Short Rotation Forestry

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SHORT-ROTATION FORESTRY

AS A SOLAR ENERGY TRANSDUCER AND STORAGE SYSTEM

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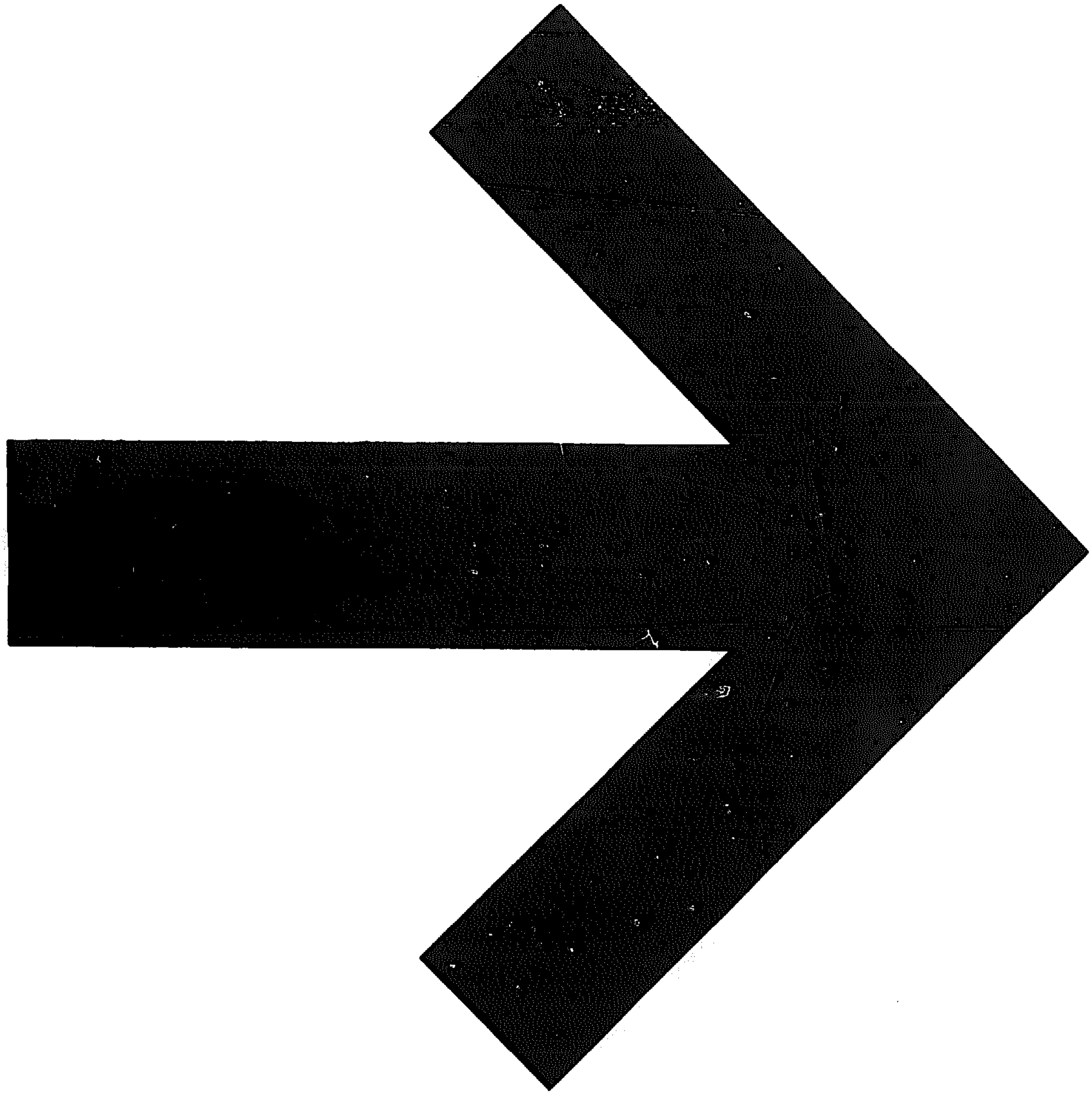

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SHORT-ROTATION FORESTRY

AS A SOLAR ENERGY TRANSDUCER & STORAGE SYSTEM.

Coppicing is almost unknown in the USA - perhaps only a few of you know what the word means. It is a technique of woodland husbandry which has an unbroken history in Europe which goes back at least 5,000 years. Under normal forestry management today we grow of the order of 0.5-10 tons of wood per acre per year - the annual increment; the national norm is 1½-3 tons/acre. By coppicing we can certainly achieve 5-10 tons annual increment immediately, and we can confidently expect that by normal agricultural programs of selection and mutation engineering we can raise that to 20-30 tons each year within a decade or two.

During the last few years there has been an awakening of interest here in coppicing techniques; the reports call it silage sycamore, puckerbrush, short-rotation, and mini-rotation forestry.

