeding in these crops has not been very successful like cereals, so the diseases incidences are high and yield losses in legume crops due to diseases infestations are also very high. Thus disease pressure is a major factor and responsible for the low and unstable legume seed yields globally. Thus it is imperative to develop more and more resistant cultivars having resistance against various major diseases. However, incorporation of resistance against one single disease and than another disease is a time-consuming process and costly-phenomenon. Therefore, it is more advisable and more practical approach to incorporate multiple resistances in legume crops which can provide a durable and predictable resistance.

Development of multiple disease- resistant varieties through conventional breeding approaches is cumbersome and time-consuming. There are difficulties in selecting donors with desired combinations of genes and also single plant selection in segregating populations is time consuming. MAS (Marker Assisted Selection) can provide an effective and efficient tool for detecting, trekking and combining stress resistance genes in segregating and advanced generations. This approach can be a more useful, convenient and time shaving technique in developing the multiple resistant cultivars in legume crops. Legume breeders need to create these multiple resistant lines.

17.12 Integrated Insect- Pests Management

Pest management is important under dry ecologies production systems. Previous studies have shown that pest (weed, insect, mite, etc.) do more damage under drought conditions than in conditions where the legume is growing rapidly (Glen et al., 1995; Van Emden and Peakall, 1996; Brooks and Roberts, 1999; Gurr et al., 2004). Pulse (chickpea, lentil, faba bean, peas) production in dry areas is harshly degraded by insect pests, viral and fungal diseases that can cause seed, seedling, and root diseases.

Many systems for integrating different pest control techniques have been developed which including host plant resistance, biological control, reduced and safe use of chemicals, and appropriate cultural practices (Brooks and Roberts, 1999; Hardie and Minks, 1999; Matthes et al., 2003; Powell and Pickett, 2003; Hester and Harrison, 2005). Recently Hassanali et al. (2008) reported that there is a risk that uncertainty of weather means that the farmer will be justifiably reluctant to invest in technologies that would undoubtedly improve the crop, because there may be no crop at all due to abiotic stresses. The major pests observed attacking the legume cropping system in the dry, semi-arid and sub-humid areas are: Nematodes, root rots, fungal wilts, root aphids, parasitic weeds, bean stem maggot, white grubs, and root worms. An integrated pest management plan begins with crop rotation of pulse crops with other crops. Crop rotation is an important tool in management of weeds and diseases and in minimizing residual herbicide injury to the crop. Weeds can be defined as plants that grow where people do not want them to grow. They compete with the major desirable plants in the legume crop for resources such as light, soil moisture and nutrients. Weeds need to be controlled to conserve soil moisture. Therefore, weed control is even more important when water is scarce. There are different methods to control these serious weeds in pastures including the use of chemical herbicides (such as phenoxy, benzoic, or picolinic acid herbicides), physical removal (using tillage, root plowing, clipping and hand weeding), biological agents (using of natural enemies such as insects, fungi and animals), burning and integrated weed management (combines cultural, mechanical, biological and chemical weeds control practices to keep weeds pressure below the threshold levels that can reduce yields qualities and quantities). Different types of natural enemies that can be used in biological control of weeds include fungi, insects, animals and nematodes. There are three types of biological control methods, which include classical, inundative and herbivore management. There is evidence that different types of enemies can be used in biological control of weeds, which include: fungi, bacteria, and viruses insects and animals (Kok, 1975; Sims et al., 1987; Chandramohan, 1999; Rosskopf et al., 1999). Integrated weed management programs in legumes combine cultural (e.g. managing fertilizer rates, timing and placement, planting more competitive varieties) mechanical (using tillage, root plowing, clipping and hand weeding), biological (using natural enemies such as insects, fungi and animals) and chemical (rotating herbicides with different mode of action). Weed control practices aim to keep weed pressure below the threshold levels that reduce yields qualities and quantities (Minoti and Sweet, 1981). It is very important to integrate two or more control methods into a system of management.

17.13 Components of Integrated Management

In the last 50 years, attempts to overcome biotic constraints of legume crop production have mainly focused on use of chemical pesticides and/or host- plant resistance. Theses single – factor management strategies to combat biotic and/or abiotic constraints were studied in isolation from each other. As a result the yield losses caused by pests or disease epidemics, along with poor agronomy, remained alarming and significant. There is a greater opportunity to combine best technologies that combat insect-pests and diseases with improved agronomical practices and emerge with integrated management packages. Integrated management packages of legume crops provide greater scope and need validation, up-scaling and out-scaling with the involvement of farmers.

Integrated management is an holistic approach that coordinates available crop and pest management technologies in an economically and ecologically sound manner. The important components of integrated management are (i) the development and use of newly developed improved cultivars which possess high-yield genetic potential, better disease resistance, insect tolerance, and improved adaptability. (ii) inclusion of seed treatments with fungicides and insecticides (iii) improved agronomical practices such as use of Rhizobium, seed priming (soaking seeds for 8 h in water before sowing), optimum plant population density, optimum seeding time, use of phosphorus (p) fertilizer in low-P soils, use of proper row spacing (iv) nutrient management (v) disease management (vi) Integrated pest management e.g. applying need – based spray of pesticides to manage biotic constraints, monitoring of pests population, use of traps, etc. It is an holistic guiding principal that encompasses all the activities from selection of crop to harvest and storage. Broadly speaking, however, integrated management strategies are based on three main pillars viz. prevention, monitoring and intervention (Pandey et al., 2007).

Most of the integrated management activities emphasis is heavily on the preventive measures especially before the crop in sown, i.e. at the field preparation or seed treatment stages, since the initial inoculum of the propagule is largely responsible for the subsequent high pest build-up. Agronomic practices such as deep summer ploughing, soil solarization, cleansing of crop refuse, elimination of weed hosts, crop rotation, water management, intercropping, trap cropping, boarder cropping, nutrients management, as well as genetic sources of resistance along with habitat management are the major tools of prevention.

Regular monitoring is crucial for pest management as it is one of the most important decision- making tools. An efficient monitoring programme can pay huge dividends in lowering pest control costs. An agro-ecosystem analysis based on crop health at different stages of growth, population dynamics of pests and natural enemies, soil conditions, climatic factors and farmers past experiences is considered for decision making. Field scouting, use of sticky traps, pheromone traps and soil sample analysis for soil-borne plant pathogens are usually employed as monitoring tools. Diagnosis techniques, economic threshold level and pest forecasting models are now available to assists in the proper timing of integrated management interventions.

Various integrated management interventions are devised to reduce the effects of economically damaging pest populations to acceptable levels. Mechanical, biological cultural and chemical control measures are applied individually or in combination. Some of the integrated management interventions include cultural and physical measures, monitoring of pests, bio-control agents (bio-pesticides, natural enemies), host–plant resistance, botanicals and target-specific, less hazardous chemical pesticides.

17.14 Future Thrust

17.14.1 Research Needs and Opportunities

Susceptibility of legume cultivars to biotic stresses adversely affects yield stability in legume crops. In recent years, cultivars resistant to one or more stresses have been bred, which increased the stability of legume crop production. However, single gene-based resistance proved to be ephemeral in nature due to the emergence of increasingly more virulent races or pathotypes. Therefore, insulation of varieties against major biotic stresses through pyramiding of genes should be taken up with the help of both conventional and molecular tools to meet the challenge posed by highly virulent pathogens like Fusarium wilt, Ascochyta blight and BGM (Botrytis Grey Mould). Stable resistance sources for many disease and insect-pests are needed besides precise information on important aspects such as identification and characterization of races or pathotypes, rate of emergence of new races or pathotypes, and genetic control. These are needed immediately for directed improvement in resistant breeding. Research activities on the development of transgenics, QTL's (Quantitative Trait Loci), molecular marker, etc. are been carried out at different national and international organizations to incorporate multiple resistance against biotic and abiotic stresses in legume crops.

17.14.2 Seed Systems Bottlenecks

It is known that investment in fertilizers, water, plant protection, chemicals and other inputs do not yield economical returns with out the use of quality seeds. Quality seed is the basic critical and cheapest input for integrated management, and for enhancing agricultural productivity and increasing higher net monitory returns per unit area. Returns on investment depend on varietal purity and physical quality of the seed that is used in the production of crops. For centuries, farmers have used their own seeds by selecting and saving part of their harvest. These practices are still followed by most of them through organised seed production. Globally, legume crops are most cultivated on marginal lands with low fertility and moisture stress as farmers consider that legume crops do not have high potential as cash crops. Farmers seldom use good-quality seeds and adopt new production technologies. New improved varieties and technologies can potentially increase the production with proper management conditions.

An efficient seed production system that can provide quality seeds at economically viable costs is the backbone of any crop production technology. Seed cost plays an important role in the adoption of integrated management technology. The technology itself and other crop management practices are critical in determining the production costs.

Improved seed is one of the major inputs to increase production and improve the grain quality for export. Even though the production area of legume crops has increased during last 3–4 decades, the quality of seeds available to farmers is far bellow the actual needs. Suitable varieties for varied agro ecological domains are still not available to them.

Quality seed production is a prerequisite for securing sustainable production, expanding production areas and increasing productivity of improved cultivars through integrated management. The entire "seed chain" – nucleus seed to breeder seed to foundation seed to certified seed and distribution to needs attention.

17.14.3 Germplasm Screening and Evaluation

It is predicted that moisture stress, high and low temperatures and CO_2 levels will increase substantially by 2050. The status of the response of many new cultivars to climate change for all these factors is entirely un-known. Under such situations, it is imperative to understand the physiological and morphological phenomenon of each legume crop. What will be the impact of climate change on the phenotypic performance under increased levels of such stresses. These are some practical questions to be answered for future strategies formulation. Thus it is important to screen and evaluate the diverse germplasm of these legume crops under increased levels or various levels of moisture stress, low and high temperature ranges and different CO_2 levels so that scientists can provide vital donors for breeding programmes for the development of new cultivars.

17.14.4 Government Policies and Support

Food legume crops play a key role in soil improvement, nutritional security, income generation, environmental improvement, etc. Governmental interventions play a major role to sustain research and development activities which are vital for industrial production of food legumes. Few governments are currently promoting policies to prioritize and promote food legume crops by investing in R & D for improved varieties and agronomic management for food legumes, and providing credits for food legume farmers. Crop diversification as a strategy has been adopted by a few countries like India, Philippines, Vietnam, Nepal, Bangladesh, etc. to promote and accelerate agricultural growth, maximise use of land and optimise farm productivity and availability. Likewise, many governments have declared new policies to minimise the CO_2 emission, increase plantation areas under forest, create efficient utilization of irrigation system, etc. Such measures can decrease the influence of warming climates globally.

17.15 Conclusions

Food legume crops are important components of cropping systems and provide an opportunity to produce diversified food products for mankind's survival. With the inclusion of these crops into agricultural production and cropping systems, food security will be more sustainable globally. Rotation of these crops with cereal crops makes cereal production more profitable. Thus legumes have a crucial role in terms of food and nutritional security and are the important pillar of sustainable food production globally.

However, for these legume crops, the major constraints are susceptibility to diseases, insects and pests, drought, low and high temperatures, salinity, water logging, etc. Due to these biotic and abiotic stresses their productivity is low globally. Therefore, it is necessary to enhance their tolerance against biotic and abiotic stresses. On the other hand, various options are available for increasing water availability and supporting growth of crop plants in drought-prone environments, such as plant configuration, plant breeding techniques, agronomic management, use of natural elicitors, tephra covers for soil moisture conservation, integrated pest management, treatment with plant hormones, judicious use of fertilizers, enhancing biological nitrogen fixation and arbuscular – mycorhiza, etc.

It is certain that in the years to come, the total food requirement of legume crops will increase due to changes in dietary habits and population growth and overall productivity may decrease due to climate change which may adversely affect their yielding ability. Under these environmental changes it is important to maintain the harmonious balance of legume crop production systems to meet the demand at national and international levels. Therefore, it is essential to utilize appropriately the available options and more importantly implement integrated crop production and management technologies in legume crop production systems.

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Chapter 18
Legumes Cultivars for Stress Environments

C. Toker and Shyam S. Yadav

18.1 Introduction

The genera *Cicer* L., *Lathyrus* L., *Lens* Mill., *Lupinus* L., *Pisum* L. and *Vicia* L. are referred to as cool season food legumes (Saxena, 1993; Muehlbauer and Kaiser, 1994) because they need cool conditions during vegetative growth stages. Chickpea (*Cicer arietinum* L.), grass pea (*Lathyrus sativus* L.), chickling vetch (*Lathyrus cicera* L.), lentil (*Lens culinaris* Medik.), white lupine (*Lupinus albus* L.), blue lupine (*Lupinus angustifolius* L.), yellow lupine (*Lupinus luteus* L.), Andean lupine (*Lupinus mutabilis* Sweet), pea (*Pisum sativum* L) and faba bean (*Vicia faba* L) are mainly cultivated as food and sometimes grown as feed. They are quantitative long day plants however some genotypes are day-neutral. They have hypogeal germination and germinate at relatively low temperatures (van der Maesen and Samaatmadja, 1992) except for lupines which have epigeal germination and need warmer temperatures (Gladstones et al., 1998). Apart from the cultivated lupines (Cowling et al., 1998a), these cool season legumes are able to tolerate frost and to withstand temperatures below 0°C during the seedling stage (Singh and Saxena, 1993). Faba bean and pea are suited to 650–1,000 mm and 400–1,000 mm rainfall per year, whereas chickpea, grass pea, chickling vetch, lentil and lupines are adapted to drier areas (van der Maesen and Samaatmadja, 1992; Siddique et al., 1993, 1998, 1999, 2000). Thus *Cicer* L., *Lathyrus* L., *Lens* Mill. and *Lupinus* L., are known as drought resistant genera; in contrast, *Pisum* L. and *Vicia* L. are known as drought sensitive genera.

Although most of the world's agricultural areas are managed by coping with water scarcity, about 300 million ha globally is equipped for irrigation (FAO, 2008). The cultivated chickpea, grass pea, lentil and lupines are generally grown in marginal areas and subjected to biotic and abiotic stresses. Improved varieties of

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these crops are usually cultivated without irrigation and using minimal or no inputs in marginal rainfed areas, because of social and economic reasons (Muehlbauer and Kaiser, 1994). In addition, traditional local cultivars or populations with low yield potential are commonly sown and grown in major producing countries (Erskine, 1997). Drought accompanied by heat stress is the most important constraint in most production regions (Saxena, 1993).

Yields of *Cicer* L., *Lathyrus* L., *Lens* Mill., and *Lupinus* L., have increased little from 1961 to 2007 (FAO, 2007) despite substantially increased efforts to improve these crops via breeding (Singh, 1993; Singh et al., 1994; Knight, 2000). On the other hand, yields of improved pea and faba bean varieties have increased considerably over the same period (FAO, 2007). The basis of this difference is that pea and faba bean are mostly grown with more inputs than the former group (van der Maesen and Samaatmadja, 1992).

To maintain or even increase production per area of cool season food legumes in increasingly drought prone environments resulting from climate change effects several approaches are possible. Agronomic management may be altered for example by, applying irrigation if available, shifting to suitable soil tillage options including zero tillage where economic, increased use of fallow, improved fertilization, modified rotations, inoculation with rhizobacteria, enhanced pest and disease control. Linked to these agronomic changes are likely to be use of drought and cold resistant cultivars better suited to the new management systems. Another way to increase production per area of cool season food legumes is to escape terminal drought via early sowing (Siddique et al., 1998, 1999; Farooq et al., 2009) which shifts sowing time from spring to autumn or winter. This shift must be accompanied by breeding of cold tolerant cultivars (Singh, 1987). Therefore, drought resistant cultivars and lines of chickpea, faba bean, grass pea, lentil, lupines and pea and their morphological and agronomical advantages are highlighted in this communication.

18.2 Drought Resistant Genera

18.2.1 Cicer L.

The genus *Cicer* consists of nine annual species including the cultivated chickpea, *Cicer arietinum* L. and 35 wild perennials (van der Maesen et al., 2007). The cultivated chickpea has been divided into two distinct groups namely *microsperma* or “desi” and *macrosperma* or “kabuli” (van der Maesen, 1972; Moreno and Cubero, 1978). The *macrosperma* chickpeas have relatively large seeds, white flowers and creamy seed colour with no pigmentation of the plant. In contrast, the *microsperma* chickpeas have small seeds, purplish flowers and various seed colours with pigmentation of the plant. The *microsperma* chickpeas are generally more drought resistant than *macrosperma* chickpeas (Leport et al., 2006; Nayyar et al., 2006a, b, Yadav et al., 2006; Canci and Toker, 2009a).

18.2.1.1 Breeding for Resistance to Drought and Cold

Ali and Kumar (2003) reported that chickpea research dates back to 1905 in India. The first systematic research on genetics of chickpea was started in 1911 at the Imperial (now Indian) Agricultural Research Institute (IARI), Pusa, Bihar, India. These studies concentrated on simply inherited characteristics (Bahl, 1988) which can be called the initial phase. Varietal improvement based on selection from landraces was also initiated in 1920s at the IARI, Pusa, Bihar, India. Selection and a few hybridization studies resulted in several improved varieties (Bahl, 1988), called the second phase. The third phase was started with the instigation of the "All Indian Coordinated Pulse Improvement Project" in the mid-1960s. This phase developed alongside international studies by the establishment of the Food and Agricultural Organization/International Atomic Energy Agency (FAO/IAEA), Vienna, Austria (Salimath et al., 2007), the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India and the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. The fourth phase focused on breeding for stress tolerance in the cultivated chickpea and the introgression of important alleles from wild species, such as the resistance or tolerance to abiotic and biotic stresses. A fifth phase has commenced on marker assisted selection using molecular techniques, gene pyramiding and transgenics. Bahl (1988) reported that the oldest chickpea variety, RS10, was released in 1951 as tolerant to drought and high temperature.

Yield loss caused by drought in chickpea was found to be between 30 and 80%, depending on geographic location and climate (Leport et al., 1999; Saxena et al., 1993a, b; Yadav et al., 2006). Yield losses can extend to 100% when sensitive cultivars are sown at the end of spring rainfall in the Mediterranean region (Canci and Toker, 2009a). Globally estimates of chickpea yield losses due to drought and heat stress has indicated average annually losses of 3.3 million tons (Ryan, 1997). Chickpea has a range of different mechanisms to adapt drought conditions. These mechanisms are reported by Farooq et al. (2009) as: (A) *morphological mechanisms*; (i) drought escape with early phenology (early flowering, podding and maturity) under terminal drought, (ii) dehydration postponement (drought avoidance) through maintaining water uptake and reducing water loss, mainly by high root length density (RLD) and small, tiny and thick leaf characteristics, and (iii) phenotypic flexibility (either by leaf shedding or production of smaller leaves); (B) *physiological mechanisms*; (i) cell and tissue water conservation (an ability of cells to continue metabolism at lower water status), (ii) antioxidant defence (both enzymatic components that include superoxide dismutase, catalase, peroxidase, ascorbate peroxidase and glutathione reductase, and non-enzymatic components that consist of cystein, reduced glutathione and ascorbic acid), (iii) cell membrane stability (maintenance of integrity and stability of membranes under water stress is a major component of drought tolerance), (iv) alterations in levels, distribution and timing of plant growth regulators (these substances protect the plants from drought effect when externally applied or internally produced), (v) use of compatible solutes (they protect plants from stress through different means such as contribution towards osmotic adjustment, detoxification of reactive oxygen species, stabilization of membranes, and native structures of enzymes and proteins); and (C) *molecular mechanisms*; (i) aquaporins (these have the ability to facilitate and regulate passive exchange of water across membranes), (ii) stress proteins (synthesis of these proteins is a ubiquitous response to cope with prevailing stressful conditions), and (iii) signalling and drought tolerance (signals like reactive oxygen species, calcium and calcium regulated proteins involved in inducing stress).

18.2.1.2 Variety Improvement

In chickpea, Gumber and Sarvjeet (1996) found that time to flowering was controlled by two genes. Or et al. (1999) observed that late flowering was dominant over early flowering traits (Anbessa et al., 2006), affecting a major photoperiod response gene (*Ppd*) in chickpea. Kumar and van Rheenen (2000) deduced the presence of one major gene (*Efl-1/efl-1*) as well as polygenes for time to flowering in chickpea. Kumar and Abbo (2001) suggested that the major early flowering alleles *efl-1* and *ppd* may be located at the same locus in chickpea. Both the early flowering trait and the photoperiodic response, being simply inherited, may be easily introduced into late flowering genetic backgrounds.

Kashiwagi et al. (2008) studied the genetic effects of drought avoidance root characteristics and they proposed delaying selections in later generations to exploit additive by additive interactions. Table 18.1 consists of chickpea varieties and lines having early phenology, drought-avoidance root characteristics and high yield under drought conditions.

Autumn or winter sowing is a drought escape strategy in Mediterranean environments which has many advantages such as; suitability for machine harvest due to a taller crop, earlier harvest than spring sown, long vegetative (greater leaf area duration) and reproductive period compared to spring-sown crop, more N_2 fixation, and reduced soil erosion in winter (Singh, 1987, 1997; Toker et al., 2007b). ILC 8262 (Singh et al., 1992) and ILC 8617 (Singh, 1997), with rosette-type and dark green leaves in the seedling stage plus late flowering, are the best sources of cold tolerance during the seedling stage (freezing resistance, below 0°C without snow cover). ICCV 88502 and ICCV 88503 were found to be chilling tolerant (below 15°C) at the flowering stage (Srinivasan et al., 1999). Using the pollen selection technique, Clarke et al. (2004) developed two chilling tolerant cultivars (WACPE 2075 and WACPE 2095) and commercially released these in Australia as Sonali and Rupali. Pollen tubes in chilling tolerant genotypes (ICCV 88516/CTS 60543, ICCV 88510/CTS 11308 and JM 2106) continued to grow down into the style (Clarke and Siddique, 2005) at low temperatures.