Coppicing consists of growing nursling trees very densely - a 4 x 4 ft. spacing is not unusual. Juvenile vigor, a quickly closed canopy, and intense competition, induce great height increments in the spring; this is followed by substantial increases in girth later in the year. After 3-5 years the growth is harvested during the winter as close to the ground as possible. The dormant buds at the root collar zone in the stump are thereby excited into maturation, and in the early spring they call on the sugars stored in the intact root system and grow swiftly into strong water sprouts. These sprouts are again harvested in 3-5 years, and so the cycle is repeated indefinitely. That is the principle; the details vary, depending on climate, species, soil, marketable product, etc. Today I will talk mainly about the coppicing practices needed to maximise yield for use as a furnace fuel. But before that I will give you a little insight into the long and respectable history of coppicing, and a quick rundown on some of the energy budgets involved.

1. ENERGY BUDGETS

1.1 COPPICE YIELDS

Table 1.1 shows some working figures for annual increment in the above-ground biomass which is harvestable; that is, leaves are not included.

Table 1.1
Some Indicator Values for Fuel Plantations:

Dry Weight	Metric	US
Timber yield per year	7.5 - 35 tonnes/ha	3.5 - 15 short tons/acre
Energy value, per year	35.0 - 165 x 10^6 k. cals/ha	60.0 - 260 x 10^6 Btu/acre
Energy value/weight, dry	4.77 x 10^6 k. cals/tonne	17.2 x 10^6 Btu/ton
Nett energy (fuel consumed by harvesting, chipping and transport deducted from total fuel energy in the chips) (63.23)		99.85%

TABLE 1.2
HEAT VALUES COMPARED

	k.cal/gm	ref #
H_2, liquid	29.93	(39.70)
Gasoline	10.50	(39.70)
Animal fats	10.0	(62.16)
Plant oils	8.8	(32.84)
Charcoal	8.0	(---)
Coal	7.7	(39.70)
Sludge solids	5.8	(33.36)
Protein	5.5	(62x16)
Methanol	5.3	(39.70)
Peat	5.0	(---)
Wood	4.73	(35.23)
Cellulose, starch	4.17	(39.79)
Glucose	3.75	(62x16)
Cow-chips	3.52	(39.79)
Municipal refuse	2.5	(40.08)

1 Btu/lb. = 0.55 cals/gm 1 cal/gm = 1.8 Btu/lb.

1.2 TIMBER OR ANNUALS?

An important question is whether timber or annual crops are better as solar energy storage devices; here the annual dry above-ground biomass production/acre/year must be an important criteria. We have, as yet, insufficient information on which to make our assessment, since field crops have been intensively developed, especially by modern scientific hybridising methods, with other end-uses in mind. For example, "densities of maize which produce the greatest biomass and hence are the most efficient in the conversion of solar energy, are totally barren of grain because of the extreme competition for light" (62.44, p. 305); timber trees have been developed with emphasis on their bole formation for boardwood; the side branches are usually considered to be nuisance to harvest; for they need hand-trimming, they have a low weight/volume ratio for transport, and it is not economical to recover them. In earlier days they were converted to charcoal on site, but during this century they have been burned, or stacked and left to rot away as a nuisance - trash. Only in the last few years have side-branches been recognized to provide a significant addition to the harvest when pulping is the objective. We therefore have no knowledge about the total harvestable yield of most commercial species, and also none for those which have short boles and branch freely.

The total biomass yields of annual crops are greater than annual incremental gains of most trees even when coppiced. But this apparent advantage is offset by a major disadvantage: the annual crop must be planted and harvested within the short time of a few weeks in spring and fall; this is expensive, for high-capital equipment must lie idle most of the year; and seasonal labor must be used; further, weather conditions may make even those periods unpredictable. Coppices, by contrast, can be planted in early and late winter when the ground is soft, harvested when the ground is frozen, and thinned most of the summer; both the equipment and the labor force are used over a much longer time. And of course annual crops must be husbanded every year, some of them intensively to produce the high yield required; coppices require attention only the first and second years after each harvest.

1.3 ADVANTAGES OF COPPICE-WOOD AS A FUEL

Short-rotation young forest wood has one important advantage over mature timber - whether that be large tree or ancient scrub-and-brush: during the short life-span of the shoot (3 - 7 years before harvesting) it has not yet had time to form heartwood. It is therefore free from the higher oils, phenols, and resins that characterize so many heartwoods; it is a relatively clean-burning fuel which does not deposit tars in the smoke-stack.

Timber is a low-sulphur fuel, defined as 0.3% sulphur or less; forest wood lies within the range traces to 0.10% sulphur (Table 1.3).

TABLE 1.3
Sulphur in Trunk and Twigs of Some Typical Trees (34.71, p. 131)

Species	Trunk Content	Twig content, % by weight
Oak	.003	.02
Tilia cordata	.08	.08
Fagus sylvatica	traces	--
Ulmus laevis	.04	.08
Betula verrucosa	.01	--
Populus tremula	.03	--
Pinus sylvestris	trace	.02
Larix	trace	--
Picea excelsa	trace	.03

1.4 FUEL NEEDS FOR ELECTRICAL SUPPLY

A generally accepted rule-of-thumb figure for the total energy consumption is the USA for all purposes is

per person = 10 kW continuous rating = 8.766×10^3 kW/year,
hence for 100,000 people = 1000 MW continuous rating = 87.66×10^9 kW/year.

However, only a fraction of this is electrical energy; the national average consumption of electricity is
per person =10^3kWr/year (01.00) = 1.14kW_e continuous

If we assume, for timber fuel, a conservative value of 30% efficiency of conversion from energy in the fuel to energy in the transmission line, this is 3.80kW thermal continuous = 13,000 Btu thermal/person/yr. = 114×10^6 Btu/person/year.

Wood has an average calorie value of 16×10^6 Btu/dry ton;
So that the timber fuel needs would be 7.12 tons/person/year

If for this calculation we suggest an annual increment of 7.12 tons/acre/year, that works out as
1 acre of coppice/person;
so 100,000 people need 156 square miles;
that is, 12.5 miles^2, or 14.1 miles diameter.

1.5 EFFICIENCY OF TRANSDUCTION

Table 1.4 shows the average annual insolation received at the surface of the earth at different latitudes. If we adopt the convenient figure of 100 k.ly/year
= 10^{10} k.ca./ha/year
the annual production of 7.12 tons/acre, dry weight, at 4 k.cal/gram provides 64×10^6 k.cal/ha. This will be a transduction efficiency of 0.64% of the total solar radiation at ground level. This seems to be the most useful way of calculating efficiency, even though it is of great theoretical interest to calculate the efficiency in terms of visible spectrum only, of narrow-band wave lengths absorbed by chlorophyll only, or of photons absorbed - all of which appear in the literature.

TABLE 1.4
Average Energy Received at the Surface of the Earth, in Kilo-langleys/Year

Latitude, N.	Energy
0°	155
10°	155
20°	150
30°	140
40°	120
50°	100
60°	70
70°	45

1 k.ly = 1 k.cal/m^2 = 10^8 k.cals/ha

2. HISTORY

Man has been felling trees since the beginning of his history; we have evidence that as long ago as the last ice age man was felling the timber as he advanced northwards with the receding glacier line. In 2,000 B.C. enormous volumes of timber were being felled to make roadways across marshes (B3.10); that this was all done with stone axes may seem remarkable, but a modern knapper has made a flint axe and with it felled a 5" diameter tree in 3 minutes. We know from study of primitive tribes today that larger trees are not so easily felled, and we can presume that the earlier peoples visited the same area at intervals, to fell the sprouts when they reached the desired size. That is, they coppiced. Pliny the Elder explicitly records coppicing (35x86), and from that time until around 1850, when coal became freely available, coppice wood was the only fuel available for homes as well as for industry.

The long history of coppicing is closely linked with the history of tools. It is difficult for us today who have magnificent hand-tools made of superb grades of steel to realize how much time it takes to cut wood with a steel of poor quality which must be sharpened frequently. If one only has such tools, then any technique which reduces the need for cutting wood is valuable. Eric Sloan has collected tools which have survived from the time of the American colonization; he has also recorded in a series of fine books the extent to which splitting (riving) was an essential part of furniture and homebuilding. The sawed timber planks as we know them today are unique to our civilization; all other civilizations have been able to make smooth planks only by adzing the riven trunk. This is not to say that high quality cutting edges were not available. The Romans had a technique for hardening bronze copper to take a razor edge by work hardening - tapping with repeated light blows of the hammer applied in a staccato rhythm; and the Toledo sword-makers knew how to laminate different grades of steel so to combine flexibility with hardness. But these were exceptional instruments, reserved to the wealthy for adornment or for warfare: the common handtool was made by the village blacksmith.

Timber for furniture was therefore used mainly as grown, in the round, with the bark peeled off and the worst bumps evened off with plane and spokeshave. Roofs were built with the intact roundwood flattened by notching only at points of contact. Coppicing therefore was not just a way of increasing the yield of fuelwood from stumps near to the village, it was a means for securing construction timber of the right size other than by selection from a natural mixed forest. These coppices also furnished the wood for the enormous quantity of baskets, barrels, tubs, and pails all of which were made by the cooper from riven wood. Sheet metal containers were as unknown as were plastic; goods were transported either in basketware, or in cooperage - and all these were made from coppice-wood. Next, we must remember that barbed wire fencing was also unknown, and all livestock was constrained either by live hedges, by split-rail fences, or by wattles. These required enormous amounts of timber from the coppice. Indeed, it has been said the expansion of America westwards by farmers was due not to the land being exhausted, but to their need for more native timber to enclose their cattle. In Europe the population pressures on the fast-dwindling forest reserves made some form of regenerative husbandry essential in a way that, historically, has not been generally felt to be needed in America until our own lifetime. Coppicing of the natural stumps provides a ready-made natural technique which only had to be improved on by generations of observation and care.