18.2.1.3 Resistance to Multiple Stresses, Varieties and Sources

Under changing climates resistance to multiple stresses are required to maximize yield. However, systematic approaches to incorporate multiple resistances against low or high temperature, salinity, moisture stress, and diseases have not been

Table 18.1 Chickpea cultivars suitable for changing climates which possess resistance or tolerance against drought, soil born diseases, early maturity and high yield potential

Cultivars/lines	Main characteristics	Origin	References
ICCV2	Early maturing	ICRISAT	Kumar et al. (1985)
ICC 4958	Higher RLD	ICRISAT	Saxena et al. (1993a)
FLIP 87-59C	Higher yield in drought	ICARDA	Singh et al. (1996)
ILC 142, ILC 391, ILC 588, ILC 1306, ILC 1799, ILC 2216, ILC 2516, ILC 3550, ILC 3764, ILC 3832, ILC 3843, ILC 4236, FLIP 87-7C, FLIP 87-8C, FLIP 87-58C, FLIP 87-85C, FLIP 88-42C	The lowest drought resistance score, higher yield in drought	ICARDA	Singh et al. (1997)
ICCV 96029	Very early maturing	ICRISAT	Kumar and Rao (2001)
ACC 41235, ACC 209025	Drought response index, Smaller leaf area	Ethiopia	Anbessa and Bejiga (2002)
ICCV93043, ICCV93044	Higher yield in drought	ICRISAT	Bakhsh et al. (2003)
ICCV 92944, K 850	Higher RLD and yield in drought	India	Basu and Singh (2003)
RSG143-1, Phule G 5, Vijay, RSG 44, RSG 936	Early maturing and higher yield	India	Chaturvedi et al. (2003)
Pusa 212, 362, 372, BGD 72 and Pusa 1103 (Desi types)	Early maturing, wilt resistant, high yielding, wide adaptation	India	Yadav et al. (2002a, b, 2004)
Pusa 1053, 1088, 1105, and Pusa 1108 (Kabuli types)	Early maturing, wide adaptation, high yields multiple resistances against soil born diseases and drought.	India	Yadav et al. (2004, 2002a)
ICCV 94916-4	Higher RLD	ICRISAT	Ali et al. (2005)
ICC 8261	Higher RLD	ICRISAT	Kashiwagi et al. (2005)
Gokce	Better chlorophyll fluorescence parameters and higher yield	ICARDA	Kalefeoglu (2006) and Kusmenoglu et al. (2006)
ILC 1799	Higher yield in drought	ICARDA	Sabaghpour et al. (2006)
ICC 6122, ICC 8155	Early flowering	ICRISAT	Upadhyaya et al. (2007a)
ICC16641, ICC 16644	Early maturing	ICRISAT	Upadhyaya et al. (2007b)
ICC 13124	Higher yield and drought resistant	ICRISAT	Parameshwarappa and Salimath (2008)
BG 2024	Higher yield	India	IARI (2008)
ACC 316, ACC 317	Very early maturing, Higher yield in drought and heat stress	Turkey	Canci and Toker (2009a)

strongly studied by the scientific community. For example chickpea crop is generally subjected to more than one stress in most chickpea growing regions and, thus, cultivars with multiple stress resistance are needed to enhance and stabilize chickpea production. While numerous cultivars possessing good resistance against individual stress are available, few have been found having resistance to multiple stresses. Breeding for multiple stress resistances is a complex challenge, particularly when donors with multiple stress resistance are not available. Under those situations, resistance genes or gene pools from different sources need to be combined using multiple crosses during hybridization.

Multiple crosses have been used to develop cultivars with resistance to multiple stresses at the Indian Agricultural Research Institute (Kumar et al., 2003; Yadav et al., 2004). For example BG 1063 and BG 1075 possess resistance to fusarium wilt, root rots, and stunt virus. Pusa 1088, BG 1089 kabuli types, BG 1093 and BG 72 have resistance to fusarium wilt, root rots and tolerance to moisture stress, BGD 112, and Pusa 362 have resistance to fusarium wilt, stunt virus, root rots, low and high temperatures and tolerance to moisture stress. It is important to identify donors for multiple stress resistance, so that the numbers of crosses required to develop multiple stress tolerant cultivars can be minimized.

18.2.2 Lathyrus L.

The genus *Lathyrus* L. is one of the largest genera with 154 species reported by Kupicha (1983) while Campbell (1997) indicated 187 species. Grass pea, *L. sativus* L., is a food, feed and fodder crop and commonly grown for its seeds, while other species are generally cultivated for both forage and ornamental plants (Campbell, 1997). There is a strong relationship between the consumption of grass pea and "lathyrism" disease caused by a neurotoxin, β-N-oxalyl-L-a, β-diaminopropionoc acid called ODAP or BOAA (Campbell et al., 1994). The ODAP levels of grass pea genotypes were found between 0.01 and 7.20 g/kg (Campbell, 1997). The levels were influenced mainly by genotype (Hanbury et al., 1999). If ODAP level in a cultivar is below 0.2%, they are thought to be safe for human consumption (Dahiya, 1976).

18.2.2.1 Breeding for Resistance to Drought and Cold

Genetic improvement studies on grass pea commenced with collecting and evaluation germplasm accessions in 1966 in India and this effort produced fruitful results (Lal et al., 1985). In 1980, a drought tolerant mutant of grass pea, Poltavskaya 2, was registered by the International Atomic Energy Agency (IAEA, 2008). The cultivars having low ODAP content are given in Table 18.2. Due to the fact that grass pea is commonly resistant to drought it is valuable as human food only when it has a low ODAP level. Haghighi et al. (2006) reported that six landraces (3, 4, 6, 10, 11 and 12) of grass pea were drought tolerant using a stress tolerance index, high biomass and seed yield. Grass pea has been grown successfully in areas with an average annual precipitation of 380–650 mm (Sinha, 1980; Abd El Moneim and

Table 18.2 Grass pea cultivars suitable for food consumption

Cultivars	Main characteristics	Origin	References
Pusa-24	Low ODAP content	India	Lal et al. (1985)
LS 8246	Low ODAP content	Canada	Campbell and Briggs (1987)
Line 8612	Low ODAP content	Bangladesh	Campbell (1997)
Chalus (*L. cicera*)	Low ODAP content	ICARDA	Hanbury and Hughes (2003)
B1	Low ODAP content	India	Yadav (2005)
Ceora	Low ODAP content	Australia	Siddique et al. (2006)

Cocks, 1993). This crop as a whole has multiple resistance against drought and temperature extremes and consequently has wide adaptation. It is grown under water limiting/moisture stress environments and temperature fluctuating environments in Indian Sub-Continent in India, Bangladesh, Nepal, Pakistan and Srilanka. This crop possesses a very hardy gene pool and such crop varieties will survive well under changing climates due to flexibility in adaptation.

18.2.3 Lens Miller

A total of seven taxa have been recognized in the genus *Lens* Miller; *Lens culinaris* Medikus, *L. ervoides* (Brign.) Grande, *L. lamottei* Czefr., *L. odemensis* Ladiz., *L. orientalis* (Boiss.) Ponert, *L. nigricans* (M. Bieb.) Godron and *L. tomentosus* Ladiz. The cultivated taxon, *L. culinaris* ssp. *culinaris*, includes two varietal groups namely small-seeded *microsperma* and large-seeded *macrosperma* (Sarker and Erskine, 2006; Muehlbauer et al., 2006; Redden et al., 2007; Sandhu and Singh, 2007; Toker et al., 2007c).

18.2.3.1 Breeding for Resistance to Drought and Cold

Varietal improvement in lentil was most probably initiated by collecting genotypes all over India which started in 1924. Breeding studies were focused on selection from the bulk population to increase yield and then the studies were continued with the All Indian Coordinated Pulse Improvement Project in 1960s (Jeswani, 1988). Since that start plant breeders have been financially supported by the Food and Agricultural Organization/International Atomic Energy Agency (FAO/IAEA) from 1964 onwards (Toker et al., 2007c). Also, the International Center for Agricultural Research in the Dry Areas (ICARDA) in 1977 encouraged plant breeders by supplying all kind of seed materials (ICARDA, 1999). Erskine (1998) reported results of a survey that indicated land races covered more than 80% of the area in most major lentil producing countries, whereas about 80 lentil varieties originating from ICARDA have been registered so far (Materne and McNeil, 2007). Erskine et al. (1998) pointed out that among indigenous lentils, a specific ecotype (*pilocae*), was grown in South Asia, which constituted approximately half of the world's area (48.2%) of lentil in 1994. The specific ecotypes bereft of variability and this bottleneck has limited breeding progress (Erskine et al., 1998). In the last three decades, plant breeders have focused on breeding for stress tolerance in lentil (Erskine et al., 1994; Erskine, 1997; Materne and McNeil, 2007).

Lentils are almost completely grown world wide as a dryland crop in rainfed areas (Andrews and McKenzie, 2007). They are grown without irrigation in Canada, USA and Australia (Siddique et al., 1998; McNeil et al., 2007). Among the abiotic stresses drought accompanied by heat stress is the most important limiting factor for lentil production (Saxena, 1993; Erskine et al., 1994; Muehlbauer et al., 2006; Andrews and McKenzie, 2007). Yield losses due to drought can range from 6 to 60% in rainfed environments (Saxena et al., 1993a, b; Shrestha et al., 2006).

Under drought conditions, direct selection for yield could be misleading (Canci and Toker, 2009a). Silim et al. (1993) pointed out that early vigour, early maturity and early development of a high percentage ground cover were strongly associated with biomass and seed yield in lentil, and concluded that drought escape was clearly the key response to drought. Selection for early flowering is therefore required for severely drought-prone areas. Early flowering is determined by a single recessive gene (*sn*) modified by minor genes in lentil. This is supported by the existence of transgressive segregants in the F_2 generation (Sarker et al., 1999). Drought resistant and early flowering varieties or germplasm lines of lentil are listed in Table 18.3.

Traditionally spring-sown lentil faced drought linked with heat stress in southern Europe and the highlands of West Asia and North Africa (Erskine and Muehlbauer, 1995). On the other hand, autumn-sown lentil can yield 50–100% more than the traditional spring-sown lentil using cultivars with winter hardiness (Sakar et al., 1988). Winter hardiness of lentil has been ranked similar to that of faba bean and greater than that of pea and chickpea (Murray et al., 1988). Experiments in

Table 18.3 Drought resistant and early flowering lentil cultivars and lines

Cultivars/lines	Main characteristics	Origin	References
ILL 2914, ILL 2915, ILL 3124, ILL 3397, ILL 3399	Early maturing	ICARDA	Erskine and Witcombe (1984)
MI-30	Higher leaf water in drought	Pakistan	Salam and Islam (1994)
ILL 3715, ILL 5821, ILL 6025	Early flowering	ICARDA	Hamdi (1996)
ILL 1861, ILL 784	Higher yield in drought	ICARDA	Hamdi and Erskine (1996)
HUL-35	Tolerant to osmotic drought stress	India	Singh (2001)
FLIP 92-12L	Stabile and high yield in drought	ICARDA	Mohebodini et al. (2006)
TN-1768	Field performance and germination in PEG	Iran	Mohammad et al. (2008)
ILL 4605, ILL 6037	Early flowering	ICARDA	Sarker et al. (1999)
Cassab	More flowers and pods in drought	–	Siddique (2000a) and Shrestha et al. (2006)
Cumra	Early flowering	ICARDA	Siddique (2000b)

Ankara, Turkey have shown that Kislik Pul 11, Kislik Yesil 21 and Kislik Kirmizi 51 survived at –25°C air temperatures without snow cover (Murray et al., 1988). A world collection of 3,592 lentil accessions was screened for cold tolerance near Ankara, Turkey and 238 accessions from Chile, Iran, Turkey, Syria and Greece were found undamaged by the cold winter at –26.8°C with 47 days of snow cover (Erskine et al., 1981). Available winter hardiness cultivars which survived at –29°C in Sivas, Turkey are: Kafkas (Aydogan et al., 2007) and Ozbek (Aydogan et al., 2008). Morton, WA8649041 and WA8649090 have also been reported to be winter hardy (Kahraman et al., 2004a, b, Muehlbauer and McPhee, 2007).

18.2.4 Lupinus L.

Commonly four lupines, albus/white/Mediterranean lupine (*L. albus* L.), narrow-leafed/blue lupine (*L. angustifolius* L.), yellow lupine (*L. luteus* L.) and Andean/pearl lupine (*L. mutabilis* Sweet), are commonly cultivated in the world (Gladstones, 1998; Cowling et al., 1998a). The cultivated lupines have the highest protein content (between 32 and 45%) among food legumes (Petterson, 1998) and have medium level fat (between 4 and 15%) in their seeds (Petterson, 1998; Uzun et al., 2006). Seeds can only be used as a human food after the alkaloids are removed from seeds by debittering and using sweet cultivars. For example in Antalya, Turkey; seeds of white lupine are consumed as a snack by humans after being boiled and then the alkaloids are removed with the water. In Australia, the limit for phomopsins, mycotoxin produced by *Diaporthe toxica*, and alkaloids was reported to be 5μg/kg and 200 mg/kg, respectively (Cowling et al., 1998a; Petterson, 1998). The alkaloid content of seeds is affected by species (Sanchez et al., 2005), genotype, time of drought stress and canopy structure in narrow-leafed lupine (Christiansen et al., 1997).

18.2.4.1 Breeding for Resistance to Drought and Cold

Cowling et al. (1998b) reported that the first modern lupine breeding was started in 1928/1929 in Germany by von Sengbusch selecting the first cultivars with low alkaloids in yellow and blue lupines. Many cultivars have now been released with those that perform well under terminal drought given in Table 18.4. Rodrigues et al. (1995) indicated that there is genetic variation for drought resistance in lupine, however, one of the most important strategies would be to escape drought before water deficits occur (Huyghe, 1997). Early flowering, early podding, fast rates of seed growth and pod retention were found to be significantly correlated with seed yield in terminal drought growing conditions (Palta et al., 2007).

Most lupine species are grown with at least 300 mm annual rainfall in their environment and wild species can be commonly grown in the lower rainfall areas (Cowling et al., 1998a). Narrow-leafed lupine is one of the most drought resistant species among the cultivated lupine species (Cowling et al., 1998b; Palta et al., 2004). Berger et al. (2008) pointed out that early, productive germplasm in yellow lupines came from warmer/low elevation environments with inconsistent rainfall and stronger terminal drought.

Table 18.4 High yielding, drought tolerant lupine cultivars

Cultivars	Main characteristics	Origin	References
Line 6 (*L. albus*)	Better physiologic characters	Portugal	Ramalho and Chaves (1992)
Popiel (*L. angustifolius*)	Drought susceptibility index < 0.31	Poland	Grzesiak et al. (1996)
Bac (*L. albus*)	Drought susceptibility index < 0.31	Poland	Grzesiak et al. (1996)
Belara (*L. angustifolius*)	2.0 t/ha seed yield, 67% pod retention	Australia	Palta et al. (2004)
Tellarack (*L. angustifolius*)	230 kg/ha seed yield	Australia	Palta et al. (2004)
Quilinock (*L. angustifolius*)	2.0 t/ha seed yield, 80% pod retention	Australia	Palta et al. (2004)
Tanjil (*L. angustifolius*)	2.3 t/ha seed yield, 80% pod retention	Australia	Palta et al. (2004, 2007)

Cold tolerance in lupines has been studied since the 1950s in the USA (Wells and Forbes, 1982). However, no genotypes have been found with sufficient tolerance to withstand the worst winter freezing conditions despite breeders having significantly improved cold tolerance (Cowling, 1998a). Yellow lupine has been found to be moderately resistant to cold during its seedling stage in spring down to –7°C (Cowling, 1998a).

18.3 Drought Sensitive Genera

18.3.1 Pisum L.

Although *P. formosum*, *P. transcaucasicum*, *P. abyssinicum*, *P. syriacum*, *P. aethiopicum* and *P. arvense* have been morphologically recognized as different species by botanists, they are most frequently considered as belonging to *P. sativum* species (Cousin, 1997) or the other genus *Vavilova* Fed. (Smartt, 1990). *P. sativum* ssp. *sativum* var. *sativum* (Garden pea), *P. sativum* ssp. *sativum* var. *arvense* (Field pea, fodder pea or winter type), *P. sativum* ssp. *elatius* var. *elatius*, *P. sativum* ssp. *elatius* var. *brevipedinculatum* and *P. sativum* ssp. *elatius* var. *pumilio* (*P. humile* is putative pregenitor) are considered to form a single species (Muehlbauer et al., 1994). Ben-Ze'ev and Zohary (1973) concluded that *P. fulvum* Subth & Smith is a completely divergent species, while *P. humile*, *P. elatius* and *P. sativum* form a single complex (Cousin, 1997). The genus *Pisum* comprises distinctly different two species, *P. sativum* and *P. fulvum* (Davies, 1995).

18.3.1.1 Breeding for Resistance to Drought and Cold

The genetics of pea have long been studied and the first crosses for breeding purpose may have been done by Knight in 1787 (Messiaen et al., 2006) and Mendel

Table 18.5 High yielding pea cultivars and lines for moisture stress environments

Cultivars/lines	Main characteristics	Origin	References
88P084-5-22	High yield in low rainfed areas	Australia	Khan et al. (1996)
Solara	Greater ground and root mass	England	Grzesiak et al. (1997)
Local Aleppo 2	High yield in low rainfed areas	Syria	Al-Karaki (1999)
WA 932	High yield in low rainfed areas	Australia	Al-Karaki and Ereifej (1999)
Arka Ajit	High yield and relative water content	India	Upreti et al. (2000)
Acc. 623	Thermo-tolerant	India	Srikanthbabu et al. (2002)

in 1865 who is called the "father of genetics". Pea is the most popular cool season food legume to research with the number of published studies on cool season food legumes taking the order: pea > faba bean > chickpea > lupine > lentil > grasspea (ISI, 2008). In spite of the many publications related to drought and physiological characteristics of pea (Sanchez et al., 2004; Okcu et al., 2005), there have been few published reports on the field performance of pea varieties and lines in drought conditions (Table 18.5).

Drought has several effects on peas including stopping nitrogen fixation and reducing the total biomass (Cousin, 1997). Pea crop grown as a rainfed crop subjected to drought in some part of the world (Saxena, 1993). In drought conditions, dry matter yield in faba bean, pea, and chickpea was reduced in 36.4, 23.9 and 14.5%, respectively (Amede et al., 2003). Drought and high temperature stresses caused yield losses between 21 and 54% in India, Syria and New Zealand (Saxena et al., 1993a, b). Benjamin and Nielsen (2006) found that chickpea was superior to pea for dryland crop production in semi-arid climates due to an adaptive root distribution.

Most breeding programs have been focused on freezing tolerance in pea since winter types can survive temperatures of about –6 to –14°C without damage. Air temperatures of –23°C or below are considered lethal (Murray et al., 1988). Breeders have developed winter forage peas because of their good resistance to freezing (Cousin, 1997).

18.3.2 Vicia L.

The genus *Vicia* consists of 140 species according to Kupicha (1981). Maxted (1995) classified the genus *Vicia* and two subgenus as outlined. Maxted's classification of subgenus *Vicia* contains nine sections, nine series, 38 species, 14 subspecies and 22 varieties. The only cultivated species is faba bean (*Vicia faba* L.) which is taxonomically classified in the section *Faba* (Miller) Lebed. which consists of four taxa: *V. faba* ssp. *paucijuga* Murat., *V. faba* ssp. *faba* L. var. *minor*, *V. faba* ssp. *faba* L. var. *equina*, *V. faba* ssp. *faba* L. var. *faba* (Maxted, 1995).

Faba bean contains condensed tannins which are considered to be the main antinutritional factors reducing faba bean protein digestibility. Faba bean also contains vicine and covicine (Duc, 1997) which can cause "favism" disease. This causes a medical condition (anemia) due to an enzyme deficiency in the blood (Jamalian and Ghorbani, 2005). Zero tannin with undetectable (zero) vicine and covicine faba bean varieties have been developed (personal com. with G. Duc in 2005, Dijon, France).

18.3.2.1 Breeding for Resistance to Drought and Cold

Faba bean is known as a drought susceptible species among the cool season food legumes (Bond et al., 1994) especially during its flowering period (Duc, 1997). However, Link et al. (1999) and Ricciardi et al. (2001) reported genotypic variation for drought tolerance in faba bean especially in North African and Latin American genotypes, and they concluded that genetic improvement for drought tolerance in faba bean seemed feasible. Faba bean yield losses due to drought are about 34% in Northern India (Saxena et al., 1993a). A list of well adapted, high yielding, drought resistant cultivars and lines is presented with their most important characteristics (Table 18.6). Abdelmula et al. (1999) found that the heritability of drought tolerance was 0.48 in F_1 hybrids and 0.70 in their parents.

Faba bean is known to be the best cold tolerant species among cool season food legumes (Bond, 1995; Duc, 1997), and the minimum air temperature reported to allow faba bean survival under field conditions was –25°C, Ankara, Turkey (Murray et al., 1988). The best known freezing tolerant genotype is a French genotype "Cote d'Or" which can survive –22°C if previously hardened (Duc, 1997). Also, some more freezing tolerant faba bean genotypes have been identified (personal com. with Dr. G. Duc in 2005, Dijon, France). Further promising accessions/ cultivars [BPL 4628, line F7-(Cor1 x BPL)-95, Karl] for winter hardiness and frost tolerance in faba bean are available (Arbaoui et al., 2008; Link et al., 2008).

Table 18.6 High yielding cultivar of faba bean for drought conditions

Cultivars	Main characteristics	Origin	References
Gobo	Greater ground and root mass	England	Grzesiak et al. (1997)
ACC286	High yield in drought	Australia	Mwanamwenge et al. (1999)
Uran	High yield in drought	Germany	Amede et al. (1999)
MG-106458, MG-109263	High yielding, high ABA content in drought	Ethiopia	Ricciardi et al. (2001)
Giza-40	High osmolyte concentration (soluble sugars and free amino acids and proline)	Egypt	El-Tayeb (2006)
ILB-938/2	Lower stomatal conductance, minimized water loss, high yield in drought	ICARDA	Khan et al. (2007)

18.4 Resistance to Drought and Cold in Wild Species

18.4.1 Wild Cicer Species

Wild *Cicer* species possess resistance sources for a range of different biotic (Singh et al., 1998; Collard et al., 2001; Sharma et al., 2006) and abiotic stresses (Croser et al., 2003a, b, Toker, 2005; Toker et al., 2007a; Canci and Toker, 2009b). Gaur et al. (2008) reported that the root systems of annual wild *Cicer* species were found to be smaller than the cultivated chickpea except for *C. reticulatum* Ladiz. (Krishnamurthy et al., 2003; Kashiwagi et al., 2005). Canci and Toker (2009b) found that some accessions of *Cicer reticulatum* and *Cicer pinnatifidum* Jaub. & Sp. were as drought and heat resistant as the best drought resistant checks (ICC 4958 and ICCV 96029). *C. anatolicum* Alef., *C. microphyllum* Benth., *C. montbretii* Jaub. & Sp., *C. oxydon* Boiss & Hoh. and *C. songaricum* Steph. ex DC. were found to be significantly superior to a range of annual wild species and cultivated chickpeas including the best drought tolerant chickpea, ICC 4958 when grown under drought conditions (Toker et al., 2007a).