These many uses consumed larger diameter stems. The smaller were bundled together for firewood (faggotwood) and the smallest were fed to cattle as winter-browse. There were strong laws which required that at least 8-20 large trees were left standing per acre; these were usually, like the coppice, of beach or chestnut, and the fruit (mast) fattened the geese and the swine for Christmas. In these many ways the coppice provided an essential role in village life, and since cart tracks were poor and difficult to maintain, most of the products were made in the woods. In this way the leafy lanes and grassy glades "where sheep do gently graze" of summertime were transformed in the winter to resemble a widespread factory, with geese, swine, and cattle being driven past the loggers, sawyers, rivers, turners, coopers, treeners, charcoalers and others all plying their trades close to the felling line.

The adoption of coal which began in the mid 19th century not only replaced wood as a fuel, but also, through the introduction of steam-power and the invention of steel-making, brought in good-quality and cheap hand and power saws; by these means the wood-finishing industry could move from the forest, first to the rivers for water-power, and later to any industrial center which had ready access to both labor and coal. Thus small-diameter coppice wood progressively became un-useable, and timber-quality boles, previously a luxury reserved for ship-building, took over because their higher weight/volume ratio made them cheaper to transport than smaller-diameter coppice-wood. Recently our forestry industry has become aware of the large volumes of wood of good pulping quality that are left behind in the forests as 'slash' if attention is focused exclusively on the boles. That these small-diameter residues can be used both for paper pulp and for chip-board has led to an interest in the potentials of high-yield coppicing, now that a market can be foreseen for its chips. Coppicing has two important advantages over mature timber: firstly, the yield/hectare/year can be many times greater; and secondly, repeated harvestings at intervals of 3-7 years provide a much shorter-term return on invested capital.

In America (USA) coppicing to this European pattern seems not to have been practiced. The forestry literature from 1870 to 1900 shows increasingly the concern over the indiscriminate uncontrolled destruction of virgin forests. The foresters observed that young and mature stumps (from 20-100 year old trees) sprouted, and this growth they mistakenly called coppice. They do not seem to have realized that high-yield coppicing starts with a 3-10 year old tree, planted and grown only for coppicing: they tried to coppice on a stump that had already yielded board timber, and were disappointed when the results were not very good after 1 or 2 rotations.

Indeed, this misconception has been explicitly stated: "the coppice or sprout system . . . is the simplest method of securing natural reproduction. Because of the excellent sprouting capacity of most of our hardwoods, the forest may be reproduced by merely cutting off the trees at maturity . . . The old stumps, however, deteriorate after a certain number of rotations, and the forest must be renewed from seed . . . this system has been used for many years in parts of New Jersey, Pennsylvania, Connecticut, and Southern New York" (10.05). Biologically it is likely that under this brutal treatment the original roots yield their stored foods to the first generation sprout growth, but that a healthy new root system for these sprouts never forms.

2.1 ORIGINS OF COPPICING

Coppicing as a method of husbandry can be presumed to have arisen spontaneously, as a response to population pressures: as each plot of virgin forest was felled, the stumps sprouted. These second growths were then felled whenever large enough to meet immediate needs. This was repeated over many centuries by the population which, in Europe, characteristically was non-migratory. Deliberate planting as a row-crop with young nursery stock seems to have been adopted slowly, although it was occasionally practiced by kings and large landowners;

this is explainable when it is realized that no single person has any interest in providing the labor and husbandry necessary if the land is owned by their liege lord or in common, and if everyone has rights to harvest the fruits of their labor.

However, there is one important exception to this generalization: osier-beds (willow coppice) were laid out in regular rows like any other field crop from earliest times, probably because the very much shorter cycle of harvesting (1-2 years) made them seem more like a field crop than a forestry procedure.

Charcoal was an important product, partly because, as a fuel, it is about seven times lighter than wood of equivalent heating value and so was easier to transport; and partly because so much of it was used for smelting iron ; indeed the voracious consumption of raw wood for roasting the ore and of charcoal for converting pig-iron to steel decimated the forests of northeast USA. But there was always more forest further out, and so coppicing was not adopted. This is surprising because it was still the normal practice throughout the deciduous forest zones of Europe and Russia, and large numbers of immigrants from there must have brought knowledge of the practice with them. Whatever the reasons, in the USA interest in coppicing began only after 1950, when the demand for pulping-quality wood rose steeply in response to the increased use of paper for newsprint, packaging and zerographic and computer papers.

But this lack of interest is peculiar to the USA. Coppicing has been, and still is, actively practiced in many other countries: Table 2.1 lists 91 species which are reported in the literature as being coppiced commercially or in trials; and Table 2.2 lists the 30 countries which have furnished those reports.

3. FACTORS THAT GOVERN BIOMASS YIELD

Other things being equal, total yield of biomass is dependent on a number of factors, these include:

3.1 Length of Growing Season:

This can be estimated as the number of daylight hours in a year that the air temperature is above 6 degrees C, or the number of days when the average 24-hour temperature is above 10 degrees C (62.50).