Wild species of chickpea have been found to be not only drought resistant but also tolerant to cold (van der Maesen and Pundir, 1984; Singh et al., 1990, 1995a, b; Robertson et al., 1995; Toker, 2005). *C. microphyllum* was reported as cold tolerant (van der Maesen and Pundir, 1984). *C. anatolicum,* PI 383626, have survived in a growing environment from a minimum temperature of –30°C (or lower) in the winter to a maximum temperature of 30–35°C. It has continued to produce over a 10 year period in the field nurseries at Pullman, WA, USA (Kaiser et al., 1997). In addition to perennial *Cicer* species, some accessions of annual species including *C. bijugum* K.H. Rech., *C. reticulatum* Ladiz. and *C. echinospermum* P.H. Davis were found to be cold tolerant in both low- and high-land environments (Singh et al., 1990, 1995a, b, 1998; Toker, 2005).

Excellent sources of multiple stress resistance have been identified in wild relatives. For example accessions ILWC 70 and ILWC 73 of *C. bijugum* have resistance to ascochyta blight (score 3 on 1–9 scale), fusarium wilt (score 1), bruchid (score 1), cyst nematode (score 2) and tolerance to low temperature stress (score 2–3) (Robertson et al., 1995). Only two annual wild species, *C. reticulatum* and *C. echinospermum*, which can be easily crossed with the cultigen's, have been used in breeding programmes. One variety (Pusa 1103) has been developed and released in India by IARI using *C. reticulatum* as one of the parent in crosses. This variety is resistant to stunt virus, fusarium wilt, and tolerant to drought stress (Yadav et al., 2002a, b). Thus it would be more efficient to use wild species in development multiple stress resistant cultivars for future use in commercial cultivation under climate changes.

18.4.2 Wild Lathyrus Species

Grass pea is probably a derivative form of the genetically nearest wild species *L. cicera* L. (Hopf, 1986). *L. cicera* was found to be more drought resistant than grass pea (Icoz, 2008). Robertson and Abd El Moneim (1995) have reported that most accessions of *L. cicera* are resistant to cold, whereas *L. ochrus* and *L. sativus* are generally very susceptible to cold. The reasons for this are that most *L. sativus* and *L. ochrus* accessions are from low altitude, mild winter environments, whereas many *L. cicera* accessions are from high altitude, continental environments with severe winter (Vaz Patto et al., 2006). Nevertheless, tolerance to cold has been reported in an accession of *L. ochrus* (Abd El Moneim and Cocks, 1993).

18.4.3 Wild Lens Species

Hamdi and Erskine (1996) found that the cultivated lentil had markedly more seed yield than the wild *Lens* species. On the other hand, yield reduction due to drought was higher in the cultivated lentil (50%) than the wild species. *L. culinaris* ssp. *odemensis* had the least reduction of 13% whereas *Lens nigricans* ssp. *ervoides* had yield reduction of 24% (Hamdi and Erskine, 1996). An accession, ILWL 91 of *Lens culinaris* spp. *orientalis* originated from Turkey, had the highest biological and seed yield per plant (Hamdi and Erskine, 1996). Gupta and Sharma (2006) found that a few accessions of *L. culinaris* ssp. *orientalis* were earlier to flower and had higher seeds and seed yield/plant when compared to the cultivated lentil in drought conditions. Of *Lens* taxa, *L. nigricans* had the most resistant accessions for biotic and abiotic stresses (Gupta and Sharma, 2006).

18.4.4 Wild Lupinus Species

Some accessions of lupines including *L. albus*, *angustifolius*, *L. atlanticus*, *L. hispanicus*, *L. luteus*, *L. micranthus*, *L. mutabilis*, *L. palaestinus*, *L. pilosus*, *L. prince* and unspecified accessions of *Lupinus* sp. were evaluated for drought resistance in lowland environments and cold tolerance in highland environments of Anatolia, Turkey (C. Toker unpublished data). Some accessions of *L. albus* and *L. luteus* responded better to drought. A few plants from local populations of *L. albus* and *L. angustifolius* withstood temperatures as low as –11.8°C and were found to be more cold tolerant than accessions of cultivated and wild species collected from high altitudes in the world (Ceylan et al., 2006).

18.4.5 Wild Pisum Species

Two accessions of *P. sativum* subsp. *elatius* and *humile* and one unknown species of pea collected from Taurus Mountains, Turkey were superior to cultivated species for cold tolerance and survived at –11.8°C without snow cover (Ceylan et al., 2006).

18.4.6 Wild Vicia Species

The best cold tolerance sources among *Vicia faba*, *V. montbretti* and *V. narbonensis* were all accessions of *V. montbretti* and *V. narbonensis*. Generally wild species were superior to cultivated species. Cold tolerance scores of cultivated species were faba bean > pea > lupine (Ceylan et al., 2006).

18.4.7 Gene Pools in Cool Season Food Legumes

The invaluable variation existing among wild species can be exploited following introgression into the cultivated species. Harlan and de Wet (1971) designated germplasm resources of crop plants as primary, secondary and tertiary. The primary gene pool (GP1) consists of the biological species that includes the cultivated species itself and any wild forms that breeding tests show to be conspecific with

Table 18.7 Gene pools of cool season food legumes with chromosome number

Crop	2n	Primary gene pool	Secondary gene pool	Tertiary Gene Pool
Chickpea	16	*Cicer arietinum* *C. echinospermum* *C. reticultum*	*C. bijugum* *C. judaicum* *C. pinnatifidum*	Other species
Lentil	14	*Lens culinaris* ssp. *culinaris* *L. culinaris* ssp. *orientalis*	*L. culinaris* ssp. *odemensis* *L. culinaris* ssp. *tomentosus* *L. culinaris* ssp. *lamottei* *L. ervoides* *L. nigricans*	Not known
Grass pea	14	*L. cicera* *L. amphicarpos*	Other species in the section *Lathyrus*	Not known
White lupine	50	*Lupinus albus* var. *albus* *Lupinus albus* var. *graecus*	*Lupinus micranthus*	Other species
Narrow-leafed lupine	40	*L. angustifolius*	*L. luteus* *L. hispanicus*	Other species
Yellow lupine	52	*L. luteus*	*L. hispanicus* ssp. *hispanicus* *L. hispanicus* ssp. *bicolor*	Other species
Andean lupine	48	New world species with $2n = 48$	*Lupinus albus* *Lupinus micranthus*	Other species
Pea	14	*Pisum sativum* spp. *sativum* *Pisum sativum* spp. *elatius*	*Pisum fulvum*	Not known
Faba bean	12	All taxa in the section *Faba*	Not known	Not known

it. Many crosses have shown to be possible between cultivated and wild species in the primary gene pool. Consequently, gene flow among species of the GP1 can be accomplished by conventional breeding methods. The secondary gene pool (GP2) includes all those biological species among which gene flow is rarely possible via interspecific hybrids. Hybridization is too difficult usually due to chromosomal rearrangements. Despite sterility of these hybrids, tissue culture techniques have enabled breeders to overcome post fertilization barriers. The tertiary gene pool (GP3) contains those taxa among which hybridization is possible but the hybrids themselves are infertile, inviable or anomalous and do not permit gene flow by normal introgressive processes. Gene pools of cool season food legumes are detailed in Table 18.7 (Smartt, 1990; Yunus and Jackson, 1991; Muehlbuer et al., 1994; Campbell, 1997; Atkins et al., 1998; Addis and Narayan, 2000; Singh, 2005; Singh et al., 2007; van der Maesen et al., 2007).

18.4.8 Germplasm Screening and Evaluation

It is important for all legume crop breeders to collect germplasm lines which possess desirable resistance genes against stresses like drought, low and high temperatures, insects and pests, diseases, etc. Their maintenance and documentation is also essential for further utilization in population improvement. Under changing climates the rainfall pattern, fluctuations in temperatures, incidences of diseases, crop damage by insects and pests, concentration in carbon dioxide (CO_2) etc. are predicted to occur worldwide and some changes are already visible. Therefore, screening of desirable germplasm lines under increased (CO_2) levels, low and high temperature ranges, moisture stress environments etc. is essential to develop cultivars suited to changing environments. Identification of resistant desirable lines will help in formulation of breeding strategies for the development of future varieties which can withstand the impact of changing climates.

18.4.9 Generation Advancement and Selection in Segregating Populations

Generally, the legume crops are improved through conventional breeding methods and approaches. The possibility of developing stable hybrids which utilize hybrid vigour is still very far away for most of these crops. Therefore, it is imperative to understand the dynamics of advancement of segregating populations and their screening under appropriate environments. The requirement of future varieties will be for production in increased or decreased temperature and moisture regimes. Thus the screening and selection of segregating populations should also be carried out under such environmental conditions in multiple stress sick plots where breeders and physiologists can select the suitable plant types needed for changing environments.

It will be more appropriate if modified selected bulk methods are used in the advancement of such populations (Yadav et al., 2004).

18.5 Conclusions and Future Outlook

To meet the threat of changing climates in the years to come, legume breeders and other workers have to consider the plant type requirements for these future changing environments. The development of new cultivars should concentrate around increased temperatures, moisture stress, increased carbon dioxide, specific insect and other pests and disease resistances etc. Multiple resistances incorporated into cultivars which may include those introduced by transgenic methods will be needed. Therefore, breeding strategies have to be focused around these factors.

Most of the available germplasm in cultivated species of cool season food legumes has been screened for resistance to important biotic and abiotic stresses including drought. Considerable numbers of drought and cold tolerant/resistant cultivars/lines have been identified. However, most of them contain other far from desirable characteristics which prevent their use in farmer fields. These characteristics include such things as small seeds and susceptibility to other important biotic stresses as ascochyta blight.

The following major areas need to be worked on in the future to improve resistance against individual or combined biotic and abiotic stresses. Firstly, productive plant types should be characterized for each cool season food legume under terminal and intermittent drought areas. (ii) Drought resistance, increased temperature tolerance and important biotic stresses at the target area should be pyramided. (iii) Drought and increased temperature resistant markers linked for earliness and root-avoidance characteristics should be extensively used for marker assisted selection (MAS). MAS allows selection for a desirable characteristic with a nearby marker on the chromosome from within a plant genotype (Millan et al., 2006). When MAS has been achieved, selection can be conducted in the laboratory in early stages of plant development. (iv) Identification and utilization of wild species representing potential resistance in primary and secondary gene pools of the cool season food legumes should be used in medium and short term breeding programs. Hence, interspecific crosses should be made which allow for the introgression of important alleles from wild species, such as the resistance or tolerance to abiotic and biotic stresses. (v) Mutagenesis under bottleneck conditions provides an opportunity to increase the genetic variability for resistance to drought in cool season food legumes. (vi) Drought and cold resistant transgenics or genetically modified varieties/organisms (GMOs) offers a great opportunity. However, the genes need identification and transgeneic technologies need development for some species. There will be a need for care if transgenics are grown to prevent gene(s) flow from transgenics to wild relatives which could create environmental gene pollution. (vii) Drought or cold or heat tolerant/resistant cultivars should be grown in the target areas using the other agricultural management practices to overcome these stresses. Suitable cultivars need to be developed for growth under these modified management methods.

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Chapter 19
Molecular Biology for Stress Management

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19.1 Introduction to the Genomics of Drought Tolerance in Legumes

Drought is a meteorological term and an environmental event, defined as a water stress due to lack of or insufficient rainfall and/or inadequate water supply (Toker et al., 2007). The impact of drought and importance of drought tolerance to legume crops has been discussed in other sections of this book (Chapters 8, 9, 10, 19, 20, etc.). Drought tolerance is a complex trait associated with several physiological attributes. In the agronomical sense, drought resistance refers to the ability of a plant to produce its economical product with minimum loss in a water-deficit environment, relative to normal water conditions. In a genetic sense, the mechanisms of drought resistance can be grouped into three categories, viz., escape, avoidance and tolerance (Turner et al., 2001; Malhotra and Saxena, 2002). These mechanisms are inter-related and there is no fixed line of demarcation.

Drought escape: Drought escape can be defined as the ability of a plant to complete its life cycle before serious soil and water deficits develop. Plants facing terminal drought at the end of the growing season may escape drought by early vigour, early flowering and maturity. The two usual approaches toward drought escape are by using early maturing (short-duration) varieties (Kumar et al., 1996) or early sowing (Toker et al., 2007), which depends on the prevalent cropping system. In chickpea, a shift of growing season from spring to winter to efficiently utilise available soil moisture was suggested (Singh, 1990) and has become the norm for southern Australia.

Drought avoidance: Drought avoidance is the ability of a plant to maintain relatively high tissue water potential in a water-stressed environment. Drought stress can be avoided by maintaining water uptake and reducing the water lost by the plant. The two important traits conferring drought avoidance are a larger/deeper root

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system (allowing greater water extraction) (Saxena et al., 1993) and a smaller leaf area (reducing transpirational loss) (Saxena, 2003; Toker et al., 2007). Other traits that allow drought avoidance or turgor maintenance are increased hydraulic conductance, reduced epidermal (stomatal and lenticular) conductance, leaf movement (like folding and rolling) and phenological plasticity (Mitra, 2001).

Drought tolerance: Drought tolerance is the ability of cells to metabolise at low leaf water status (Toker et al., 2007). Turgor maintenance is achieved through osmotic adjustment (accumulation of solutes in the cell), increase in cell elasticity, decrease in cell size, and protoplasmic resistance (including stabilising cell proteins) (Mitra, 2001). Membrane stability is achieved by reducing the leakage of solutes from the cell (Nayyar et al., 2005). The cell water content is maintained by accumulating compatible solutes like fructan, trehalose, polyols, glycine betaine, proline and polyamines that are non-toxic and do not interfere with cellular activities (Mitra, 2001). Degradation of cellular proteins due to the stress is stabilised by amino acids like proline (Munns, 2005).

Information regarding the types, interactions and levels of expressions of genes involved in these drought-tolerant mechanisms would potentially lead to selective development of elite varieties. Recently, Australian wheat geneticists have developed transgenic wheat lines with a 20% higher yield increase under drought conditions (Spangenberg, 2008 pers. comm.). Additionally, it was demonstrated that expression of related cold shock proteins (CSPs) from bacteria, CspA from *Escherichia coli* and CspB from *Bacillus subtilis*, promotes water stress adaptation in multiple plant species (Castiglioni et al., 2008). Expression of CSP proteins in maize was not associated with negative pleiotropic effects, indicating that stress tolerance does not come at a cost to crop productivity under well-watered conditions. Although release of genetically modified wheat/maize is currently not possible due to strong resistance from consumer and environmental groups worldwide, this may change as world food shortages grow and grain prices remain high. The need to develop varieties able to grow with minimal inputs in more hostile, drought environments is likely to put further pressure for the development and release of genetically manipulated food sources, with the implicated drought-tolerance genes coming from wider germplasm than is currently available in breeding programs.

19.2 The Currently Available Germplasm Resources and Phenotypic Responses to Drought Worldwide

The following section outlines the germplasm sources and methods used to select drought tolerant genotypes of several legume species. The identified genotypes will be pivotal for use in future molecular studies to identify the underlying drought tolerance mechanisms and associated genetic components. Once identified, they may potentially be selected to introgress through breeding or to artificially move into elite genetic backgrounds.

19.2.1 Common Bean (Phaseolus vulgaris *L.*)

The common bean is the most important grain legume and about 60% is cultivated under drought stress conditions in the developing world (Graham and Ranalli, 1997). A common bean germplasm collection comprising over 40,000 accessions is maintained at the *Centro Intemacional de Agricultura Tropical* (CIAT) in Cali, Colombia, and includes indigenous wild and weedy specimens, unimproved landraces, and pure lines of *Phaseolus vulgaris,* as well as numerous related species (Hidalgo, 1991). However, the breeding material of common bean has been mostly grouped into landraces and utilised likewise because of the potential incompatibility between different landraces, e.g. Andean and Mesoamerican germplasm are incompatible (Singh and Gutiérrez, 1984; Gepts and Bliss, 1985). In fact different core collections have been reported for different landraces; e.g., common bean core collections have been reported for the Netherlands (Zeven et al., 1999), the Iberian peninsula (Rodiño et al., 2003) and Mexico (Skroch et al., 1998). Further, genotypes selected for drought tolerance in the Mexican highlands and Columbia did not perform well in other environments and it was suggested that the importance of a particular genotype as a drought tolerant parent depends on its yield in that environment (White et al., 1994).

As seen for other legumes, common bean germplasm has been screened for root and shoot characters that confer drought tolerance. Evaluation of root growth of two drought tolerant and two drought sensitive bean cultivars in different soil types suggested that drought avoidance through greater root growth and extraction of soil moisture are important traits but limited where soil conditions restrict root growth (Sponchiado et al., 1989). Further, Boutraa and Sanders (2001) interrogated the influence of water stress on grain yield and vegetative growth of indeterminate and determinate bean cultivars that were stressed at flowering and pod-filling stages. They found that water stress during both phenological stages affected the seed weight, number of seeds per plant and number of pods per plant, and delayed maturity specially when stressed at flowering stage. Water stress also reduced vegetative growth parameters like the number of trifoliate leaves, stem height, number of main branches and number of nodes on the main stem.

Ramirez-Vallejo and Kelly (1998) studied the association of specific phenological and physiological traits with drought resistance in common bean. The study of five genotypes and 16 progeny lines concluded that the most effective approach in breeding for drought resistance in common bean would be based first on selection for high geometric yield followed by selection among the high-yielding individuals for low to moderate levels of the drought susceptibility index. Previously, the effect of water stress on diverse shoot genotypes that were grafted on selected root genotypes concluded that the effect of shoot genotype on growth and yield under water deficits was small compared with that of root genotype (White and Castillo, 1992). Studies at the cellular level have also been conducted to identify drought tolerant bean cultivars. On the basis of evaluation of oxidative stress and the plant antioxidant system of three contrasting bean cultivars, Zlatev et al. (2006)

identified "Plovdiv 10" and "Prelom" as drought tolerant and "Dobrudjanski" as drought sensitive.

Different screening methods for drought tolerance in common bean have identified SEA 5, SEA 10, SEA 13, San Cristobal 83, ICA Palmar, LEF 2RB, AC 1028, Matterhorn and Pinto Villa as drought tolerant genotypes (White and Singh, 1991; Acosta-Gallegos et al., 1995; Schneider et al., 1997a; Kelly et al., 1999; Singh et al., 2001; Rosales-Serna et al., 2004). In an attempt to develop a line resistant to terminal drought and diseases, Frahm et al. (2004) screened RILs from crosses between a drought tolerant line and two disease resistant lines. They identified line L88-63 as the one with highest yield potential and broad adaptation to all four locations tested. Subsequently, Munoz-Perea et al. (2006) recorded the response of three dry bean landraces and 13 cultivars evaluated under non-stressed and intermittent drought-stressed environments over two years. They found that "Common Red Mexican" and "CO 46348" had high seed yield in both non-stressed and drought-stressed environments, whereas "Matterhorn" and "Othello" yielded comparatively high under a drought-stressed but moderately in a non-stressed environment. Not surprisingly, recent evaluation of common bean landraces and cultivars to identify those with greatest water use efficiency (WUE) showed that the cultivar "Othello" and the landrace "Common Red Mexican" had the highest WUE in the *pinto* and *red* market classes, respectively (Munoz-Perea et al., 2007).

19.2.2 Soybean **[Glycine max** ***(L.) Merr.*****]**

Soybean is our primary source of protein and oil and its genetic diversity has been reviewed in detail by Carter et al. (2004). The USDA has the most extensive soybean germplasm collection consisting of 18,603 cultivated and 1,116 wild soybean accessions (http://www.ars.usda.gov). Most of the early breeding efforts in soybean were directed at shatter resistance, disease and pest resistance, whilst abiotic stresses received little importance. One of the first methods to screen soybean germplasm for drought tolerance involved the use of growth chamber (Sammons et al., 1978) and drought box (Sammons et al., 1979) methods. However, both these methods failed to characterise genotypes as drought tolerant or sensitive by themselves and further testing in the field was recommended. Later, Bouslama and Schapaugh Jr. (1984) evaluated three different techniques to screen 20 soybean genotypes for drought and heat tolerance. Of the three methods, the hydroponic seedling test (subjecting seedlings to –0.6 MPa osmotic pressure in hydroponic solution for 14 days) was found to be most reliable and recommended for screening soybean for drought tolerance. Kpoghomou et al. (1990a) tested 17 determinate soybean cultivars for drought tolerance at germination and seedling stages. They observed that the cultivars that grew taller under drought stress conditions had greater dry matter accumulation and higher germination stress indices, indicating the reliability of height to predict cultivar performance under such conditions. They further tested three cultivars at vegetative, flowering, and pod-filling stages under stressed and well-watered conditions in glasshouse and field. They found reproductive stages were more sensitive to drought than vegetative stages and identified Lee 74 as the most drought tolerant cultivar (Kpoghomou et al., 1990b).

In another study, several soybean genotypes from maturity groups III through VII were evaluated at three osmotic potential levels (–0.017, 0.3 and –0.5 MPa) using polyethylene glycol M.W. 8000. This study identified the lines PI 408.155, PI 423.827B, PI 423.759 and Pershing as drought tolerant (Sapra and Anaele, 1991). Further, Djekoun and Planchon (1991) interrogated the use of photosynthetic activity of water stressed plants to assess drought tolerance in soybean. A PAM modulation fluorometer was used to measure the effects of dehydration on the activity of the photosystems of detached or attached leaves at ambient CO_2. They concluded that the readily and rapidly measurable fluorescence parameter such as Rfd (that is associated with photosystem activity and CO_2 exchanges) is a valuable selection criteria for drought tolerance in soybean. Moreover, cultivars with higher drought tolerance were shown to have high crop growth rate and larger leaf area under drought stress (Oya et al., 2004).

Symbiotic N_2 fixation in soybean is very sensitive to drying soil and has a negative impact on crop yield under many cropping situations (Purcell and King, 1996). In an effort to identify soybean germplasm that might have substantially decreased sensitivity of N_2 fixation to water deficits, 3,000 plant introduction lines were screened in a three-stage screening process. Eight lines having substantial tolerance of N_2 fixation to soil drying were identified (Sinclair et al., 2000). Recently, 100 progeny lines from a cross between Jackson, a cultivar proven to have N_2 fixation tolerance to drought, and KS4895, a high-yielding line were screened. Two lines with higher yields than commercial checks in low-yielding environments were identified. These lines also had nitrogen fixation activity at lower soil water contents than exhibited by the sensitive parent (Sinclair et al., 2007).

19.2.3 Chickpea **(Cicer arietinum *L.*)**

Chickpea is the second most important legume in the world with 11.6 million ha under cultivation (http://faostat.fao.org). The most extensive chickpea germplasm collection is at ICRISAT, India containing 16,992 accessions from 44 countries (Upadhyaya, 2003). Extensive and deep root systems have been recognized as one of the most important traits for improving chickpea productivity under progressively receding soil moisture conditions. Genetic variability for the root traits in the minicore germplasm collection of ICRISAT and several wild relatives of chickpea was evaluated using a cylinder culture system during two consecutive growth seasons (Kashiwagi et al., 2005). The largest genetic variability was observed at 35 days after sowing for root length density (RLD) (heritability, $h2 = 0.51$ and 0.54) across seasons, and followed by the ratio of plant dry weight to root length density with $h2$ of 0.37 and 0.47 for the first and second seasons, respectively. Accession ICC 8261 had the largest RLD and one of the deepest root systems, whilst ICC 4958 had one of the most prolific and deep root systems.

Since a direct relationship exists between transpiration efficiency and SPAD Chlorophyll Meter Readings (SCMR, Nageswara Rao et al., 2001), the mini core subset of chickpea was evaluated for SCMR (Kashiwagi et al., 2006). Accession ICCV 2 had the highest SCMR reading (55.5), under rainfed conditions. Also, regardless of the irrigation schemes, ICC 16374 had a superior SCMR with 66.4 (1st rank) in irrigated conditions and its rank was 4th in a rainfed environment. Moreover, ICC 4958 also had a better SCMR irrespective of the irrigation schemes (11th rank in a rainfed environment, 3rd in an irrigated one).

Previously, more than 1,500 chickpea lines were screened for drought tolerance and the genotype ICC 4958 was the most promising (Saxena et al., 1993). Subsequently, ICC 4958 was used in a three-way cross with *cv*. Annigeri and the *Fusarium* wilt resistant genotype ICC 12237. The progeny were selected for high yield and drought tolerance traits (Saxena, 2003). Several lines combining the large root trait of ICC 4958 and the small leaf area trait of ICC 5680 were reported to be more drought tolerant and yielded similarly to the high-yielding parent (Saxena, 2003). Also, genotypic variation for osmotic adjustment in chickpea has been reported but its correlation with yield under drought stress is unclear and the heritability was low ($h^2 = 0.20$–0.33) (Morgan et al., 1991; Turner et al., 2001; Moinuddin and Khanna-Chopra, 2004). Recently, a chickpea collection of 1,600 *desi* and 1,400 *kabuli* lines was evaluated for drought resistance (Yadav et al., 2007). From detailed evaluation of 82 lines, terminal drought was shown to reduce yields by 13–37%, depending on plant type. The yields in the *kabuli* types were more severely reduced than the *desi* types, due to a greater reduction in the number of branches and pods per plant.

19.2.4 Peanut (Arachis hypogea *L.*)

Peanut is a widely used oilseed crop around the world with the greatest variation found in Brazil, where the species *Arachis* originally evolved (Gregory et al., 1980). The largest collection of cultivated peanut is at ICRISAT, consisting of 14,310 accessions from 92 countries in addition to 413 accessions of other *Arachis* spp. (Upadhyaya et al., 2001). The USDA collection has over 8,000 accessions of *A. hypogea* (Holbrook, 2001) and ~800 other *Arachis* spp. (Stalker and Simpson, 1995).

The peanut germplasm has been screened using various methods to identify drought tolerant genotypes that have high soil water extraction capacity and/or greater water use efficiency. Del Rosario and Fajardo (1988) conducted greenhouse tests to evaluate four high-yielding, five intermediates, and one low-yielding genotype under water-stress and well-watered conditions. Genotypes Acc 847, 55-437 and GNP 1157 performed better than others in morphophysiological characters and seed yield. High-yield correlated to high leaf area, high leaf water potential, high shoot weight and plant height. Further, drought tolerant cultivars were identified by evaluating leaf transpiration efficiency (Wright et al., 1994) and rooting habit (Rucker et al., 1995; Songsri et al., 2008). Later, Nageshwara Rao et al. (2001) successfully used the ratio of leaf area to dry weight for large-scale screening of drought tolerant genotypes in Australia. The SPAD chlorophyll meter was used to identify genotypes with high transpiration efficiency and thus drought tolerance (Nageshwara Rao et al., 2001).

Recently, a detailed study to investigate the effect of drought stress on Total Dry Matter (TDM), pod yield, Water Use Efficiency (WUE), harvest index (HI), SPAD Chlorophyll Meter Reading (SCMR), Specific Leaf Area (SLA) and canopy temperature was conducted in Thailand to identify drought tolerant genotypes and establish relationships among drought resistance traits (Jongrungklang et al., 2008). Drought was reported to reduce TDM, pod dry weight, HI, WUE and SLA, but increased SCMR and canopy temperature. Also, WUE was positively related to SCMR under water-limited conditions and could be useful for selection of drought tolerance. Genotypes Tifton-8, 14 PI 430238 and 205 PI 442925 possessed high WUE at all drought levels, whilst KK 60-3, 101 PI 268659 had high WUE only under severe drought conditions.

19.2.5 Cowpea **[Vigna unguiculata *(L.) Walp.*]**

Cowpea is one of the most important food and forage legumes in the semi-arid tropics including Asia, Africa, Southern Europe, Southern United States, and Central and South America (Singh, 2005). The International Institute for Tropical Agriculture (IITA, Nigeria) has the most extensive collection of cowpea germplasm including over 15,000 cultivated and 2,000 wild genotypes. Also, USDA has about 7,000 accessions collected from IITA and around the world (www.isp.msu.edu).

Cowpea is relatively drought tolerant compared to other legumes; and earliness, delayed leaf senescence, and indeterminate growth habit are the traits being combined to improve drought adaptation (Ehlers and Hall, 1997). The accession “CB5” was identified to have one of the best indeterminate growth habits, being able to survive vegetative stage drought and recover after subsequent irrigation to produce yields of about 4,000 kg/ha (Turk et al., 1980). Also, two accessions, “Ein El Gazal” and “Melakh” that had erect growth habit and flowered early (30–35 days after sowing) were released in Sahel (Cisse et al., 1997; Elawad and Hall, 2002) to help plants escape terminal drought. Singh et al. (1999) evaluated a wooden box screening method to select drought tolerant plants in cowpea at the seedling stage. This method showed good correlation with drought tolerance at vegetative and reproductive stages. The accessions Kanannado, Dan Ila, IT88D-867-11, and IT90K-59-2 were rated as highly drought tolerant; TVu 11986, TVu 13464, IT89KD-288, and TVu 11979 as moderately drought tolerant; TVu 12349 and TVu 12348 as slightly drought tolerant, and TVu 8256 and TVu 7778 as susceptible to drought stress. Later, Matsui and Singh (2003) used a pin-board root-box method to identify the role of root characteristics in drought tolerance. By comparing rooting patterns of drought tolerant and susceptible genotypes they observed that drought tolerance was associated with an increase in root dry matter per leaf area under mild water-stress conditions, and downward movement of roots (increasing access and use of soil moisture in deep soil layers) under mild and severe water stress conditions.

19.3 Mapping Populations, Identification of Drought Tolerance QTL and MAS

Breeding for drought tolerance is hampered by our limited knowledge about the genetic basis of drought resistance and negative correlations of drought resistance traits with productivity (Mitra, 2001). Moreover, selection for yields in legumes like chickpea is not effective in early segregating generations because of their indeterminate growth habit (Ahmad et al., 2005). Traditional selection for drought tolerance is also difficult because the timing and severity of episodes of drought in the field are extremely variable (Passioura et al., 2007).

Drought tolerance is a complex trait governed quantitatively by many genes. In contrast to conventional breeding, the advent of molecular markers has allowed us to dissect quantitative traits into their single genetic components, called the quantitative trait loci (QTLs; Dudley, 1993; Tanksley, 1993). Further, molecular markers tightly linked to a QTL could assist the selection and pyramiding of the beneficial QTL alleles through marker-assisted breeding (MAB; Ribaut et al., 2002). The use of molecular markers for the indirect selection of improved crops speeds up the selection process by alleviating time-consuming approaches of direct screening under greenhouse and field conditions. Thus, QTLs linked to different root, shoot and physiological traits that confer drought tolerance can be transferred into an elite cultivar using associated markers.

Although linkage maps and molecular markers have been published for all important legume crops, most of the work on QTL mapping and molecular breeding has been done to address disease and insect resistance. The status of molecular breeding of pulse crops has been recently reviewed in detail in books published by Springer (edited by Kole, 2007; edited by Moore and Ming, 2008). Here we outline the work addressing QTLs and molecular markers for drought tolerance in legumes and discuss the future perspectives.

In common bean, Schneider et al. (1997b) evaluated the potential to select drought tolerance with QTL analysis and MAS in seven environments in Michigan, USA and highland Mexico. Using RAPD analysis, four markers for drought tolerance QTL were identified in one population and five in a second population. Selection based on MAS was effective under severe drought in Michigan but not for moderate drought in Mexico. It was suggested that the Genotype × Environment (G × E) interaction affected the expression of QTL, the genome coverage was incomplete and some unidentified QTL might have determined yield in the Mexican environments. Further, drought tolerance QTL have been identified for the BAT 477 source under non-irrigated conditions at *Centro Internacional de Agricultura Tropical*, Colombia (Blair et al., 2002).

In soybean, Mian et al. (1996, 1998) mapped seven QTL for WUE in two mapping populations; Young × PI416937 and S-100 × Tokyo. Among them, two QTL linked to RFLP markers cr392-1 of linkage group (LG)-J and A489H of LG-L explained 13 and 14% phenotypic variation, respectively. Another QTL linked to RFLP marker A063E for WUE was common in both the populations, but the phenotypic effect was less than 10%. Later, Specht et al. (2001) determined the genetic basis of beta and carbon isotope discrimination using a population of 236 RILs developed from a cross between Minsoy × Noir 1. They reported one QTL on LG C2 with a phenotypic contribution of <10% and with no effect on beta. Subsequently, Bhatnagar et al. (2005) identified a major QTL linked to SSR marker Sat_044 on LG K that explained 17% of the phenotypic variation for slow wilting. Recently, Wood et al. (2006) documented a number of QTL related to water stress tolerance in soybean. They reported three QTL for root architecture of basal root, Satt509 (LG A2), Sat_083 (LG B2), and Satt316 (LG 316); one QTL for root dry weight, Satt554-CAA19 (LG F); and one QTL Satt214 in (LG G) for root and shoot dry weight ratio. In the same year, Monteros et al. (2006) identified three QTL associated with seed yield and slow wilting in a mapping population of 140 F4 lines from the cross Hutcheson × PI471938 (drought tolerant). One QTL from the PI471938 mapped to LG D2 near the SSR marker Satt226 and two QTL were located on LG F1 near the markers Sat_375 and Sat_074. The PI471938 QTL on LG D2 and LG F1 were associated with yield and linked with slow wilting.

In Chickpea, in the hope to help plants escape terminal drought by early flowering, two QTL for days to 50% flowering have been located on LG 3 (Cho et al., 2002; Cobos et al., 2004). Since selection of root traits is very laborious, it was suggested that molecular tagging of major genes for these traits may enable MAS and greatly improve the precision and efficiency of breeding. Serraj et al. (2004) evaluated the root traits of 257 RIL derived from a cross between a breeding line with a large root system (ICC 4958) and an agronomically preferred variety (Annigeri) to assess the potential for identifying QTL for desirable root traits and to investigate the relationship between root traits, plant growth and seed yield under terminal drought stress. The existence of large variability among RILs justified their use towards efforts for the identification of molecular markers for root traits. Over 250 STMS markers were initially screened on parents of the RILs (Chandra et al., 2004). Fifty-seven STMS markers detected polymorphisms and were mapped on the RIL population. A QTL flanked by the STMS markers TAA 170 and TR 55 on LG 4A accounted for maximal phenotypic variation in root length ($R_a^2 = 33.1\%$), root weight ($R_a^2 = 33.1\%$) and shoot weight ($R_a^2 = 54.2\%$), where R_a^2 was the adjusted coefficient of determination (Chandra et al., 2004). This locus also accounted for substantial variation observed in these traits under simulated and actual field conditions. Subsequently four accessions that contrasted extremely in rooting depth and total root biomass (ICC 8261 and ICC 4968 with large roots; ICC 283 and ICC 1882 with small roots) were selected for development of new mapping populations. Two crosses were made (ICC 4958 × ICC 1882 and ICC 8261 × ICC 283) and about 260 RIL developed from each cross. These two mapping populations have been phenotyped in 2005 and 2006, and genotyping is underway to generate sufficient markers to identify QTL for drought avoidance traits (Gaur et al., 2008).

Research focussed on identifying QTL for drought tolerance and associated markers in legume crops is very much in its infancy. Although MAS is yet to be exploited to produce drought tolerant legumes, it has been used to generate disease and insect resistant varieties. MAS has been successfully used for the breeding soybean resistant to cyst nematode (Diers, 2004), common bean resistant to common bacterial blight (Mutlu et al., 2005) and lupin resistant to phomopsis stem blight and anthracnose (Yang et al., 2002; You et al., 2005). The results obtained in other crops to introgress drought tolerance traits using MAS are also encouraging enough to explore MAS for this trait in legumes. MAS has been used to introgress QTL alleles for reducing the anthesis-silking interval in maize as it is negatively associated with grain yield under drought (Ribaut et al., 2002). The molecular markers linked to five QTLs for anthesis-silking interval were used to select lines that outperformed unselected controls under severe drought stress (Ribaut et al., 2004). In Rice, marker-assisted back-cross (MABC) programme was used to introgress four QTL from the tropical *japonica* rice variety “Azucena” into the Indian upland rice variety, “Kalinga III”. The introgressed QTL9 (on chromosome 9) significantly increased root length in the new genetic background. The field testing for agronomic traits in near-isogenic lines (NILs) revealed that NILs out-performed “Kalinga III” for grain and straw yield (Steele et al., 2007).

The quantitative complexity of the drought tolerance trait that has been approached by scientists by breaking it into major components that increase yield under stress, such as larger roots, smaller leaves, and greater water use efficiency. Plants need a different combination of these and other traits to perform well under drought in a given environment. For example, common bean cultivars selected for drought tolerance in one environment did not perform well in another environment (White et al., 1994). The genetic background and particular environment in which a plant is growing both have significant influence on the types and locations of the quantitatively inherited and expressed genes (Flowers, 2004). Moreover, the fact that a single QTL may represent many, perhaps, hundreds of genes, poses a problem in finding the key loci that actually govern tolerance (Flowers, 2004). Sometimes it is difficult to find a marker tightly linked to a QTL and there is always a chance of identifying a false positive marker. These factors greatly hinder marker-assisted breeding, causing “linkage drag” of undesirable traits due to the large regions of chromosomes identified by the QTL (Asins, 2002). The logical way forward is to identify specific and individual candidate gene sequences that may account for the QTL effects. This would require validating the function or role of the genes associated with the QTL individually. The identification of candidate genes and elucidation of their role can be facilitated by combining QTL analysis with different sources of information and technological platforms (Wayne and McIntyre, 2002). The recent progress in genome sequencing and mass-scale profiling of the transcriptome, proteome and metabolome facilitates investigation of concerted responses of thousands of genes to a particular stress. This area of study known as “functional genomics” involves development and application of global (genome-wide or system-wide) experimental approaches to assess gene function by making use of the information provided by genetic, physical and transcript maps of an organism.

19.4 Transcriptomics and Expression of Candidate Drought Tolerance Genes

In order to dissect the complex genetic basis of drought tolerance, the diversity of stress responses and their contributions to the survival of plant needs to be investigated. Such studies on diversity of stress responses and identification of candidate drought tolerance genes have been facilitated by the analyses of gene expression products at transcriptomic, proteomic and metabolomic levels.

Transcriptomics involves comparison of changes in gene expression profiles between treated and untreated plants, allowing the association of a particular set of genes with the treatment under investigation and hence suggesting gene function (Alba et al., 2004). A variety of tools are available to study changes in gene expression in response to the treatment of drought stress in plants. These include RNA gel blot (Hauser et al., 1997), differential display (Liang and Pardee, 1992), cDNA amplified fragment length polymorphism (cDNA AFLP; Bachem et al., 1998), microarrays (Schena et al., 1995), serial analysis of gene expression (SAGE; Velculescu et al., 1995), massively parallel signature sequencing (MPSS; Brenner et al., 2000), real time polymerase chain reaction (RT-PCR), suppression subtractive hybridization (SSH), and cDNA fingerprinting. Some of these methods are suitable for the intensive study of a relatively few number of genes and others allow genome-wide analysis of gene expression in response to the particular stimulus.

Most of the gene expression studies in response to drought in legumes have been limited to cloning of homologous known drought responsive genes using sequence information available from other species, and interrogating their expression levels in response to specific drought treatments. Here, we present a review on our current understanding of drought tolerance responses in legumes based on gene expression studies. First, we provide a crop wise update on work reported to date, followed by a discussion on how to utilise the current knowledge and develop future resources for better understanding of drought stress responses in legumes.

19.4.1 Common Bean (Phaseolus vulgaris *L.*)

Common bean is susceptible to drought compared to other bean species (Vasquez-Tello et al., 1990). A comparative study on aspartic protease (AP) activity in common bean (drought susceptible) and cowpea (drought tolerant) under drought stress found AP to be strongly induced in common bean (Cruz de Carvalho et al., 2001). They concluded that induction of AP only in common bean plants under drought stress may contribute toward its susceptibility.

Colmenero-Flores et al. (1997) identified several cDNA clones that were induced in common bean under drought stress. The expression of these clones encoding one lipid transfer protein (LTP), two late-embryogenesis abundant (LEA) proteins and two proline-rich proteins (PRP), was further characterised in different plant organs (Verdoy et al., 2004). The LTP transcript was highly induced only in the leaves of drought stressed plants. Whilst, both LEA transcripts were induced in the roots, one transcript, *Pvlea-18*, was highly induced in the nodules. The PRP transcripts were induced in roots and nodules under drought stress. The LTP, LEA and PRP have been shown to be induced under drought stress in other crops and are thought to help in drought stress adaptation (as reviewed by Bartels and Sunkar, 2005).

Among the transport facilitators, a putative organic cation transporter (OCT) transcript, located in the phloem, was shown to be transitorily induced in the roots of common bean plants an hour after dehydration stress (Torres et al., 2003). Furthermore, the effects of drought, abscisic acid (ABA) and transpiration rate on the regulation of PIP aquaporin gene expression has been reported (Aroca et al., 2006). Drought and ABA caused decline in transpiration rate and induced the expression of two PIP transcripts in the leaves. Whilst, in the roots, only drought stress raised the expression of three PIP genes examined. Interestingly, the expression of PIP genes in the roots under drought stress differed by the presence or absence of arbuscular mycorrhizal fungus *Glomus intraradices* (Aroca et al., 2007).

Among the regulatory genes, a root-specific bZIP transcription factor that is transcribed only under water deficit conditions has been reported (Rodriguez-Uribe and O'Connell, 2006). In situ hybridisation and immuno-localisation revealed that this protein accumulated in the epidermis and phloem of the roots. The bZIP transcription factors were shown to mediate the abscisic acid regulated dehydration response in the vegetative tissues of *Arabidopsis* and barley (Uno et al., 2005; Xue and Loveridge, 2004).

Further, Torres et al. (2006) used differential display RT-PCR to identify 42 clones responsive to dehydration in common bean roots. These clones were identified to encode genes involved in signalling, protein-turnover and translocation, and root modulations. Differential display has also been recently used to identify genes responsive to drought in the leaves (Kavar et al., 2008). Fifteen transcripts were significantly expressed in all the eight cultivars assessed. All these were different to those reported for roots by Torres et al. (2006).

Microarrays have recently been employed to study drought stress response in common bean. Comparative transcription profiling in roots of common bean and its drought tolerant relative *P. acutifolius* identified 64 and 488 genes to be drought responsive, respectively (Micheletto et al., 2007). Most of the drought responsive genes in *P. vulgaris* were in the functional class of stress responsive genes, while the largest functional class in *P. acutifolius* was populated with unannotated or novel genes.

19.4.2 Cowpea (**Vigna unguiculata** *L. Walp.*)

Cowpea is a drought tolerant legume (Summerfield et al., 1985) and has been therefore utilised to study molecular mechanisms of drought tolerance. Ten cDNAs induced by drought stress were cloned from cowpea using differential display. Nine of these were induced by drought stress at different time points (Iuchi et al., 1996). Three genes were further characterised out of which two (old yellow enzyme and LEA protein) were also induced by ABA but one (dihydroflavonol-4-reductase) was not; indicating the presence of both ABA-dependent and ABA-independent pathways. The involvement of ABA-dependent gene regulation under drought stress was reinforced by isolation and characterisation of a clone related to 9-cis-epoxycarotenoid dioxygenase (*VuNCED1*) from drought stressed cowpea plants (Iuchi et al., 2000). Both, the accumulation of ABA and expression of *VuNCED1* were strongly induced by drought stress.

Most of the gene expression studies in cowpea have been done by cloning genes from drought stressed plants and studying their expression in tolerant vs. susceptible cultivars. These include expression profiling of transcripts related to phospholipase D (PLD), patatin and multicystatin, all of which showed varied responses among tolerant and susceptible cultivars (El-Maarouf et al., 1999; Matos et al., 2001; Diop et al., 2004). The maintenance of steady levels of PLD and multicystatin, and low levels of patatin in the drought tolerant cultivar compared to the susceptible cultivar, have been proposed to contribute towards tolerance/susceptibility.

Further, gene expression of clones related to two key detoxification enzymes, ascorbate peroxidase and glutathione reductase have been studied (Contour-Ansel et al., 2006; D'Arcy-Lameta et al., 2006). Comparison of gene expression of four different ascorbate peroxidase genes among tolerant and sensitive cultivars revealed early expression in the tolerant cultivar suggesting a capacity to efficiently detoxify active oxygen species at their production site. Similarly, comparison of gene expression of two glutathione reductases among tolerant and susceptible cultivars revealed a quicker response by the tolerant cultivar to fast desiccation, suggesting a better ability to respond. Recently, a drought expression cDNA library was constructed in South Africa using SSH (Gazendam and Oelofse, 2007). Clones from this library are being employed to interrogate their differential expression under drought stress using microarray.

19.4.3 Soybean **[Glycine max** ***(L.) Merr.*****]**

The characterisation of a cDNA clone related to proline-rich protein revealed its expression to be induced under drought stress (He et al., 2002). Two studies on gene expression of transcripts related to pyrroline-5-carboxylate synthetase (P5CS), and late embryogenesis abundant (LEA) protein in the roots of mycorrhizal and non-mycorrhizal plants under drought stress showed lower transcript accumulation in non-mycorrhizal plants for both (Porcel et al., 2004, 2005). Therefore, it was proposed that the induction of P5CS and LEA is not the mechanism by which mycorrhizal symbiosis protects soybean against drought.