3.2 Insolation and Cloud-Cover During this Period:

High intensity sunlight produces the highest rates of phosyn, but efficiency of transduction increases at lower lighting intensities: theoretical values are 4% efficiency at full sunlight, 20% at low intensity (60.26). (See Table 3.2)

TABLE 3.2
Relationship Between Insolation Intensity & Transduction Efficiency for Chlorophyll ([illegible].26)

100% intensity provides yield of	2% of full efficiency
50	3.5
25	5
12	7.5

3.3 EFFICIENCY OF TRANSDUCTION

There is good reason to suppose that woody species should be able to provide annual biomass yields comparable to the best field agricultural crops; all that is required is that they be developed by selection, hybridization, and cloning to the same extent as are field crops. Indeed, they may even do better, since the leaf index of a forest canopy (the total area of leaf upper surface to area of ground covered by the canopy) is of the order of x 6 for trees, but only x 4 - x 5 for field crops (62.51, p. 325; 62.50, p. 316).

3.4 CARBON DIOXIDE SUPPLY

CO_2 is normally limiting, especially at high light intensity: Under those conditions raising the level from the ambient 3ppm up to 10ppm can double the yield. These two factors - light intensity and CO_2 availability - together affect the total yield (60.26)..

It is remarkable that plants have apparently not developed a mechanism for re-absorbing directly through their roots the captive CO_2 that is generated by the soilorgs that are respiring within the confines of the volume of soil that is colonized by their root system. Calculations show that if this CO_2 were reabsorbed directly through the roots, it would provide some 5% of the total needed by the plant (63.26) although 8%, and up to 20% are also quoted. (61.19). In actual fact it seems that this CO_2 diffuses to the soil surface and so into the free air, to be absorbed either by the canopy or by any competing plants downwind. However, the reduced air movement beneath a closed canopy will enable most of this CO_2 to be retained within the tree community. Since CO_2 is limiting it is important to retain as much of the cellulosic detritus (leaf litter, twigs, slash) in the area as possible, preferably by leaving it lying on the soil surface so that it can biodegrade slowly by normal pathways, and the CO_2 be reassimilated. The alternative of burning it and thereby exporting in the smoke the carefully accumulated C is bad practice, and the local abuse is further compounded by the concomitant effects of destruction of the valuable energy-providing substrate required by soil microrgs, and the loss of micronutrients in the smoke and ashes blown away by the wind or washed away in runoff. This principle of good husbandry is all the more important in that saprophytic soil respiration is greater in the spring while the leaves are unfurling, and this is the same period that the CO_2 requirements per active leaf surface area is greatest since it is needed for development of new leaf surface.

The large C storage and recycle reserve provided by the leaves in the form of detritus is evident from table 35.26.

TABLE 3.4
Composition of Litter from a Mixed Oak Stand, %

Leaf	52
Twigs	17.5
Branch	13
Scales	4
Flowers	2.5
Acorns	3
Misc.	7

The biodegradation half-life of this litter-fall is only 7 - 14 months (35.26). The pathway by which this recycle occurs is being intensively studied (eg. 35.26, 34.73).

It might be suggested that the CO_2-rich flue gases from the generating furnace should be piped into the coppice area; this would probably be unfeasibly expensive. It has been proposed that fast growing sunflowers "be grown in a gigantic greenhouse, and the stack gases piped into the greenhouse". (62.56). This would enable planting and harvesting to be done to a schedule relatively independent of weather, but the dollar costs of building and maintaining many square miles of greenhouse for such a low-valued crop could be uneconomic. There is, however, an alternative which offers more promise: to scrub the stacked gases through the aeration tanks in the municipal sewage treatment plants. Here the CO2 will be utilized to increase the C:N ratio and so enable algae to use all of the available soluble nitrofixate from which to synthesise their own biomass growth. The resulting algal biomass will then be pumped out onto the coppice plantation, there to biodegrade and release the conserved CO_2.

3.5 WATER SUPPLY

Synthesis of 1 kg of plant material requires about 1,000 litres of water (34.58); this is for the C3 pathway; C4 plants need only 20% of that to synthesise the same biomass (62.54); clearly the coppicing potential of C4 shrubs needs to be investigated for semi-arid zones, since yield/ha. is no longer an important economic criterion, whereas yield/litre of water certainly is.

3.6 NITROGEN

Both nitrogen and trace metals can be limiting, especially in disturbed soil (after strip-mining or land-levelling), in clear-cut forestry subjected to heavy leaching and slow reestablishment of ground-cover, and in exhausted farm-land which has been "overcropped". In all these cases the lack of nitrogen may be real, but lack of some at least of the metals may be due more to non-availability (i.e. preciptated as insoluble salts or chelated) than to absolute absence.