Among the regulatory genes, three dehydration-responsive element-binding (DREB) genes were cloned from soybean and their response to abiotic stresses was characterised (Li et al., 2005). The transcriptions of *GmDREBa* and *GmDREBb* were significantly induced in the leaves, whilst *GmDREBc* was significantly induced in the roots under drought stress, revealing the specificity of gene functions. Interestingly, a study of DREB gene expression in a drought tolerant soybean cultivar and a more drought tolerant wild relative (*G. soja*) showed that the expression of DREB was rapid and higher in the wild relative (Chen et al., 2006). These results reinforced the involvement of DREB genes in drought tolerance, while highlighting the importance of a quick response by the plant for drought stress tolerance.

A few studies have reported changes in protein/metabolite abundance under drought stress. One such study concluded that sucrose synthase may play a key role in the regulation of nodule carbon metabolism and, therefore, of nitrogen fixation under drought stress conditions (Gonzalez et al., 1995). Another study indicated that under drought stress, the accumulation of pinitol was more pronounced than that of proline or other sugars and may be linked to drought tolerance in soybean (Streeter et al., 2001). Further, consistently higher glutathione reductase activity in the roots and nodules of mycorrhizal soybean plants than the roots of non-mycorrhizal plants has been observed under drought stress (Porcel et al., 2003). It was proposed that this high GR activity protects the roots and nodules against oxidative damage to biomolecules under drought stress.

Microarray resources like ESTs and oligonucleotides have recently become available for soybean. About 300,000 ESTs and 38,000 unique oligos have become available due to a community based program at University of Illinois, USA (URL: www.soygenetics.org). This resource will be highly valuable to study the genetic response to drought, however, to date these microarrays have only been used to investigate the response to pathogens, CO_2 atmospheric conditions, seed development and germination (Zou et al., 2005; Ainsworth et al., 2006; Gonzales and Vodkin, 2006).

19.4.4 Peanut (Arachis hypogea *L.*)

Drought tolerance-related gene expression studies in peanut include cloning and characterisation of 9-cis-epoxycarotenoid dioxygenase (NCED) that is believed to catalyse a rate-limiting step in ABA biosynthesis. The *AhNCED1* was induced by drought but repressed upon rehydration, suggesting its involvement in ABA biosynthesis under drought stress (Wan and Li, 2005). Another study involved cloning of a lipid degrading enzyme, phospholipase D (PLD), and studying its expression in peanut cultivars differing in ability to tolerate drought (Guo et al., 2006). The PLD gene was expressed faster in sensitive cultivars than in tolerant ones and may be indicative of sensitivity/tolerance to drought as PLD hydrolyses phospholipids to produce phosphatidic acid which acts as signalling messenger.

Luo et al. (2005a) developed two EST libraries for peanut after challenging *Tomato spotted wilt virus* (*TSWV*) and drought resistant cultivars with the respective stresses. A cDNA microarray containing 386 unigenes from these libraries was used to generate gene expression profiles in response to drought in a tolerant cultivar (Luo et al., 2005b). A total of 52 genes belonging to secondary metabolism, detoxification, heat shock proteins, ion transporters, defence, and signalling were induced in response to drought. Recently, cDNA clones related to membrane phospholipid, proteases and LEA protein were employed to study comparative expression in drought tolerant and sensitive cultivars under drought stress and rehydration. A good correspondence between molecular responses of these cultivars and their physiological responses previously defined in field and greenhouse experiments was observed (Dramé et al., 2007). Such molecular characters if well established can be integrated into the peanut breeding programmes.

19.4.5 Chickpea (Cicer arietinum *L.*)

Gene expression studies in response to drought in chickpea include construction of a cDNA library to investigate drought response in seedlings and plants (Romo et al., 2001). Genes coding for LTP and LEA proteins were found to be important in chickpea water stress response. The expression of LTP was higher in young than mature tissues, and its transcript level decreased gradually as the age of epicotyls increased. Another study identified 101 dehydration-inducible transcripts by repetitive rounds of cDNA subtraction and investigated the steady state level of these transcripts during the recovery period between consecutive dehydration stresses (Boominathan et al., 2004). Seven transcripts maintained threefold expression after 24 h and more than twofold expression even at 72 h after removal of the stress. A correlation between the longer period of abundance of these transcripts in the recovery period and improved adaptation of the plants to subsequent dehydration was observed and suggested their role in maintenance of messages from previous stress experiences.

Recently, a 768-feature cDNA microarray was used to compare the expression profiles of two drought tolerant (BG 1103 and BG 362) and two drought susceptible (Kaniva and Genesis 508) chickpea cultivars (Mantri et al., 2007). Significant differences were shown to exist between the responses of drought tolerant and susceptible genotypes, and highlighted the multiple gene control and complexity of the drought tolerance mechanism(s). The key findings included repression of the transcripts associated with senescence like auxin-responsive protein IAA9, magnesium chelatase, phosphate-induced protein, and senescence-associated protein in the tolerant genotypes. Further, the induction of a protein-transport protein and a lipid-transfer protein, that facilitate solute transport, may be essential for drought tolerance. Subsequently, the induction of RAC-GTP binding protein that facilitates pollen tube growth may contribute towards drought tolerance by promoting successful fertilisation and seed production.

19.4.6 Alfalfa (Medicago sativa *L.*)

Gene expression studies of drought tolerance in alfalfa have identified an ankyrin protein kinase (*Msapk1*) under osmotic stress. The *Msapk1* expression was induced in roots starting from 3 h up to two days of osmotic stress (Chinchilla et al., 2003). Gene expression was also studied with respect to involvement of carbon metabolism and oxidative stress in the decline of nitrogenase activity in nodules of drought stressed alfalfa (Naya et al., 2007). Under drought stress, oxidative stress occurred in nodules prior to any detectable effect on sucrose synthetase or leghemoglobin. A limitation in metabolic capacity of bacteroids and oxidative damage of cellular components was concluded to contribute towards inhibition of nitrogenase activity in alfalfa nodules.

Recently, a 16K *Medicago truncatula* microarray was used for gene expression profiling of two non-nodulated alfalfa cultivars in response to drought stress (Chen et al., 2008). Many known drought-responsive genes were induced in the shoots and roots, including up-regulation of heat shock-related protein, dehydrin and LEA after 3 and 8 h of drought stress. Interestingly, the genes encoding caffeoyl-CoA *O*-methyl transferase and dirigent were induced in 3 h stressed roots, while two aquaporin genes were repressed, suggesting that lignification and prevention of water loss in roots in initial dehydration stress was a common strategy for both the cultivars.

19.4.7 Pea (Pisum sativum *L.*)*, Mung Bean* [Vigna radiata (*L.*) *Wilczek*] *and Faba Bean* (Vicia faba *L.*)

A single study of gene expression related to drought stress has been reported for each of pea, mung bean and faba bean. The expression of cytokinin oxidase/dehydrogenase (CKX) was monitored in drought stressed leaves of pea and showed an unexpectedly low level of transcription (Vaseva-Gemisheva et al., 2005). In mung bean, the expression of phosphoinositide-specific phospholipase (PI-PLC) was characterised in response to drought stress. Among the three PI-PLC clones studied, *VrPLC1* and *VrPLC2* were observed to be constitutively expressed to varying degrees in all the tissues examined, while *VrPLC3* expression was rapidly increased in an ABA-independent manner only under drought and high-salinity stresses (Kim et al., 2004). PI-PLC catalyses the hydrolysis of phosphatidylinositol 4,5-bisphosphate to generate two secondary messengers (inositol 1,4,5-trisphosphate and diacyglycerol), which may serve in drought stress signalling. In faba bean, a novel calcium-dependent protein kinase (CDPK) was cloned and its expression in response to drought stress was interrogated (Liu et al., 2006). The *VfCPK1* was induced in the leaves submitted to drought stress or ABA. The CDPKs are predominant Ca^{2+}-regulated protein kinases and play an important role in calcium signal transduction in plants subjected to drought stress (Yamaguchi-Shinozaki and Shinozaki, 2006).

19.4.8 Model Legumes: Barrel Medic (Medicago truncatula) *and Lotus* (Lotus japonicus)

M. truncatula and *L. japonicus* have been proposed as model legumes to investigate various growth and developmental processes, and resistance and tolerance to stresses (Harrison, 2000; Dita et al., 2006). However, to date, there are no published reports involving gene expression studies of drought tolerance in shoots or roots in these species. Although one related study reports transcriptional profiling of processes leading to desiccation tolerance in seeds using the 16K *M. truncatula* microarray (Buitink et al., 2006). More than 1,300 genes were differentially expressed during the re-establishment of desiccation tolerance in germinated seeds, most of them belonging to carbon metabolism. The genes induced at later stages of re-establishment of desiccation tolerance were comparable to those involved in late seed maturation. This coincided with the repression of large number of genes related to cell cycle, biogenesis, primary and energy metabolism. The re-establishment of desiccation tolerance in germinated radicles was concluded to agree with a partial return to the dormant state prior to germination.

19.4.9 Perspectives

Studies on the transcriptomics for drought tolerance in general has led to the identification of a number of associated genes including osmosensors (SLN1 and SHO1), Ca^{2+} signalling cascades, various transcription factors (including MYC, MYB, NAC), regulatory elements (DREB, zinc-finger proteins, PKS5, bHLH, AP2/ERF), and response proteins (e.g. osmoprotectants like proline, trehalose, etc.) that function in a ABA-dependent or ABA-independent manner (Bartels and Sunkar, 2005). The ABA-independent gene expression functions through a drought-responsive element binding (DREB) protein that binds to a drought-responsive element (DRE) motif of the effector gene. One of the genes induced by drought, cold and ABA in *Arabidopsis* is *RD29A/COR78/LTI78* (Kreps et al., 2002).

Most of this information about drought stress response comes from study of the model species *Arabidopsis thaliana*. As seen above, most of the studies in legumes have involved utilising the information generated from studying other crops (mainly *Arabidopsis*), to identify and clone corresponding genes, and study their expression under drought stress. Even though these studies have been done in bits and pieces in different legume crops, a good thing about some of these studies is that gene expression data was matched to physiological changes like transpiration rate, root hydraulic conductance, osmotic potential, and accumulation of proteins, enzymes, or metabolites. These kind of studies are key to link the genome to phenome.

19.5 Transgenic Approaches to Overcome Drought Stress

As discussed in the previous section, a number of drought-inducible “tolerance” genes have been identified, mainly in *Arabidopsis*, and some of them have been cloned and characterised in legumes. The functional analysis of these genes is critical to our further understanding of the molecular mechanisms governing drought stress responses and tolerances. One mode of establishing this ‘proof-of-function’ is by overexpressing these genes by genetic manipulation and observing the phenotype for desired changes.

The genes induced in response to drought stress can be classified into two main types, functional and regulatory proteins. The functional proteins include protectors of macromolecules (e.g., chaperones, LEAs, LTPs), detoxification enzymes (e.g., GST, peroxidases), and osmoprotectants (e.g., proline, glycine betaine, sucrose, mannitol). Regulatory proteins include transcription factors (e.g., DREB, ERF, MYB, MYC, bZIP), protein kinases (e.g., MAPK, MAPKKK, CDPK), protein phosphatases, and calmodulin-binding proteins (Seki et al., 2003). Most of these genes have been transformed into plants to interrogate their contribution towards drought tolerance. Again, these studies have predominantly been performed in the model plant *Arabdiopsis* (as reviewed by Umezawa et al., 2006). A limited number of these studies have been done in crop plants including legumes. Here we review the current progress in understanding the mechanisms of gene regulation and roles of protective metabolites in drought stress tolerance of legumes by genetic or metabolic engineering. First we provide a status update of work done in legumes followed by an outline of how to harness the information available from other species.

Legumes are generally recalcitrant to transformation (Somers et al., 2003). However, significant progress has been made to develop efficient transformation system. The reproducibility, robustness and efficiency of these methods have been evaluated by Popelka et al. (2004). The various genes introduced into legumes to assess their role in drought tolerance are listed in Table 19.1. All these studies used the *Agrobacterium*-mediated transformation method.

19.5.1 Transgenics Involving Functional Proteins

Among the functional proteins, the L-Δ^1-pyrroline-5-carboxylate synthetase (P5CS) that controls a common step for both the proline synthesis pathways (glutamic acid and ornithine) has been intensively studied in soybean. The *P5CS* gene from *Arabidopsis* was cloned and its antisense version was introduced into soybean under the control of a heat shock-inducible promoter (*IHSP*). Under drought stress at high temperature, the *IHSP* was activated to induce the production of the antisense transcript, blocking proline synthesis (de Ronde et al., 2000). This confirmed an association between *P5CS* translation and proline accumulation. However, the transformants failed to survive a 6-day drought stress at 37 °C, indicating that proline plays a definitive role in survival of soybean plants under drought stress.

Further, a comparative study was performed between transgenic soybean containing the *P5CS* gene in sense or antisense orientation and an untransformed control under drought stress. The sense plants showed significantly higher relative water content (RWC), particularly after eight days of stress, that coincided with much higher free proline levels compared to control and antisense plants (de Ronde et al., 2004). The proline dehydrogenase activity was highest in antisense plants, followed by control plants, and least in sense plants, confirming that some of the proline measured in antisense plants was degradation products. The sense plants were more drought tolerant than control or antisense plants, again reinforcing the involvement of *P5CS* and thus proline in drought tolerance reaction of soybean.

Table 19.1 Use of transgenics to study role of functional and regulatory proteins in conferring drought tolerance to legumes

Gene name	Gene function	Gene origin	Promoter	Transgenic plant	Performance of transgenic plants	References
Functional proteins						
P5CR – antisense	Block proline biosynthesis	*Arabidopsis thaliana*	*IHSP*	*Glycine max*	Failed to survive a 6-day drought stress at 37 °C	de Ronde et al. (2000)
P5CR – sense/antisense	Induce/block proline synthesis	*Arabidopsis thaliana*	*IHSP*	*Glycine max*	Sense plants were more tolerant to drought, had highest RWC and proline levels than antisense and control plants	de Ronde et al. (2004)
P5CR – sense/antisense	Induce/ block proline synthesis	*Arabidopsis thaliana*	*IHSP*	*Glycine max*	Manipulation of proline affected the GSH concentration and antioxidant levels	Kocsy et al. (2005)
P5CR	Proline synthesis	*Arabidopsis thaliana*	*IHSP*	*Glycine max*	Accumulated 6-times more proline than control. Level of proline accumulation affected levels of other amina acids	Simon-Sarkadi et al. (2006)
MnSOD, FeSOD	Antioxidant	*Nicotiana plumbaginifolia*	*CaMV 35S*	Alfalfa	Higher photosynthetic activity at mild stress; performed similar to non-transformed plant at moderate and severe stress	Rubio et al. (2002)
LEA		*Brassica napus*	*CaMV 35S*	Kidney bean	Enhanced tolerance; delay in development of drought stress sympotoms	Liu et al. (2005)

Table 19.1 (continued)

Gene name	Gene function	Gene origin	Promoter	Transgenic plant	Performance of transgenic plants	References
Regulatory proteins						
WXP1	Wax production	*Medicago truncatula*	*CaMV 35S*	*Medicago sativa*	Wax accumalation led to reduced water loss and chlorophyll leaching, and enhanced drought tolerance	Zhang et al. (2005)
DREB1A	Transcription factor	*Arabidopsis thaliana*	*rd29A*	*Arachis hypogea*	Maintained transpiration rate equivalent to well watered controls and showed higher transpiration efficiency	Bhatnagar-Mathur et al. (2007)
NTR1	Methyl jasmonate synthesis	*Brassica campestris*	*CaMV 35S*	*Glycine max*	Better dehydration tolerance during seed germination and seedling growth	Xue et al. (2007)

Koscy et al. (2005) studied the effects of different proline accumulation levels in sense, antisense, and control plants, on antioxidant activities under drought stress. The antisense plants had highest H_2O_2 and lipid hydroperoxide levels and greatest injury, whilst the opposite was true for sense plants. Moreover, during stress treatment, the highest proline and ascorbate levels were detected in sense plants, whilst the highest recuced/oxidised glutathione ratio, ascorbate/dehydroascorbate ratio, and ascorbate peroxidase activity, was detected in antisense plants. This indicated that manipulation of proline affects not only the (homo)glutathione concentrations, but also the levels of other antioxidants. Similar study to question the effect of proline accumulation on free amino acid concentrations revealed that manipulating the content of a single amino acid influences the whole free amino acid composition in soybean (Simon-Sarkadi et al., 2006).

Among other functional proteins, antioxidant enzymes like Mn-containing superoxide dismutase (MnSOD) and Fe-containing-superoxide dismutase (FeSOD) were constitutively overexpressed in alfalfa under the control of the *Cauliflower mosaic virus* 35S (*CaMV35S*) promoter. Three types of transgenic lines that overproduced MnSOD in mitochondria of leaves and nodules, MnSOD in chloroplasts, and FeSOD in chloroplasts were generated. Under mild water stress, transgenic lines displayed 20% higher photosynthetic activity than untransformed lines. However, both untransformed and transgenic lines performed similarly during moderate and severe water stress, and recovery with respect to important markers of metabolic activity and oxidative stress in leaves and nodules (Rubio et al., 2002). The base genotype used for transformation and background SOD isozymic composition was concluded to potentially intensely effect the relative tolerance of transgenic lines.

Subsequently, late embryogenesis abundant (LEA) protein that is reported to have a protective role enabling cells to survive protoplasmic water depletion was constitutively overexpressed in kidney bean. Transgenic kidney bean containing a group 3 *lea* gene from *Brassica napus* demonstrated enhanced growth ability under salt and water deficit conditions (Liu et al., 2005). The increased tolerance was reflected by delayed stress damage in the transformants. The role of *lea* in drought tolerance was reinforced by the observation that higher stress tolerance was seen in the transformants with higher levels of *lea* gene expression and lower tolerance was seen in lines with lower expression levels.

19.5.2 Transgenics Involving Regulatory Proteins

Recent progress in engineering for drought tolerance has involved manipulation of transcription factors believed to confer tolerance. Among them, transcriptional activators of wax production (*WXP1*), floral nectary-specific protein (*NTR1*), and dehydration-responsive element-binding protein (*DREB2*) have been transformed in legumes. The *WXP1*, a transcription factor belonging to the AP2/ERF family is able to activate wax production. Overexpression of *WXP1* in alfalfa under the control of *CaMV35S* led to significant increase in cuticular wax loading on leaves (Zhang et al., 2005). Transgenic plants showed reduced water loss and chlorophyll leaching, and enhanced drought tolerance as demonstrated by delayed wilting under stress and faster recovery after rehydration (Zhang et al., 2005).

Another transcription factor, *DREB1A*, belonging to the AP2/EREBP family was overexpressed in a drought-sensitive peanut cultivar under control of the stress inducible promoter from *rd29A*. Under drought stress, the transgenic plants maintained a transpiration rate equivalent to well watered controls. The transformants also displayed higher transpiration efficiency than untransformed controls under well watered conditions, which was explained by a lower stomatal conductance (Bhatnagar-Mathur et al., 2007).

Further, the *NTR1* from *Brassica campestris* that is involved in methyl jasmonate (MeJA) production was constitutively overexpressed in soybean under control of *CaMV35S* (Xue et al., 2007). MeJA is a signalling molecule involved in plant development and regulates gene expression in response to environmental stresses (Creelman and Mullet, 1995). The transgenic soybean plants accumulated more MeJA than untransformed controls which conferred dehydration tolerance during seed germination and seedling growth as reflected by percentage of fresh weight of the seedlings (Xue et al., 2007). Detached leaf testing also showed superior water retention ability of the transgenic plants.

19.5.3 Perspectives

Transgenic approaches offer a powerful means to acquire important knowledge that will lead to a better understanding of drought tolerance mechanisms. As reported above, scientists can introduce a single gene into plants that lack or do not express them, and observe physiological and biochemical changes under drought stress at different stages of plant growth. This preliminary investigation of overexpressing functional and regulatory proteins in legumes has produced promising results. These studies have reinforced the fact that knowledge gained from studying model species and other crops is transferable across species (e.g., overexpression of *DREB1A* in peanut that was originally studied in *Arabidopsis*).

Most of the known candidate drought tolerance genes have been transformed and their importance under stress interrogated (as reviewed by Umezawa et al., 2006). Although manipulation of most of these genes has proven their possible contribution in conferring drought tolerance, none of these can be pronounced as a key to tolerance. Following a focus on downstream genes producing osmoprotectants or antioxidants there is a growing realisation that it would be more beneficial to manipulate the key genes that govern the production of all these molecules under stress. Hence, the focus has shifted towards manipulating regulatory genes like transcription factors. Recently, in an attempt to find those key genes, researchers have manipulated various signal transduction systems (like those involving protein phosphorylation/dephosphorylation, phospholipid metabolism, and calcium sensing) that function upstream of transcription factors (Bartels and Sunkar, 2005; Boudsocq and Lauriere, 2005). Some of the problems of using a constitutive promoter (like *CaMV35S*) to express these genes were overcome by exploiting stress inducible promoters (like *IHSP* or *rd29A*). However, the major breakthrough discovery of what key genes control drought tolerance response pathways under different conditions and across different environments is yet to be made.

19.6 Future Molecular Approaches for Drought Tolerance

The mechanisms through which plants perceive environmental signals and transmit them to cellular machinery to generate adaptive response is of fundamental importance to biology (Xiong et al., 2002). Plants sense a change in environmental condition and the signal is relayed through signalling cascades that amplify the signal and notify parallel pathways resulting in the production of effector molecules that mitigate stress (Vij and Tyagi, 2007). Drought stress response is complex and diverse, and every gene involved in the tolerance response, from perception to signalling to direct involvement, forms part of a coordinated response network. It is interesting to note that varieties of single plant species exhibit a high degree of variation in salt and drought tolerance suggesting that only a few key genes might enhance plant adaptation to adverse growth conditions (Crespi, 2007).

Functional genomics research of drought tolerance over the past decade has significantly enhanced our knowledge on the molecular control of the tolerance mechanism. Compared to the information available for molecular mechanisms of drought tolerance in *Arabidopsis* and some cereal crops, the research in legume crops is much in its infancy. The *Arabidopsis* model is likely to be different from legumes in the responses to stress in relation to grain filling, nitrogen utilisation, fixation and transport, root architecture and interactions – all physiological processes that are fundamentally different in legumes (Crespi, 2007). Therefore, there is a need to develop molecular resources (like gene/EST sequences, oligonucleotides, cDNA libraries and BACs) for legumes so that large scale gene expression profiling experiments can be performed. Since genome sequencing of all legumes is a costly affair (some legumes have huge genomes, e.g. faba bean = 13.06 pg), selection and sequencing of a model legume was proposed. Leguminous species *Medicago truncatula* and *Lotus japonicus* were chosen mainly because of their compact genome. Recent sequencing initiatives have led to the *M. truncatula* genome being completely sequenced and *L. japonicus* sequencing is nearly finished (URL: http://www.ncbi.nlm.nih.gov/genomes/PLANTS/PlantList.html). However, their microsynteny and thus functional homology and usefulness to studying the crop legume species is debatable.