Insufficient nitrofixate in the soil can be managed by adding artificial fertilizers in the manner used for field crops; aerial spraying (foliar feeding) of the young growing leaves in the spring may prove more economic than soil surface applications. A better strategy may be to plant, or at least to interplant, species which are known to fix atmospheric nitrogen in their rhizosphere system: alder (Alnus sp.) and false acacia (Robinia pseudoacacia) (10.07) are two examples already extensively proven for coppicing out of some 12 dicotyledonous woody genera which are reported to nitrofix (35.79). The nitrofixing pathways (e.g. the Azotobacter-Nitrosomonas - Nitrobacter chain) all require a source of energy to drive them: 1 gm. of available COH is used to fix 10 - 20 mg. of N. (37.02, p. 149). Normally this COH is provided by the biodegradation of the forest floor litter (35.26) which is taken underground by the surface and subsurface soil fauna, mainly insects (26.90 , 38.11). In an established forest this energy source is richly available throughout the topsoil; but in a plantation newly established on poor land only those organisms which are in the rhizosphere may have access to an energy supply, from the root exudates; in that case they will be working more as symbionts than as saprophytes, and the above-soil biomass accumulation will be reduced accordingly. Nitrogen fixation by epiphytes, which is considerable in a mature forest (it has been reported as 1 - 5 - 85 kg/ha/yr) (35.26, 38.01) will not be sufficient in the young coppice to meet the growth needs of the leaves during the first half of the growing season and of the stem length and diameter increases later in the season.

Nitrofixate in rainfall has been variously reported to range from little more than 1kg/ha/yr (63.02) to about 7.4 kg/ha/yr (10.02).

3.7 METALS

Metals recycle actively from the soil to the leaves, back to the soil with the fall litter drop, and so through the biodegradation pathways to the roots and up to the leaves again. During rainfall much metal may be leached from the leaf - 80% of the potassium has been reported (34.30) but this quickly is returned through the roots. Only trace quantities of available metals are imported by windborne dusts; the great majority are released locally from the soil by the metabolic activity of the soilorgs; the fungi and the mycorrhizal associations are the most active in this respect, and once again it is essential for this program that the fungi have an ample energy source - cellulose and other detritus components.

3.8 SPACING BETWEEN STOOLS

The optimum spacing between nurslings in the plantation depends on the main product desired from the coppice, on the intensity of management (labor) that is available, and on the environment.

3.9 END-PRODUCT DESIRED

If poles are required as the end-product and self-thinning is desired, the shoots should be planted closely. If fuel is required as the end-product, then annual biomass increment will be maximised by husbandry aimed at maximum solar energy storage (maximum annual increment) and the shape of the growth will not be a factor. If built-in weed control is desired, then early development of a closed cover overstory will be needed to maximize ground shading. The desired size of harvested cane, e. g. railroad tie, telegraph pole, pit prop, barrel-stave, hop pole, vine pole, broom handle, bean pole, charcoal, fuel faggot (these are listed here in descending order of diameter and of years of cycled intervals) will dictate how closely the stools should be maintained. If alternative uses, such as wildlife conservation, hunting, backpacking and horseriding are also desired, then skip rows should be included, preferably on an irregular pattern.

3.10 MANAGEMENT AVAILABLE

The space allowed between plants will also depend on whether the stumps will be thinned out during the first cycle growth and at each successive harvesting, or whether they must be planted at the final stump spacing. This, in turn, may depend on whether husbandry during the growth cycles will be mainly by hand or by machinery. The same applies to harvesting: the spacing between the stumps must be sufficiently wide apart to allow equipment to pass freely along the rows without damaging the stump or their underlying roots.

3.11 LOCAL ENVIRONMENTAL FACTORS

Local environmental factors include rainfall, annual and monthly pattern; wind; topography; ground-frost pocketing; soil quality; ground-water; and fertilizer program. When these environmental factors are reviewed for their effects on the management strategies required to optimize the end-product desired, it will be found that the basic requirement for all these end-product alternatives is essentially the same; optimum (minimal) spacing to maximize stored wood production in the desired end configuration. This is readily seen to be synonymous with quick establishment of so dense an overstory that the understory dies out: and to follow this stage with successive thinnings to secure a program for optimization of the end product which is consistent with continuing cash returns to cover the cost of doing those thinnings.

3.12 ECONOMIC CONSIDERATIONS

If we assume a newly-planted plantation, then the optimal spacing will be the least number that will yield a cash return from the first thinnings; and thinning will be continued at suitable intervals until the optimum spacing is secured for the desired ultimate harvested dimensions of the timber product that is intended to be marketed. But for an energy plantation our criteria are different: we do not want to produce a marketable pole or building timber within dimensional criteria; we wish to maximize annual harvestable biomass regardless of anything else. We have no thinnings. We cannot afford intermediate stage husbandry. We must develop our plant species and clones to meet these criteria, and manage our plantation accordingly.

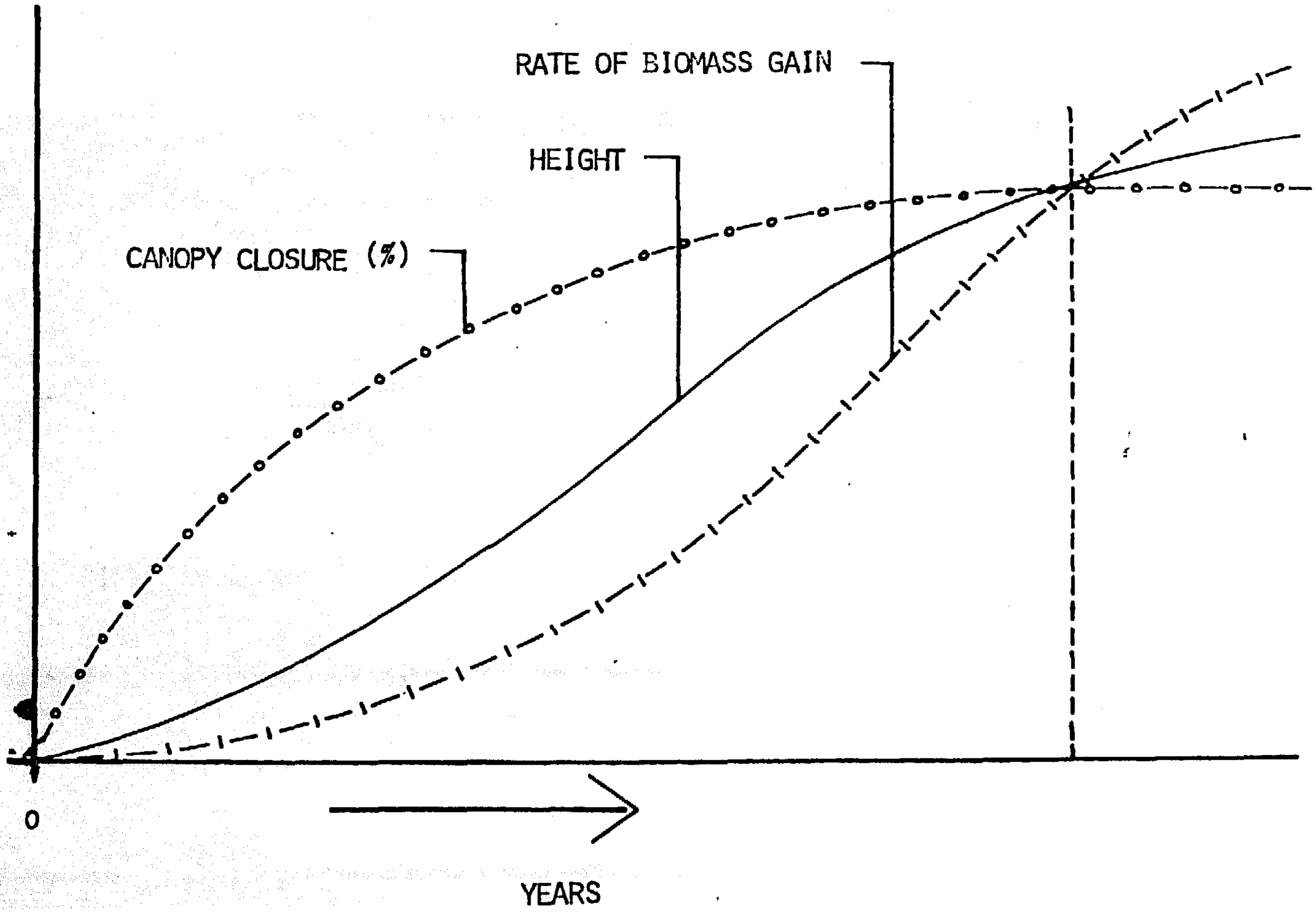
4. PROCEDURE

In order to conduct an optimum planting and any subsequent thinning program, it is desirable to understand the basic physiology involved in coppicing. The pattern of growth through several cycles is as follows:

4.1 FIRST CYCLE

The initial status of the newly-planted plantation consists essentially of single shoots. During the first year, under favorable circumstances, these grow 4 - 10 feet . During the second year height gain is reduced relative to lateral branch growth, and stem diameter increases; the lateral branches fill out to occupy the available canopy space; by so doing they shade much of the ground completely for much of the day. During the third year most of the overstory has become closed, and the understory largely disappears. Competition between the shoots for available light, (micro-nutrients being assumed adequate for all) spurs further height and branch increase to fill the overstory lacunae completely. At this stage the overstory canopy is closed. Now the annual rate of biomass increase will cease to rise, and further gain will become linear. The shoots will be some three inch or more diameter at three inches above ground. They should now be harvested for fuel, for not only is the curve for annual incremental woody mass gain beginning to flatten, but the sprout yield for the next cycle from these small diameter stumps will be at its greatest (61.29); Figure 4.1 shows this.