As the importance of understanding the molecular bases of physiological responses continues to rise, hundreds of thousands of gene/EST sequences have become available for a wide range of legume crops, which are being used to investigate stress tolerance mechanisms. To facilitate efficient utilisation of the large amount of information being generated, the Legume Information System (URL: http://www.comparative-legumes.org), has been developed by the National Centre for Genome Resource in collaboration with the USDA Agricultural Research Service (ARS). This is a comparative genome resource that integrates genomic and molecular data from multiple legume species allowing cross-species genomic and transcript comparison.

The availability of such resources has set an excellent platform, which shall greatly aid in enhancing knowledge about gene expression required to effect drought tolerance in legumes. The candidate genes identified through gene expression studies can be validated for "proof-of-function" using reverse genetic approaches like knockouts/TILLING-mutants/overexpressing-transgenics. The identification of novel genes, determination of their expression patterns in response to drought stress conditions, and an improved understanding of their functions in stress adaptation will provide basic knowledge to design effective engineering strategies for enhancement of drought tolerance in legumes.

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Chapter 20
Biodiversity Challenges with Climate Change

Robert Redden, Michael Materne, Ahmad Maqbool, and Angela Freeman

20.1 Introduction and Overview

Climate change predictions over this century are for warmer (at least 1–2°C) and drier conditions, with increased extreme weather events and increased CO_2 levels, in the regions where the principal temperate grain legumes of chickpea, lentil, faba bean and pea are mainly grown (Challinor et al., 2006; IPCC, 2007). However, rainfall may increase at higher latitudes, and frost frequency may increase with drier conditions.

Genetic adjustment of crops can help to mitigate the adverse effects on production, resulting from shorter crop cycles with warmer temperatures and reduced moisture, partly offset by growth response to increased CO_2. The availability of genetic diversity will be critical to assist plant breeders in this task. The widest possible diversity within domestic germplasm of crops is found in the collections of landraces, which are the traditional local varieties respectively adapted to agro-ecological conditions in very diverse localities, over a wide range of altitudes, latitudes, soils and climates (Street et al., 2008). This diversity has been reduced in the twenty-first century with widespread adoption of improved varieties from modern plant breeding. For new climatic and associated disease challenges, novel genes will need to be sourced mainly from *ex-situ* collections in gene banks. Such diversity has enabled agriculture to adapt to moderate changes in climate over the past 10,000 years (Lane and Jarvis, 2007).

The largest *ex-situ* genetic resource collections of the major temperate grain legumes chickpea, lentil, faba beans and pea, are in the genebanks of the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Cultivated chickpea in both collections total 29,620 accessions including 22,230 landraces plus 291 wild relatives, cultivated lentils at ICARDA total 10,098

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accessions with 3,139 land races plus 59 wild relatives, the faba bean collection at ICARDA has 6,729 accessions with 2,477 land races and 5,285 derived bean pure lines (BPL), and the pea collection at ICARDA had 6,062 accessions including 1,597 land races plus 179 wild relatives (http://singer.grinfo.net/ 05/12/2008). Other genebanks with large grain legume collections are in USA, Russia (N.I.Vavilov Institute), China, Australia, Germany, U.K., Sweden, India, Italy and Iran.

The wild relative component of collections is hugely under-represented. Crop domestication went through a genetic bottleneck or founder effect. From wild relatives of legumes there was manual selection of rare mutations for key traits such as non-shattering, loss of seed dormancy, increased seed size, and uniform maturity, plus natural selection for adaptation to a wide range of "temperate" agri-ecological environments (Ladizinsky, 1985; Smartt, 1990). Thus wild relatives contain extensive untapped genetic diversity for climatic adaptation and resistances to diseases (Singh and Ocampo, 1997; Nguyen et al., 2005). Yet the numbers of original germplasm collections of wild relatives in *ex-situ* collections represent only a small sample of this diversity in the primary, secondary and tertiary gene pools of crops, especially grain legumes (Berger et al., 2003). Examples of improved adaptation to drought and other climatic stresses have been shown with *Triticum tauschii* introgression into bread wheat (Trethowan and Mujeeb-Kazi, 2008).

Habitats for wild relatives are rapidly dissapearing under land use pressure with population increases, and will be further threatened with climate change (Imperial College, Wye (2003), Lane and Jarvis, 2007). Unlike crops, wild relatives are relegated to uncultivated lands and crop margins. Their persistance as *in-situ* collections is under threat due to an expected 50% increase in world population by 2050, with associated competition for land for urban and grazing needs (Brown, 2005). These resources are further threatened by climate change, with extinction possible within 50 years (Lane and Jarvis, 2007). It is very urgent to fully sample these remaining *in-situ* populations in regions documented for wild relatives of crop legumes.

20.2 Germplasm Collections, Diversity and Utilisation

Climate change is a threat to continued use of landraces either in remote villages or preferentially retained for a desired food use or some other benefit. They are also likely to be displaced by improved higher yielding varieties (He et al., 2008). Hence in-situ germplasm will be less available, and it is important to fill gaps in *ex-situ* collections through sampling localities with heat stress or with high levels of frost (http://www.croptrust.org/documents/WebPDF/wyereport.pdf 05-12-2008).

Genetic resources have become an even more strategic resource with climate change. Crop germplasm provides the basic resources for plant breeders to incorporate genetic resilience to altered environments and increased frequencies of extreme stresses, which will be accompanied by increased pest and disease challenges (Street et al., 2008). Land races are still grown in many areas of ancient crop diversity, and it is even more imperative to adequately collect these before they dissapear under combined pressures of displacement by modern varieties and climate changes. Gaps in *ex-situ* collections for diversity in key stress traits need to be identified, and targeted collection missions undertaken.

Wild relatives of pea, lentil and chickpea are found broadly from the Himalayan Central Asia region through to SW Asia and to southern Europe, although no wild relatives of faba bean have been identified (Ladizinsky et al., 1984; Berger et al., 2003; Redden et al., 2005). Similarly the major centres of diversity for crop legume landraces occur in the broad region around the Fertile Crescent in SW Asia (the Turkey, Iran, Iraq, Jordan region) where these crops are believed to have been domesticated, as well as in secondary centres of diversity with diverse agricultural environments in Ethiopia, the Caucasus, and central Asia (Ladizinsky, 1998).

Molecular diversity analyses of grain legumes are very recent. There is a need for wider investigation to characterise this diversity and explore whether phenotypic and molecular diversity patterns are alligned for individual crops.

For faba bean, molecular diversity was reviewed by Duc et al. (2008), with winter faba bean from Yunnan being the most distinct gene pool, and winter types from China being generally distinct from other gene pools globally (Zong et al., 2009). Large seeded faba bean landraces are found from the Fertile Crescent westwards but mainly in the Mediterranean region, and small seeded types are more widespread from the Fertile Crescent to Asia and Africa (Duc et al., 2008).

In pea, separation of the Chinese from global gene pools was found with SSR molecular analyses by Zong et al. (2009), with a unique gene pool for spring types from north-central China being separate from the rest of China. Preliminary phenotypic comparisons are consistent with a separation between Chinese and other gene pools (Redden et al., 2007). Burstin et al. (2001) found separation of European food and fodder type peas with SSR markers, and separation of these from Afghan and Ethiopian land races and from *P. abyssinicum*. Pearce et al. (2000) found distinct separation among pea phylogenetic groups of domestic and wild species using retrotransposon markers. Redden et al. (2007) report separation of gene pools within *P. sativum* including separation of feed and fodder types and of other sub-species.

Chickpea diversity has been characterised over the primary, secondary gene pools with isozyme (Sudupak and Kence, 2004), AFLP (Nguyen et al., 2004; Shan et al., 2006), SSR/RAPD (Iruela et al., 2002) and ISSR markers (Rajesh et al., 2002), with broad agreement in linking the domestic germplasm to the primary gene pool wild pro-genitor *C. reticulatum*, and to a lesser extent with *C. echinospermum* in the secondary gene pool, and separation of annual versus perennial wild relatives in the tertiary gene pool. Within the domestic gene pool the kabuli and desi gene pools were separated (Iruela et al., 2002) by RAPD/ISSR markers, and phenotypic clusters related to landrace origin within India were characterised by Berger et al. (2006).

Phenotypic biodiversity in lentil and its wild relatives is concentrated in the Middle East and distributed from Europe to central Asia (Redden et al., 2007).

Ferguson et al. (1998a) identified distinct areas for diversity for each wild relative taxon in regions from Turkey to Jordan, which could be targeted for future germplasm collection. Within the domestic *Lens culinaris* Ferguson et al. (1998b) used isozyme and RAPD analyses to show separation of land races by geographic origin, and the low diversity among distinct landraces from south Asia confirmed a genetic bottleneck also noted in phenological and morphological traits. There was also regional separation by origin into groups; Ethiopia – Yemen, Syria – Egypt, Europe – Morocco, Egypt – Iran – Turkey, and Afghanistan – north Indian subcontinent, however these did not correspond with the division of large and small seed types although both the first and the last of these groups were wholly small seeded.

A broad geographic separation of gene pools in the temperate grain legumes on both molecular and phenotypic evidence indicates likely allelic diversity and therefore the potential for pyramiding alleles for key stress traits; of high and of low (frost) temperatures, drought, altered phenologic requirements and changes in disease pressures in target crop areas (Ferguson et al., 1998b; Berger, 2007; Redden et al., 2007). Understanding the structure and sources of germplasm diversity enables the identification of target areas for collecting, in both the domestic and the wild germplasm (Street et al., 2008; Redden et al., 2008). Schema for introgressing usefull major gene and quantitative traits from wild relatives for germplasm enhancement of crops were outlined by Tanksley and Nelson (1996) and Tanksley and McCouch (1997). Positive outcomes of such introgressions including in chickpea have been reviewed (Haijar and Hodgkin, 2007). Searching for genetic variation to optimise adjustment to new environmental and biotic changes will require the collecting, conservation and evaluation of both domestic and wild germplasm.

Efficient procedures of exploring genetic variation in genebanks are important when dealing with many thousands of accessions. A Focused Identification of Germplasm Strategy (FIGS), which enables trait specific sub-sets of germplasm to be chosen for evaluation, combines coordinates of collecting sites with high resolution world environmental maps according to priorities for climate, soil or disease stresses (Street et al., 2008). Thus accessions with coordinates corresponding to high stress areas are selected on the basis that they have evolved to adjust to these selection pressures. Selection of sub-sets prospective for stress tolerances then enables efficient evaluation in suitable test locations.

Filters can be applied to the search process e.g. excluding regions where a particular disease has not been reported, exclusion (or restriction to) of low rainfall sites, or selection of test sites according to temperature stresses. FIGS has been applied to efficiently identify new sources of pest and disease resistances in wheat (Street et al., 2008), and could also be applied to germplasm of crop legumes, both to identify stress sub-sets and to identify prospective areas for further germplasm collection.

Another complementary approach is the development of search/query phenotypic database program using evaluation data of breeders and curators, with choice of multiple trait combinations, such as developed by DPI Victoria and ICARDA (Portugal et al., 2008). This program is based on the International Crop Information System (ICIS), which has been developed at the International Rice Centre but also applied to a wide range of different crop germplasms. The ICIS databases for lentil

(ILIS), chickpea (IChIS) and faba bean (IFIS) have been made available for interrogation on the internet, with site filters based on environmental data or site mean values for traits, and on-line capacity to request selected germplasm from appropriate genebanks. ICIS allows data from multiple gene banks to be uploaded with international standardised trait coding systems, thereby extending the coverage of germplasm diversity, and its evaluation, to potentially result in a Virtual World Genebank.

These various tools equip researchers to make targeted and efficient use of genetic resources to address the manifold issues of climatic, abiotic and biotic stresses.

20.3 Drought Stress

Response of grain crops to drought is a function of (i) soil water extracted, (ii) plant efficiency in water use, (iii) harvest index realised (Passioura, 1977). In wheat, landraces genetically distant from elite varieties have been identified which combine relatively high biomass under drought with favourable water extraction, stem carbohydrate and transpiration efficiency characteristics (Reynolds et al., 2006). Synthetic hexaploid wheats utilising wild relatives have displayed superior adaptation to rainfed sites in international trials and provide a new source of genetic variance for continued progress in improving adaptation to drought, salinity, high temperature, waterlogging and soil micronutrient imbalances (Lage and Trethowan, 2008; Trethowan and Mujeeb-Kazi, 2008). Similar opportunities for widening the gene pools to improve tolerances to climatic and to disease stresses also exist in temperate crop legumes (Ocampo et al., 2000). Introgression of wild relatives in chickpea has provided selections with wide adaptation in India (Yadav et al., 2004).

Water use efficiency factors affecting production of food legumes describing the inter-relationships between water use efficiency, dry matter production and evapotranspiration, were reviewed by Cooper et al. (1988).

In chickpea, depth and density of roots was characteristic of the drought avoidance parent ICC4958 and of land races from arid zone rainfed environments (Kashwagi et al., 2005), and these traits were identified as one mechanism for coping with terminal drought (Kashwagi et al., 2006). A lentil selection with rapid development of both shoot and root to result in greater root depth and lateral roots, had outstanding performance under drought conditions in Mediterannean-type environments, these root traits were highly correlated and associated with the wide adaptation of this selection (Sarker et al., 2005). Shoot and root dry weight traits were also correlated in a core collection of pea, which showed wide variation for root biomass production and archicture (McPhee, 2005). However Novikova (2001) found that leafless and semi-leafless peas had lower root biomass than leafy pea cultivars. Recombinant chickpea progeny, from crossing a large root mass parent with a low leaf area parent, had higher midday leaf related water content on the International Crop Research Institute site at Hyderbad (Saxena, 2003).

Early maturity was a terminal drought escape mechanism identified in lentil (Silim et al., 1993). This mechanism would also be relevant in autumn sown chickpea, but only if also combined with chilling tolerance at the reproductive stage (Berger, 2007). Earliness combined with a relatively long time to flowering was recommended for breeding high yielding peas adapted to semi-arid mediterranean environments (Al-Karaki, 1999). Turner et al. (2001) considered early vigor to be an important drought escape mechanism in grain legumes, when combined with phenology suitable for the target environment. But this is a challenge for breeders when high growth vigor has a significant negtive correlation with early flowering and maturity (Sabaghpour et al., 2003).

Physiological mechanisms in legumes may maintain water uptake and reduce water loss e.g.; turgor maintenance via stomatal activity, abscic acid closure of stomata to reduce water loss, osmotic adjustment, leaf types and movement, and phenological plasticity related to water deficit and to degree of determinacy of reproductive growth (Buddenhagen and Richards, 1988; Toker et al., 2007; Materne et al., 2007).

Soil salinity/sodicity is a major problem in maritime derived areas cleared of trees (e.g. southern Australia) and in many irrigation areas (Greenlee et al., 1968; National Land and Water Resources, 2000; Gupta and Abrol, 2000). This is likely to be exacerbated with lower rainfall in temperate cropping zones predicted with global warming. Grain legumes are more susceptible to saline conditions than cereals (Steppuhn et al., 2001), and increased attention will be needed in breeding for subsoil constraints such as salinity, sodicity and micronutrient toxicities e.g., Boron (Hobson et al., 2006; Maliro et al., 2008). Genetic variation for salinity tolerance is available in chickpeas and peas, respectively from saline soil regions of India and of Sha'anxi province China (Maliro et al., 2008; Redden, 2007). Initial screening of diverse faba bean germplasm indicated salinity tolerance in landraces from Zheijang province China (Enneking and Moy, pers. comm). Seedling screening tests are available for grain legumes (Stoddard et al., 2006; Hobson et al., 2006; Maliro et al., 2008), enabling establishment of breeding programs, and use of recombinant inbred lines to identify molecular markers for assisted selection. As outlined by Stoddard et al. (2006) an integrated selection for multiple tolerances to drought, frost, and salinity is feasible with both suitable germplasm and screening techniques. Pyramiding of these traits will be as important to mitigate climate change, as the need for multiple disease resistances in current legume breeding programs.

20.4 High Temperature Tolerance

Environmental or abiotic stresses represent major limitations to yield and grain quality of pulse crops in Australia. These stresses include extreme temperatures and unfavourable soil conditions related to low water availability, high salt concentrations and mineral deficiency and toxicity, all of which are frequently encountered in agricultural systems.

Increased frequency of hot winds is being experienced in Southern Australia, which cause heat stress when crops are at flowering and podding stages. In consideration of these environmental phenomena, efforts are needed to search for specific and practical approaches to enhance plant tolerance to high-temperature environments in Australia. In Australia, the major pulse crops are field pea, chickpea, faba bean and lentil. Each of these pulses is adapted to different, hence complementary, cropping environments. Heat stress can affect some plant processes more than others, with severe impact likely on pulse crops especially at anthesis, flowering and during grain filling. Extreme temperatures may affect many processes, but the most important effects are those that are first encountered as temperatures rise above optimum for plant growth.

While the temperature of plants is strongly dependent on ambient air temperature, it is also dependent on radiant energy fluxes. Almost all crop plants experience the full intensity of sunlight for at least part of their growth. To fully understand heat stress effects on plants it is necessary to know what temperatures plants experience; this is analysed by energy balance equations. At equilibrium, energy gain and loss is constant and heat gain by one process is balanced by heat loss by another. Three important routes of heat gain or loss are (1) sensible heat transfer, (2) radiant heat transfer, and (3) latent heat transfer (e.g. evaporative cooling). Typically, a photosynthesizing leaf is being heated by radiant heat gain and losing energy by sensible heat loss and latent heat loss, but each of these factors can be negative or positive.

20.5 Sensible Heat Transfer

Heat will flow to or from a plant depending on the difference in temperature between the plant and its environment. This heating or cooling is intuitive; whenever a plant is above air temperature it will lose heat to the air, if it is below air temperature it will gain heat. The rate of heat transfer will depend on the wind speed because of the boundary layer between leaf and the well-mixed air. Small structures like stems and small leaves have low boundary layer resistances to heat flow, while large leaves can have large boundary layer resistances to sensible heat exchange with the air.

20.5.1 Radiant Heat

Radiant heat gain is responsible for most of the stressful high temperatures experienced by plants. Because plants photosynthesize, many plants are optimized to receive sunlight, which will also optimize radiant heat gain. Many leave are very thin, optimizing the ability to intercept photosynthetically active radiation but also reducing the heat capacity of the leaf. This makes leaves susceptible to very rapid temperature changes.

The energy in sunlight is often divided into two parts: (1) ultraviolet, visible, and near infrared and (2) thermal wavelength. Very hot objects like sun emit nearly all of their radiant energy in the visible and near infrared regions of the electromagnetic spectrum, while objects with temperatures of plants and their surroundings emit radiant energy in thermal wavelengths (Nobel, 1999).

A substantial amount of energy can be lost by infrared emission from leaves but leaves also receive infrared energy from their surroundings. If the surroundings are the same temperature as the leaf, the net energy flux will be zero. However, on a clear sunny day, the leaf is emitting infrared radiation to the sky and receiving infrared radiation from the sky. The effective temperature of the sky on a clear day can be less than 0°C and so the radiation balance in the thermal infrared wavelength can dissipate over one half of the sunlight energy absorbed by leaves. The energy plants receive from sunlight beyond what is dissipated by thermal radiation must be dissipated by a combination of sensible heat loss and latent heat loss.

20.5.2 Latent Heat

A substantial amount of energy is required for evaporation of water. Evaporation of water from the wet surfaces inside of leaves can dissipate a large amount of energy to balance the energy input from sunlight. Under unusual conditions, latent heat loss can exceed radiant heat gain, resulting in leaf temperatures below air temperature. Sensible heat exchange will then be positive, requiring additional heat loss by evaporation. Because latent heat loss is an important component of the energy balance of leaves, high temperature stress can be a consequence of drought, if plants do not have water available for transpirational cooling (Nobel, 1999).

Different crop species have specific optimum temperatures, and response patterns to both higher and lower temperatures which may be affected by photoperiod or independent according to species, albeit with genetic variation within species for local ecological adaptation (Summerfield and Wein, 1980; Roberts et al., 1985 for chickpea, Wallace 1986 for common bean, Erskine et al., 1990 for lentil, Alcalde et al., 2000 for pea). Except for regions in high latitudes, most of the world's agricultural regions can expect warmer temperatures over the current century, requiring adaptation changes in existing crops and possibly a transition to more high temperature tolerant species.

Heat stress may be confounded by drought, and is most evident in flower and pod abortion, arrested seed development in pods, and poor seed quality, notably in chickpea (Buddenhagen and Richards, 1988, Saxena et al., 1988). Tolerance to reproductive heat stress in a controlled environment trial was found in *Phaseolus vulgaris* landraces from arid high temperature environments in Mexico (Redden et al., 1993). A desi chickpea variety was found to be more tolerant of high temperature stress than a kabuli variety, with effects on pod development more important than on flowering (Wang et al., 2006), but in combination with water stress this desi was only superior to the same kabuli variety for stress at flowering rather than at podding (Gan et al., 2004).

20.6 Low Temperature and Frost Tolerance

Field pea, faba bean, lentil and chickpea are four of the most common cool season grain legumes cultivated all over the world. Abiotic stresses are a major source of yield loss, with radiant frost being one of the principal limiting abiotic factors for grain legume production. In legumes, frost not only affects nitrogen-fixing bacteria and their symbiotic maintenance (Stoddard et al., 2006), but also are particularly damaging when the frost occurs during the reproductive phase of the plant's lifecycle (Stanley, 2003). In legumes, the most susceptible stages are flowering, early pod formation and seed filling stage (Siddique et al., 1999).

Radiant frost events occur most frequently after the passing of a cold weather front, when the moisture and wind have dissipated, leaving cold and still conditions with clear skies. Radiant frost damage is caused by a nocturnal net loss of long wave radiation, causing the plants to cool to temperatures substantially below ambient (Eujayl et al., 1999; Balasubramanian et al., 2004). Dense chilled air also settles into the lowest areas of the canopy and is where the most serious damage occurs. Plants that suffer damage on the exposure to low and non-freezing temperatures from +12°C to 0°C are termed as chilling sensitive plants. While the plants from high tropical mountains are frost resistant (Margesin et al., 2007).

The national awareness of the need for reproductive frost tolerance in pulses is relatively new, and is coupled with the increased pulse production (specifically lentil and faba bean) in Australia. Timing of exposure to low temperature is a key factor that disrupts fertilization of flowers in legumes (Stoddard et al., 2006). But the problem associated with the research done is the understanding of different definitions for low and freezing temperatures in different geographical environments. However, international efforts to breed for frost tolerance, cold tolerance, freezing tolerance and winter hardiness all vary depending on the specific local climactic conditions, where the most severe damage may be caused at the seedling stage, vegetative or the reproductive stage. There is also an inconsistency when dealing with different countries when describing the terms associated with frost work, such as winter hardiness, cold and chilling tolerance, freezing and frost tolerance all being interchangeable depending on the country and researcher. Clarke et al. (2004) describe chilling tolerance for pollen as survival of pollen exposed to temperatures less than 15°C, but not below 7°C whereas Toker (2005) describes cold tolerance of plants that are exposed to minimum temperatures down to –11ºC. Clements and Ludlow (1977) describe freezing tolerance as the ability of a plant to tolerate ice formation within its tissues. However this definition is not shared by all researchers with Badaruddin and Meyer (2001) describing frost tolerance as the ability of a plant to resist freezing temperature.

Cold acclimatisation enhances frost tolerance in peas, which are particularly sensitive to frost after a period of mild temperatures, hence reproductive frost during ripening in spring can severely reduce grain yield (Eteve, 1985). Avoidance of frost damage is possible with preferential movement of water from flower buds to vegetative parts of nodes under slow cooling, leaf primordia of conventional leaf types offer more protection to apical meristems than with semi-leafless types, and factors associated with winterhardiness are black hilum, high anthocyanin, purple flowers, and prostrate growth habit (Eteve, 1985). Field screening of pea lines has identified both *P. sativum* and *P.sativum* subsp. a*rvense* lines with useful winter hardiness, confirming laboratory screening at –6°C (Auld et al., 1983). *Pisum fulvum* accessions in the secondary *Pisum* genepool were superior to most *P. sativum* acessions at –6°C, although a few of the latter were cold tolerant (Balachkova et al., 1986). Thus genetic variation for cold and for frost tolerance exists within the *Pisum* genus.

Traditionally, breeding for frost tolerance has been challenging and limited in pulses. This has been due to the lack of reliable screening techniques and the reliance on field screening, which is slow with unpredictable spatial variation effects, avoidance effects, and yearly variances (Single, 1998; Srinivasan et al., 1998; Ali et al., 1999; Clarke et al., 2004; Stoddard et al., 2006). Unfortunately, the relative importance of abiotic stresses such as frost affecting pulse production is poorly understood. The increased uptake of pulse production particularly by Australian producers relies on the development of highly adapted and high yielding varieties. Reproductive frost and cold tolerance are vital components of increased yield and hardiness in Southern Australia (Siddique et al., 1999).

20.7 Increased CO_2 Levels – Responses in Growth and in Nitrogen Fixation

CO_2 levels in the atmosphere are expected to rise from the surent 385 to 700 ppm by the end of the twenty-first century (Ainsworth et al., 2008). In soybean Serraj et al. (2002) expect increased drought tolerance of N_2 fixation, via increased partitioning of carbon to nodules, decreased leaf uriede levels, and sustained nodule growth and nitrogen fixation. In other legumes including lupins, nitrogen fixation responses to enhanced CO_2 were found to be species specific and inconsistent between studies (West et al., 2005), while Vara Prasad et al., (2005) found in non-stressed conditions that yeild and photosynthesis of peanut, common bean and cowpea increased in response to elevated CO_2. Rogers et al. (2006) studied elevated CO_2 effects on soybean in the open air, with outcomes of increased photosynthate, increased foliar carbohydrate content, but reduced early season leaf N content. The latter effect dissapeared by mid-season, dry matter increased at final harvest with no significant effect on leaf N, suggesting that plants had acclimated to the increased N demand at elevated CO_2. Serraj (2003) expects that "legumes will have a comparative advantage over cereals under climate change", but the beneficial effects of elevated CO_2 are also expected to be offset by negative effects of heat and drought stresses.

20.8 Disease Responses and Challenges

Response of legume pathogens and disease to climate change:

Climate change factors which will affect legume pathogens are temperature, atmospheric CO_2, and rainfall. Increases in CO_2 and temperature will be worldwide but the impact of climate change on rainfall will vary (increase or decrease) depending on the region. Cool season legumes are grown in a range of regions and therefore no universal predictions can be made on the impact of climate change on diseases of cool season legumes. Many current production zones are expected to become drier, but new production areas are also likely to develop. However, predictions can be made as to the impact of climate change factors on various classes of pests and pathogens, and these can then be used in conjunction with climate change predictions for different regions.

Climate change factors will impact on diseases of cool season legumes in a number of ways including direct impacts on the pathogen life cycle, pathogen vectors and plant growth.

For foliar fungal pathogens, increasing temperatures generally shorten germination time and increase the rate of the infection process if adequate moisture is available. Increasing rainfall, resulting in longer periods of leaf wetness (dew period) also increases the rate of germination and infection. Conversely, lower temperatures and reduced rainfall and leaf moisture generally reduce the rate of germination and infection until a point is reached where these processes cease.

Soilborne (root) pathogens generally require moist soil or waterlogging to assist the infection process as the fungal zoospores need to swim through the soil to reach the roots and infect the plant. Despite the fact that reduced rainfall is predicted for many cool season legume production areas, the prediction of more intense rainfall events may lead to increased waterlogging and spread of some root pathogens. Increasing atmospheric CO_2 may increase plant canopy growth and density, which may increase canopy humidity and length of leaf wetness, favouring fungal growth. Reduced moisture and increased temperature may increase plant stress, increasing disease susceptibility but this is likely to be offset by less favourable germination conditions.

The importance of vector-borne pathogens under climate change scenarios may depend on the impact of the changes on the life cycle of the vector more than that of the pathogen. For example, most of the important viruses of cool season legumes are spread by aphid vectors and various reports predict increases or decreases in the aphid populations due to changes in temperature and rainfall.

The impact of increasing atmospheric CO_2 may also affect the chemical composition of the plant host, which may impact on aphid feeding and reproduction. Reviews such as that of Chakraborty et al. (2008) provide extensive information on the impacts of global change on diseases of agricultural crops and forest trees whilst that of Jones (2009) includes the likely impacts of climate change on plants and their viruses and vectors. Spackman et al. (2007) identified priorities for pest and disease research in key Victorian grain and horticultural crops under elevated CO_2 and this review contains extensive information on the impacts of elevated CO_2 on insect vectors. Garrett et al. (2006) examined the impacts of climate change on plant disease from the genome level through to the ecosystem level.

The main groups of pathogens affecting cool season legumes are foliar fungi, soilborne fungi, bacteria and viruses. The most important pathogens of chickpeas, faba beans, field peas and lentils are listed below in their pathogen groups:

20.9 Major Foliar Fungi (Leaf and Stem Diseases)

Ascochyta fabae- bean leaf and pod spot
Ascochyta lentis- lentil ascochyta blight
Ascochyta pisi, Micospharella pinodes, Phoma medicaginis var. pinodella- pea leaf and pod spot
Ascochyta rabei- chickpea ascochyta blight
Botrytis cinerea- bean Botrytis pod rot, bean chocolate spot, lentil grey mould, chickpea grey mould
Botrytis fabae- bean chocolate spot, lentil grey mould
Colletotricum truncatum- lentil anthracnose
Erysiphe pisi- pea powdery mildew
Peronspora viciae- bean downy mildew, pea downy mildew
Schlerotinia sclerotiorum- bean and pea white mould
Uromyces fabae- bean rust, pea rust, lentil rust

Major soil-borne fungi (wilts and root rots):

Aphanomyces euteiches- common root rot
Fusarium oxysporum f. sp. pisi- pea Fusarium wilt
Fusarium solani f. sp. pisi- pea foot rot
Phoma medicaginis var. pinodella- pea foot rot, bean foot rot
Fusarium culmorum- bean foot rot
Fusarium solani- bean foot rot
Phytophthora megasperma- chickpea root rot
Pythium spp., *Phytophthora* spp., *Rhizoctonia* spp.- seedling and root rots

Major bacterial pathogens

Pseudomonas syringae pv. syringae- pea bacterial blight
Pseudomonas syringae pv. pisi- pea bacterial blight

Major viral pathogens (aphid-transmitted)

Alfalfa mosaic virus (AMV)
Bean leafroll virus (BLRV)
Bean yellow mosaic virus (BYMV)
Beet western yellows virus (BWYV)
Cucumber mosaic virus (CMV)
Pea enation mosaic virus (PEMV)
Pea seedborne mosaic virus (PSBMV)
Major viral pathogens (beetle/nematode transmitted)
Broad bean mottle virus (BBMV)
Broad bean stain virus (BBSV)
Broad bean true mosaic virus (BBTMV)
Pea early browning virus (PEBV)

20.10 Impact of Climate Change on Groups of Pathogens

Some generalisations can be made on the impact of individual climate change factors on groups of pathogens, however, in different environments different combinations of factors will combine to give different impacts on disease occurrence and development.

Ascochyta blights are the most important diseases of cool season food legumes and are found in neally all production zones (Muehlbauer and Chen, 2007; Bretag et al., 2006; Tivoli et al., 2006; Nguyen et al., 2005). As with many other foliar pathogens, temperature and relative humidity play an important role in disease development (Trapero-Casas and Kaiser, 1992) with disease development favoured under cool humid conditions (Muehlbauer and Chen, 2007). Rain splash is generally required to release and spread the pycnidia spores formed during the initial infection and humid conditions or leaf wetness are required for their germination (Bretag et al., 2006; Biddle and Catlin, 2007). The hotter, drier conditions, particularly drier winters, predicted for many production areas, are likely to reduce the importance of ascochyta diseases (Spackman et al., 2007).

Botyrtis spp. generally only cause disease problems sporadically in pulse crops. The disease tends to occur when plant biomass is high and leaf microclimates are humid. The spores are airborne and germinate during periods of leaf wetness or high humidity (Biddle and Catlin, 2007). Increased CO_2 levels are expected to increase canopy growth and density, which will increase canopy humidity and length of leaf wetness (Chakraborty et al., 1998). These changes in the host, along with increased air temperatures would favour increases in levels of Botrytis infection in areas where moisture is not limiting (Spackman et al., 2007). However, the hotter, drier conditions, particularly in winter, predicted for many regions are likely to reduce the impact of Botrytis diseases.

Powdery mildew of peas is favoured by warm day temperatures and cool, humid nights. Downy mildew of peas and beans is favoured by cool, humid weather. Sclerotinia white moulds are favoured by warm wet conditions (Biddle and Catlin, 2007). Hotter, drier conditions are likely to reduce the impact of these diseases.

Root rots in legumes are likely to be affected by climate change. Common root rot, Fusarium root rots and Phytophthora root rots are favoured by waterlogging or wet conditions and are expected to be less important under drier soil conditions, whereas Rhizoctonias prefer drier soil conditions and may increase in importance in some environments. Increasing soil temperatures may result in the spread of rootrots requiring warmer soil temperatures, if soil moisture is adequate. E.g. Phytophthora rootrot of chickpeas, currently a much higher threat in the warmer northern cropping regions of eastern Australia may increase in importance in southern Australia with predicted temperature rises (Spackman et al., 2007).

Bacterial blight of field peas is favoured by very wet conditions and frost damage which facilitates entry of the bacteria into the plant (Hollaway et al., 2007). Hotter, drier conditions are likely to reduce the impact of this disease.

The serious diseases caused by viruses in cool season legumes are spread by vectors and occur in most production zones in a wide range of environments. Jones (2009) states that the dynamics of virus epidemics and the losses they cause are likely to be influenced greatly by the direct consequences of climate change such as altered rainfall patterns, increased temperatures and greater wind speed and indirectly by factors such as regional alterations in the areas cropped, the ranges of crops grown and changes in the distribution, abundance and activity of vectors. These factors are likely to alter the geographic ranges and relative abundance of viruses, their rates of spread, the effectiveness of host resistances, physiology of host-virus interactions, virus evolution and the effectiveness of control measures. Most important cool season food legumes viruses are spread by aphid vectors and aphids are expected to react strongly to climatic change factors due to their short generation time and low developmental threshold temperatures. However, it is difficult to generalise across different pathosystems and geographical regions on the impacts of climate change on aphid populations although milder winters are likely to increase early spring aphid activity in some areas, wheras hotter, drier summers may reduce the ability of aphids to oversummer (Frederic et al., 2009, Jones, 2009).

Increasing CO_2 levels are likely to change the carbon: nitrogen ratio in the host plant. This will affect the nutrient quality of plant sap which along with temperature is a key determinate of aphid physiology and affects development, reproduction, disease transmission, dispersal, distribution and population dynamics (Spackman et al., 2007). There is little published research on the direct impact of climatic change factors on plant viruses (Jones, 2009).

The warmer, drier conditions predicted in most temperate cropping zones are likely to reduce the seriousness of most fungal diseases except Rhizoctonia. At lower latitudes where conditions are predicted to become warmer and wetter, conditions may favour the development of some fungal diseases such as powdery mildew of peas, Sclerotinia white moulds and Phytophthora root rots. The incidence of viruses is likely to be most affected by impacts of temperature and rainfall patterns on aphid vectors, with milder winters and increased incidence of rain over summer and autumn favouring build up of alternate aphid hosts and aphid populations.

20.11 Sources of Resistance to Key Pathogens of Cool Season Food Legumes

Although many fungal diseases can be controlled by cultural management and use of chemicals, these approaches are rarely successful for viral or bacterial pathogens. Deployment of genetic resistance sources to produce resistant or tolerant cultivars is seen as the most effective and economic approach to managing cool season legume diseases. A number of reviews on sources of resistance to pathogens of cool season food legumes have been published recently including sources of resistance to all major biotic stresses (Muehlbauer and Kaiser, 1994), foliar diseases (Tivoli et al., 2006), root diseases (Infantino et al., 2006), Ascochyta blights (Muehlbauer and Chen, 2007; Bretag et al., 2006; Nguyen et al., 2005; Ye et al., 2002), Fusarium wilt of chickpea (Sharma, Muehlbauer, 2007), bacterial blight of field pea (Hollaway et al., 2007) and viruses (Boulton and Maury, 1997; Makkouk and Kumari, 2009). Although insect pests are only covered in this section in their role as virus vectors, reviews by Clement et al. (1994) and Edwards and Singh (2006) comprehensively describe research achievements in resistance to insect pests of cool season food legumes, the lack of success in developing resistant varieties and future approaches and opportunities. Both groups of authors state that although resistance for many insect pests has been found at low frequencies in germplasm collections there has been considerable difficulty in getting this resistance into commercially acceptable varieties.

The frequency of Ascochyta resistant accessions in germplasm collections is low, but sources of partial resistance have been identified in all of the cool season food legumes and the currently available resistance is being used in breeding programs to develop more resistant varieties (Muehlbauer and Chen, 2007). Details of sources of resistance and accurate screening methods are described in the reviews cited. With the exception of faba beans, Ascochyta resistance has been found in wild relatives as well as cultivated species (Muehlbauer et al., 1994; Muehlbauer and Chen, 2007; Collard et al., 2001; Bretag et al., 2006; Nguyen et al., 2005; Tivoli et al., 2006). Muehlbauer and Kaiser (1994) comment that resistance to Ascochtya blight has often been overcome by new pathotypes. Marker-assisted selection is now underway for Ascochyta blights of pea, lentil and chickpea (Tivoli et al., 2006).

Resistance to Botrytis grey mould of lentils is poorly understood but screening of germplasm is being undertaken in a number of countries and resistant lines have been identified. Some resistance to chocolate spot in faba beans has been identified and although better resistance has been found in other Vicia species its use is currently limited by the inability of faba bean to cross with related species (Tivoli et al., 2006). Wild chickpea species have also been screened for resistance to Botrytis grey mould and some resistant lines have been identified (Pande et al., 2006).

Lentil anthracnose consists of two pathogenic groups and although resistance to one group (Ct1) has been found in lentil germplasm, none has been found to the second group (Ct0) although moderate levels of resistance have been found in some wild relatives (Tullu et al., 2005; Tivoli et al., 2006).

Durable resistance is available for powdery and downy mildew (Muehlbauer and Kaiser, 1994; Kraft and Pfleger, 1984).

Infantino et al. (2006) consider that soilborne diseases are among the most important factors limiting yields of cool season food legumes, particularly common rootrot and a range of Fusarium wilts and rootrots and that the most effective control of these diseases is through the use of resistant varieties. They provide comprehensive information on sources and types of resistance to these pathogens and note that the use of molecular tools has enabled the introgression of many qualitative and quantitative resistance genes into commercial cultivars. Many studies are being undertaken to find novel sources of resistance to fungal pathogens of cool season food legumes by using molecular tools to screen germplasm collections, particularly wild relatives, and combining this information with studies of the genetics of the pathogen to come up with integrated approaches to disease control (e.g. Sharma and Muehlbauer, 2007; Knights et al., 2008; Muehlbauer et al., 2004; Pande et al., 2006). Currently, the most effective control of diseases caused by soil-borne fungi is achieved by a combination of the use of resistant cultivars and good disease management practices (Infantino et al., 2006).

Breeding for resistance to bacterial blight in field pea has been complicated by the fact that there are a number of races of the pathogen Pseudomonas syringae pv. pisi and resistances found in field pea are not effective against all races and no resistance has been found against Race 6. However, race non-specific resistance to all races of P. syringae pv. pisi has been reported from a number of accessions of the wild relative *Pisum* abyssinicum and these sources have been back crossed into adapted pea lines in the Australian national pea breeding program (Hollaway et al., 2007).

Boulton and Maury (1997) describe the main viruses of cool season legumes and the areas where they cause serious disease and state that faba beans resistant to BYMV, peas resistant to PSBMV and faba beans, peas and lentils resistant to PEMV are available. Muehlbauer and Kaiser (1994) report resistance to BLRV, PEMV and PSBMV in cool season food legumes. Generally the national or regional focus has been on screening germplasm for resistance to only the most serious viruses. In the USA, pea breeding lines with resistance to PSBMV and PEMV have been identified (Alconero and Hoch, 1988; Baggett et al., 1994). In Europe, where PSBMV is a serious problem in peas, multiple sources of resistance together with a biotechnological approach are being used due to the risk of virulent strains emerging (Boulton and Maury, 1997). PSBMV-resistant pea lines have also been identified in India (Khetarpal et al., 2008) and New Zealand (Frew et al., 2002).

In Australia, a range of cool season food legume germplasm has been screened for resistance to AMV, BYMV, CMV and PSBMV (Latham and Jones, 2001; McKirdy et al., 2000; Latham et al., 2001) and as part of the national pulse breeding program, faba bean and field pea germplasm is being screened for resistance to BLRV, BYMV and PSBMV in collaboration with the International Centre for Agricultural Research in the Dry Areas (ICARDA), Syria (Makkouk et al., 2002; van Leur et al., 2000, 2004; van Leur and Kumari, 2005; van Leur et al., 2006, 2007). In West Asia and North Africa, Makkouk et al., (2001) and Makkouk and Kumari (2009) have identified the most important viruses of cool season food legumes and state that resistant genotypes are available for some of these host/ virus combinations, including lentil lines with resistance to PEMV, BLRV and the regionally important viruses faba bean necrotic yellows virus (FNYV) and soybean dwarf virus (SDV), including six lines with combined resistance; faba bean lines with resistance to PEMV and BLRV and pea lines resistant to BLRV. As well as traditional breeding approaches, virus coat protein mediated resistance to PEMV and AMV in peas is being assessed (Chowrira et al., 1998; Timmerman-Vaughan et al., 2001). For some viruses in some crop species, resistance breeding has been limited for a number of reasons. However, in the EU and other developed nations, agricultural policy of decreasing inputs and preserving the environment is likely to increase the emphasis on conventional resistance breeding and biotechnology both for the introduction of virus resistance by genetic modification and for selection of resistance within breeding material (Boulton and Maury, 1997).

20.12 Impact of Diseases on Biodiversity Under Future Climates

It is clear that to some degree, resistance has been found to the majority of the pathogens causing serious disease in cool season food legumes. Many national and international germplasm collections have been screened for disease resistance and numerous resistant varieties have been released following incorporation of identified resistance genes from these sources. Recent identification of molecular markers tightly linked to resistance genes has greatly enhanced breeding programs by making marker assisted selection (MAS) possible and allowing the efficient screening of germplasm collections and the development of varieties with multiple disease resistance (Infantino et al., 2006). Molecular genetics are also assisting our understanding of host-pathogen interactions and the nature of the host resistance.

The availability of disease resistant germplasm from major national and international collections and the development of new molecular tools should assist breeders in the development of cool season food legumes adapted to altered climates in their region.

20.13 Conclusion

There is wide genetic diversity in both domestic and wild germplasm which relate to both manual and natural selection in the respective environments where germplasm evolved. This variation can be initially screened for drought, heat and frost stresses by the climates of the locations where sourced. Promising germplasm in target environments of a breeder can be further evaluated for specific stress tolerance traits such water use efficiency, root depth and density, early maturity, early vigor and tolerances of soil stresses such as salinity.

Heat and frost stresses can be more precisely applied in controlled environments, for screening of germplasm according to growth stage, and for confirmation of field screening.

Climate change is expected to result in more incidences of heat, drought and frost stresses, which reduce grain yield, however increased CO_2 levels could partially mitigate these effects in legumes, particularly as nitrogen fixation may increase.

The impact of diseases will be affected by climate change in various ways. Warm dry conditions may reduce many bacterial and fungal diseases, however depending on how various aphid vectors are affected it is difficult to predict their impact on viral diseases. Extensive genetic variation is available for selection of resistance to many diseases, which in the future will be assisted by marker assisted selection.

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Chapter 21
Strategies to Combat the Impact of Climatic Changes

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21.1 Introduction

The most important global debate of this century is on climate change. It is predicted that by 2050 there will be significant impacts including rising temperature, globally increased rainfall (~6%, Bengtsson et al., 2009) but increasing drought due to higher evaporation and changing rainfall distribution, and increased levels of CO2 due to greenhouse and agriculture gas emissions. Climate change predictions over this century are for warmer (at least 1–2°C) and drier conditions, with increased extreme weather events and increased CO2 levels, in the regions where the principal temperate grain legumes of chickpea, lentil, faba bean and pea are mainly grown (e.g. The Australian wheat belt, Anwar et al., 2007; Challinor et al., 2006; IPCC, 2007a; b). However, rainfall may increase at higher and some tropical latitudes (Bengtsson et al., 2009), and frost frequency may increase with drier conditions. Genetic adjustment of crops can help to mitigate the adverse effects on production, resulting from shorter crop cycles with warmer temperatures and reduced moisture, (Anwar et al., 2007) partly offset by growth response to increased CO2 (Tubiello et al., 2007).

However, the negative impact of climate change will likely be far greater closer to the equator, in some of the world's poorest and most densely populated countries. Forecasts indicate that elevated CO_2 levels will have a fertilizing effect in some regions (Tubiello et al., 2007), although this will be negated by greater drought and heat stress in lower latitude areas. In most developing countries, food legume crops are the primary source of calories for the vast majority of people and any fall in production could have dire humanitarian consequences. Interestingly, most commentators estimated that global production of food grains must double by 2050 to keep pace with increasing population growth, demand and international supply for food (APA, 2004).

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Grain legumes differ from the world's staple cereal crops of rice, wheat, maize and sorghum because of their unique ability for symbiotic nitrogen fixation. The key questions are whether legumes will be less affected by climate change due to an expected rises in nitrogen fixation associated with an increase in CO_2 levels, and how they compare with cereals for the genetic potential to adjust to global warming with more frequent extreme events, and to generally drier conditions. Scientifically this question is being addressed using FACE experiments (Free Air CO_2 Enrichment). However, mostly these have not investigated crop legumes and a recent consensus by the global FACE community has called for increased investment and investigation linking crop species/varieties, environmental changes and elevated CO_2 (Ainsworth et al., 2008). Will legumes be better equipped to adapt to climate change, and will the role of legumes become more important through adding even more nitrogen into farming systems? To address these questions this book is devoted to the role of cool season legumes with climate change.

In developed countries grain legumes are minor crops in rotation with cereals on large farms, providing diversity in sources of income, nitrogen inputs into the farming system, and a break crop to facilitate control of weeds, pests and diseases that build-up under predominantly cereal cropping. Detailed data around the global production and productivity for chickpeas and lentils are included in Yadav et al., 2007a, b). Generally grain legumes are seen as a more risky crop than cereals, and have a reduced role in the more marginal low rainfall zones. Grain legume crops tend to be grown in the medium-high rainfall regions, and/or possibly with irrigation. Farm sizes are large enough to fund the social inclusion of farm families in the modern economy, with income from farm produce. This is either sold directly, or used indirectly by converting produce to animal feed for subsequent sale of livestock/animal produce. Grain legumes have a strategic role in the food and feed economy as a high protein source, while legume pastures have a feed role, and both have a strategic role in biological nitrogen inputs for subsequent cereal and oilseed crops.

In contrast, in developing countries, with either partially or wholly subsistence farming and with lower participation in the off-farm cash economy, grain legumes tend to be minor crops. Both irrigated and high rainfall agriculture is on much smaller farms where small scale mechanization, contracted mechanical operations, animal and human labour are major features, with diversity both within and between crop regions. Generally grain production from cereals is more reliable, and more responsive than legumes to crop inputs of water, fertilizers and weed control. Cereals have benefited to a greater extent from modern plant breeding for input responsive varieties, whereas for grain legumes the breeding gains are more recent and less dramatic.

The net result is that regions of high productivity in developing countries either with irrigation or with medium-high rainfall have higher economic returns with cereals than with legumes. Cereals are almost exclusively preferred by small scale farmers. Thus grain legume agriculture tends to be concentrated in marginal areas of low rainfall without irrigation, or as a dry season rotation crop after cereals grown in the rainy (monsoon) season, e.g. chickpea grown on residual soil moisture after wheat in northern India.

The dichotomy is that cool season crop legume production is relatively more important for marginal agriculture in developing countries, but is found in the more reliable cropping regions in developed countries. Thus with marginal cropping areas likely to be more under threat in developing countries, the prospects for grain legumes under climate change would seem initially to be bleak. Only the future can tell if the agronomic advantages of legumes with increased levels of CO_2 will be a driver for a more central role in farming systems.

This chapter will focus on future strategies to combat the impact of climatic change that can be used to improve the water use- efficiency, drought, cold and heat tolerance of grain legume crop cultivars, improve crop quality and the sustainability of legume crops production systems.

21.2 Approaches to Combating Adverse Outcomes

To combat the impact of climate change in the years to come, so that world can survive, various approaches have been suggested differently world wide. However, in the context of agriculture, solutions to climate change involve two aspects: adaptation which suggest how to maintain production under changed conditions, and mitigation which explain how to soften the impacts on the most vulnerable communities. Thus various approaches have been mentioned to involve both the approaches.

21.2.1 Governmental Policies

Climate changes are occurring in all the continents with many countries having either documented changes or predicted them by climate modeling (IPCC, 2007a, b). Various ecological imbalances are being recorded and documented by national and international organizations around the world. In response to these changes and predictions governments have already initiated many policy decisions to combat the influence of climate change. If these initiatives are to be successful it is important that they receive high priority. For example President Obama of the USA has introduced a carbon emission reduction bill in the US Senate in the month of May–June 2009. India has introduced legislative amendments to combat the influence of climate changes in 2008. Like wise Japan, China, Australia, UK, Denmark, Bangladesh, Tunisia etc. have implemented policies aimed at mitigating the adverse impact of climate change. These government policies are essential otherwise it will be difficult to mitigate this impact globally.

21.2.2 Reduction of CO_2 Emission

Rising CO_2 levels are considered a precursor of climate change. CO_2 itself is the starting point for carbon fixation by the process of photosynthesis. We know from controlled-environment experiments that photosynthetic performance is enhanced by higher levels of CO_2 in the atmosphere because of the way the stomata operate. Field experiments have been set-up in several countries to examine the effects of elevated CO_2 during the cropping season and the approach is known as Free Air CO_2 enrichment (FACE). The general trend is that higher levels of CO_2 produce slightly higher yields, but different varieties may respond very differently. Also, the beneficial effects of higher CO_2 appear to be muted in drier environments (ICARDA, Caravan, 2008).

The policies aimed at the development of emission reductions programmes and the provision of carbon offsets will create *the biggest impact in tackling climate change, globally.* Environmental and human needs mean real reductions need to happen now. However, it must be remembered that none of the IPCC (2007a, b) emission reduction scenarios allow us to avoid increases in global CO_2 levels. The successful implementation of CO_2 reduction emission needs following considerations around the world.

- Reducing large scale emissions in a business takes time, and offsetting alongside a reduction strategy has a greater immediate impact. Offsetting is the only way to deal with unavoidable large scale emissions and take responsibility for total emissions impact from day one. Many small scale point source emissions can be reduced without loss of productivity with existing technology (e.g. video link rather than driving) if there is a desire to do so.
- Developing a successful carbon market which helps allocate investment where it can make the greatest longer term impact. Businesses should support this. While there are still disagreements over the exact forms (cap and trade; baseline and credit) there is a need for an efficient global system.
- Funding the development of the new low carbon technologies which the world, especially the developing world, needs. This could create longer-term capacity, skills and knowledge, bringing wider benefits to local communities.
- Developing and promoting new management practices which reduce the carbon and nitrogen footprints by enhancing the long term storage of carbon in managed land while simultaneously reducing the emission of the other greenhouse gases: nitrous oxide and methane.

Increasing levels of CO_2 and higher atmospheric temperatures associated with climate change may at the same time offer both impediments and opportunities (Wahid et al., 2007). A changed climate may favor the cultivation of crops with a C4 photosynthetic pathway rather than the less efficient C3 pathway, although if all else is constant C3 crops appear to benefit more from increasing levels of CO_2 while C4 crops may be less adversely affected by drought and benefit more in droughty situations (Tubiello et al., 2007).

Thus it is important to halt the worsening of climate change effects by introducing limitations on greenhouse gas emissions at the international level by both the developing and developed world.

21.2.3 Educating People and Strengthening National Organizations

In order to ensure successful mitigation of the impact of climate change on field crops in general and legume crops in particular, effective and well supported, institutional mechanisms should be established at national and international levels. Thus effective means can be developed to take essential policy decisions around infrastructure development, resources mobilization, capacity building and implementation of technical programmes.

21.2.4 Breeding Strategies and Development of Cultivars

Legume crops are important components of cropping systems around the world and the impact of climatic changes will be global. Thus it is imperative to develop breeding approaches so new cultivars can withstand or take advantage of climate changes in respect of high and low temperature, moisture stress, increase CO_2 levels, changes in seasonal temperature, light and rainfall distribution etc. To screen and identify resistant/tolerant donors it is essential to collect diverse germplasm lines including wild species and evaluate under the future probable environments. For example in FACE areas with modified CO2 levels (Ainsworth et al., 2008). The utilization of resistant donors in breeding programs for the development of resistant segregating populations and selection of desirable resistant plants under warmer, drier and more extreme stress conditions is an important strategy to address future climate change. The development of such legume cultivars will provide a realistic strategy to combat the influence of climate change in years to come, globally. This can be supplemented by the utilization of wild relatives to transfer resistance gene pool into cultivated popular cultivars through a back crossing approach (Tanksley and McCouch 1997). Multiple resistant cultivars can be developed using complex hybridization and involvements of four or more desirable diverse parents and selection for multi-traits under stress environment simultaneously. This can bring the desirable achievements of multiple resistant crop legumes suited to climate change.

21.2.4.1 Focusing on Drylands and Incorporation of Drought Tolerance in Legume Crops

Drylands in semi-arid regions have long been neglected by policy makers because they were perceived as being degraded marginal areas, offering poor returns on development investment. But they are now attracting growing interest from politicians and policy makers, for various reasons-their sheer size “41% of the worlds land area”, their importance to development objectives “poverty reduction is a key UN Millennium development goal; and according to the Millennium ecosystem assessment, poverty is greatest in dryland populations”, their role in food security “Drylands produced the bulk of national food supplies in many countries”, and finally their vast potential to sequester carbon, mitigate greenhouse gas emissions and make ecosystems more resilient to further climate shocks (ICARDA Caravan, 2008).

Legume crops are favored crops of semi-arid ecologies globally. It is estimated that more than 70% of the area under legume crops is rainfed around the world. It is presumed that with continuous cultivation under arid ecologies, natural selection has been for survival rather than for high yielding genes of these legume crops, during their evolutionary period (Abbo et al., 2003). Unfortunately, intensive breeding efforts of the magnitude of those used with wheat, rice, maize etc. crops have not been initiated during part 4–5 decades in these crops. Generally the plant types of these legume crops have remained the same, whereas large changes were made in plant type of cereal crops with the implementation of the green revolution in many predominantly agricultural countries. There are some exceptions e.g. the semi-leafless, semi-dwarf, non shattering KASPA pea (AWB, 2005). However, the cultivation of these partly improved legume crops in semi-arid regions is often the reason for the low productivity of these crops, and drought alone is responsible for more than 40% of yield losses in chickpea crop (Yadav et al., 2006). Thus it is essential to develop the drought resistant/tolerant legume crops varieties to meet the future challenges of legume production. In this direction it will be more desirable to screen the diverse genetic sources under moisture stress environments and legume plant breeders and physiologists should take lead to screen such material.

21.2.4.2 Low and High Temperature Tolerance in Legume Crops

Climate change will probably result in higher mean temperature in most part of the world. Crops will be exposed to higher temperatures at every stage of growth, from seedling establishment to maturity. At higher latitudes this could mean that crops could be planted earlier in the season, which in turn might require varieties with slightly different phenology. In regions where temperatures rise over the growing season, the crop may be exposed to very high temperatures at the critical stages of flowering and seed development. Heat-sensitive cultivars may be rendered sterile if exposed to hot conditions (above 35°C) at flowering time. Breeding for heat tolerance is well established, and a range of legume varieties has been developed for hot regions such as the Sudan and Central India (ICARDA Caravan, 2008).

Legume crops are very sensitive to both high and low temperatures. When there are extreme fluctuations in temperatures the production of these crops is affected adversely. Thus it is imperative to develop and identify resistant genotypes and management technologies which enhance production in both low and high temperature environments. The development of temperature resistant cultivars will help the farming communities in cultivation of legume crops in changed future environments. In this direction intensive breeding efforts should be made by leading international research organization like ICARDA, ICRISAT, CIAT and IITA to provide desirable varieties and breeding lines to developing countries to meet this challenge. It is recommended that legume breeders and physiologists should screen the diverse genetic resources under elevated temperature levels and also under low temperature ranges in artificially created environments.

21.2.4.3 Water Use Efficiency of Legume Crops

Water use efficiency is a robust concept used for yield targeting, breeding targeting, bench marking paddock and farm performance and to examine management practices. In drought prone environments large variations are recorded because of variable rainfall and its time of occurrence (Condon et al., 2004). Such a factor makes WUE a quick and simple calculation to analyze how well rain can be converted to grain. WUE also provides a guide to future crop expectations. Oweis and Ahmad (2006) showed that substantial and sustainable improvements in water productivity can only be achieved through better crop selection, improved genetic make up, appropriate cultural practices and timely socio-economic interventions. There is a great need to revise conventional water management guidelines for attaining maximum water productivity instead of maximum land productivity. Therefore, new and improved approaches are needed towards improving WUE by understanding water requirements, effects of drought, rain water conservation, improving WUE through breeding, soil and agronomic management and efficient methods of irrigation, crop nutrition and crop residue management. Scientific communities globally need to take up this challenge to buffer against increased drought in many regions resulting from climate change.

An additional complexity is the relationship between drought and high-temperatures in many production environments. High evapo-transpiration rates often lead to increased moisture stress, particularly at lower latitudes. There is significant variation for response to high temperature in most crop gene pools and materials can be selected by simply delaying planting time to expose plants to terminal heat stress. The higher heritability of the selection environment for heat tolerance compared to drought stress should lead to greater gains in productivity under elevated temperature. However, there is evidence that traits important for one stress also influence the other. Osmotic adjustment, phenology, water-use-efficiency and solute concentrations can have an impact on both tolerance to heat and drought. These relationships, if confirmed, will allow the breeder to simultaneous improve both characters.

21.2.5 Plant Modelling

Because climate change will result in altered growing conditions there is a need to gain as much information as possible in a short period, often for future environments. One year at a time experiments will not be the most efficient method for doing this, so there is a great need to use crop modeling to understand the future needs of the crop. Research of this nature is being carried out (Anwar et al., 2007) however, there is a need to develop and apply increased use of plant modelling approaches that allow assessment of impacts of changes in climate, climatic variability and extreme weather events on pest, beneficial and endangered insects, arable plant communities, plant diseases and the sustainability of crop production. The potential effects of climate change on plant disease epidemics are a concern but so far little work has been done in this area. FACE trials are needed to help understand and model disease effects as pest and disease influences may change under elevated environmental CO_2 (Ainsworth et al., 2008). Cropping systems face new or increased threats from diseases as a result of climate change, which is predicted to bring milder and wetter winters, hotter and drier summers and more extreme weather events globally. The severity of human, animal and plant disease epidemics is greatly affected by temperature and rainfall and weather based forecasts have been developed to guide control strategies for many important diseases. There is now an opportunity to link weather-based disease forecast with recent climate change, to predict the effects of different climate change scenarios on the distribution and severity of plant disease epidemics.

21.2.6 Integrated Production Management Technologies

In the last 50 years, attempts to overcome biotic constraints of legume crops production have mainly focused on use of chemical pesticides and/or host- plant resistance. These single – factor management strategies to combat biotic and/or abiotic constraints have often been studied in isolation from each other. As a result the yield losses caused by pests or diseases epidemics, along with poor agronomy, have remained alarming and significant. There is a greater opportunity to combine best technologies that combat insect-pests and disease with improved agronomical practices and emerge with integrated management packages. In Australia for example these integrated management packages are being developed for pulse crops (AWB, 2005; McNeil et al., 2006). Integrated management packages for legume crops provide greater scope and need validation, up-scaling and out-scaling with the involvement of farmers. Thus combining of different technologies like desired agronomic management including weed and irrigation management, disease management, insect and pest integrated management, development and incorporation of high yielding resistant, widely adapted and quality cultivars are essential. Under changing climates the implementation of integrated production management technologies is very important to sustain the productivity of legume crops globally.

The understanding of regional impacts of climate change on legume crops is important in relation to knowing the predicted impact of climate change. In this context, the impact on legumes of climate changes in Northern American Latitudes (Canada) has been presented below as a case study on climate change.

21.3 Climate Change and Legume Crops in Northern Latitudes: A Case Presentation

Agricultural systems as a whole will be influenced significantly by changing climates in northern latitudes (Wheaton, 1999). This may include, but is not limited to, (i) longer growing seasons, (ii) more frequent and extreme droughts and wet spells, (iii) more frequent and intense heat waves and fewer cold spells in the winter, (iii) increased risk of soil erosion by wind and water, (iv) shortened snow-cover period, (v) increased demands for water and increased conflicts over water, (vi) decreased river flows and reservoir levels, and (vii) northward expansion of the range of crops, weeds, and pests. These factors may have direct or indirect effects on pulse crop adaptability (Miller et al., 2002), production strategies (Cutforth et al., 2007; Gan et al., 2009), and their economic outcomes (Lemmen et al., 2008).

Phenological responses of annual pulse crops to the warming climate would be high, especially for the production of lentil and chickpea, as these two crops usually express indeterminate growth habit in northern latitudes (Gan et al., 2009). In the case of chickpea, the crop is considered to have a "warm-season" growth habit due to its high requirement for growing degree-days. Consequently, global warming may improve the growth of this chickpea in the cooler, higher latitudes such as western Canada. The short growing season, coupled with end-of-season rainfall, often causes delays in the maturation of chickpea and lentil. In years with moderate rainfall in the late summer or early fall, regrowth of vegetative tissues may occur, causing delays in crop maturity, increasing the risk of frost injury before harvest. Chickpea crops that do not reach full maturity prior to the onset of killing frost have small or even zero yields. Producers may apply desiccants to dry out plant tissues to hasten plant maturity. However, this practice often locks in the green seed-coat color, resulting in low quality grain and decreased profits. Improved strategies and practices are required to ensure these crops with an indeterminate growth habit can, indeed, mature in the northern high latitudes. One strategy to reduce the negative effects of climate change and use it as advantage is to plant annual pulse crops very early in spring (or even in late fall) with the expectation that much of the crop development will occur in spring and early summer, largely avoiding the deleterious effects of late-season heat and drought (Cutforth et al., 2007).

21.3.1 Combating Drought in Northern Latitudes

Changes in precipitation patterns over time have been less conspicuous compared to changes in temperature. Akinremi and McGinn (1999) reported an increase of approximately 16 precipitation events per year on the Canadian Prairies, mainly in the form of low intensity events, for the time period 1920–1995. During this same period, the average amount of precipitation increased by only 0.62 mm per year. Zhang et al. (2000) reported that annual and growing season precipitation increased from less than 5% to slightly greater than 10%, but these increases were not statistically significant.

It is an issue common to modelers that temperature changes can be predicted more accurately with estimated models than predicting changes in precipitation. Sauchyn and Kulshreshtha (2007) have run a number of climate change models trying to predict regional changes in both precipitation and temperature. Their models revealed a modest increase in annual precipitation for the 2020s, a 5% increase for the 2050s and an 8% increase for the 2080s. However, the main increase was predicted to occur as precipitation that falls in the winter and spring, not in the growing period for annual crops. Moreover, the model predicted that rainfall in July and August, the key period for pulse crop growth, is predicted to decrease in southern Manitoba and southeastern Saskatchewan. Sauchyn et al. (2003) predicted that dryness would increase in the southern part of Canadian Prairies and the arid region would expand to the north, east and west. Smith and Almaraz (2004) considered the possibility that such an increase in dryness might result in some areas becoming too dry for annual crop production.

The production of annual pulse crops in northern latitudes will be affected by frequent drought especially in years when high temperatures occur during crop flowering. High temperature during flowering can cause severe abortion of opening flowers and reduces crop yield substantially. For example, in 2001 drought occurred during the entire growing season in western Canada coupled with heat during flowering, which caused a major decline in the production of many crops including dry pea, lentil, drybean, and others. The drought occurred in an unusual pattern which showed persistent, large-scale effect, and circulation anomalies that span vast areas. Bonsal and Wheaton (2005) stated that type of drought and heat wave effects might be the consequence of changing climate.

21.3.2 Adapting Legume Crops to Changing Climates in Northern Latitudes

Many strategies can be used in terms of adapting annual pulse crops to the changing climates in northern latitudes. Some strategies are being gradually used by producers, while others are being further verified. In a recent paper, Cutforth et al. (2007) outlined several climate-related factors to be considered in developing adaptation strategies to pulse crops; these factors include (i) crop species response to carbon dioxide enrichment; (ii) regional changes in precipitation and water availability; (iii) effects of growing season temperatures on maturity rates of pulse crops; (iv) possible shifts in seeding dates that alter growing season temperatures and the availability of water for plant growth; and (v) changes in soil fertility. Based on these climate-related factors, these authors have summarized the following strategies in the adaptation of pulse crops in northern latitudes: (i) developing chickpea, lentil and dry pea cultivars that can be fall-seeded to avoid summer heat and drought; (ii) developing determinant cultivars of chickpea and lentil that will be less affected by cool and wet autumns; (iii) developing chickpea and lentil cultivars with earlier phenology to escape terminal droughts (i.e. able to mature before onset of drought); (iv) developing warm-season pulses such as dry bean and soybean adapted to warmer climates and longer growing seasons; (v) identifying cultivars that have increased heat and water stress tolerance, or cultivars having greater response to increased carbon dioxide; (vi) promoting earlier seeding options in response to earlier springs; (vii) producing pulse crops using no-tillage practices to use crop resides for water and soil conservation and improved microclimate conditions for crop growth; and (viii) determining optimum crop sequences for a specific region to optimizes water use efficiency of crops and cropping systems.

21.4 Conclusions

The production of legume crops has to be increased significantly internationally in the years to come to meet increased demand by 2050. This increased demand and supply has more relevance for global food and nutritional security, as there will be more production constraints in future due to climatic changes. These warming climates and environmental changes certainly put pressure on productivity of field crops in general and legume crops in particular as legumes are more sensitive to such fluctuations and changes. Thus it is essential internationally to take strategic decisions and implement approaches to combat and mitigate the challenges of climate change as early as possible. In this context it is important to identify the strategic approaches which will be more beneficial for the cultivation systems of cool season legume crops globally.

The important approaches which will be directly helpful in promoting appropriate production system are favourable governmental policies, reduction of carbon emission, strengthening research and educational organizations, developing resistant/tolerant legume crop cultivars suitable for moisture stress, cold and hot environments having water use efficiency and wide adaptation, development of suitable plant modelling approaches, inter linking and networking of national and international organizations and implementation of integrated crop production and management technologies.

It is further concluded that diverse genetic resources should be screened for drought, low and high temperature and elevated CO2 levels under controlled environments to understand the impact and to identify superior yielding cultivars for crop breeding improvement programmes and general cultivation. It is predicted and expected that if such approaches and strategic decisions implemented globally, then the increased demand of legumes can be meet out successfully in 2050. Thus sustainable food and nutritional security in both developing and developed world can be achieved in the years to come.

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