FIGURE 4.1



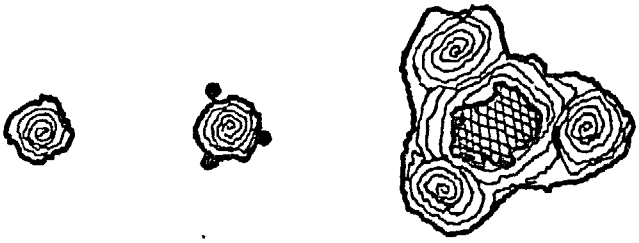


FIGURE 4.2

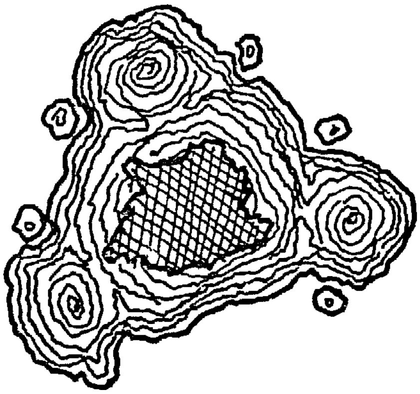


FIGURE 4.3

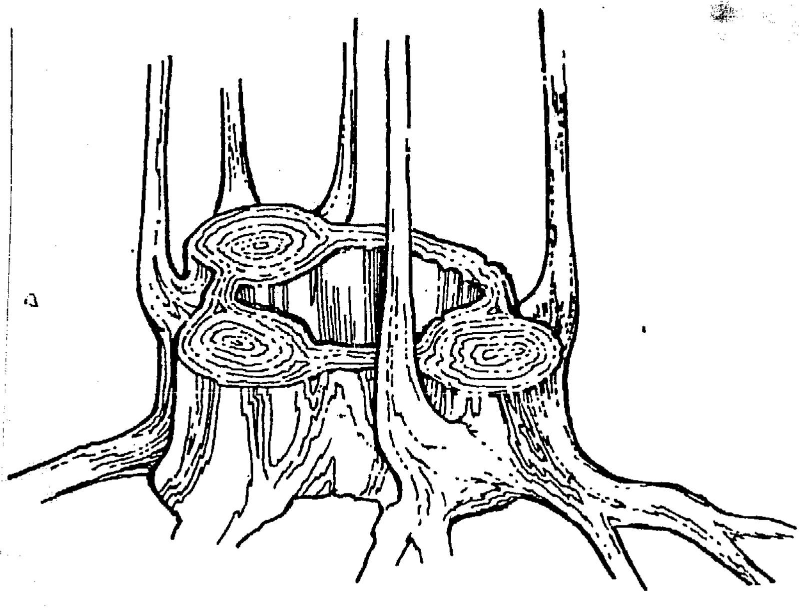


FIGURE 5

4.2 SECOND CYCLE

The stump is some three inches diameter. Two to six dormant buds will activate during the winter, and will sprout next spring. During the same winter a number of adventitious buds may form in the damaged cambium of the cut surface; they also will sprout: the taller the stump, the more upper adventitious buds will it form, and the fewer will be the number of lower dormant buds that become activated.

The competition between all these will be intense, and the resulting growth will reach closed canopy density before useful height has been achieved; thus the annual biomass yield even this first year may be lower than the maximum attainable. To prevent that, culling is essential. Either all but one of the buds on each stump can be rubbed off by hand, retaining only the strongest one at the root collar; this will maintain the original one stem per stool ratio. Or alternate stumps can be grubbed-out and the survivors allowed to carry two or three stems each. Either alternative will maintain stem density the same, but grubbing out secures a more robust root system, and is usually preferred. Under this management, during the next cycle, the remaining shoots will grow away strongly, and their associated roots will spread widely. The stump will grow further in diameter. Harvesting should again be as low down the stem as possible.

The next, third, generation of sprouts which follow this harvest will develop either from the stump of this second generation shoot, or from the root-collar region of the original stump. On the assumption that each stump produces three viable sprouts, this cycle would produce up to nine strong shoots. That is certainly too many, and it should be reduced to four or five at the most. Further grubbing-out of the unproductive stumps continues, so keeping the overall stocking rate of stems constant. At this stage the stump numbers will be considerably less than the initial planting rate, especially if that was by seed.

Nine to fifteen years will now have elapsed, and the final pattern, stocking rate, and best husbandry techniques for the prevailing local conditions will have been learned.

By this time the first cycle stump will have succumbed at its center to fungal infection, and will have rotted away to a greater or lesser extent. This is inevitable in most species that are coppiced, since the center of their stump, which in the intact tree would at this stage have been converted to heartwood, will not have been converted, and so will not have any resistance. Thus the original stump will now be hollowed out, and the stump section will most likely appear as a ring of thickened, distorted, peripheral wood and bark (Fig. 5) carrying 9 sprouts. Clearly, if this stump is relatively high, and the sprout is allowed to grow past 5 years to 25 and even to 75 for timber, as was also practiced in earlier days (05.00) then this heavy shoot, connected to its root only by that strip of ancient peripheral stump, will fall over in high wind or heavy snowload. This is the reason why the distance from base of sprout to origin of root must be managed by careful husbandry to zero. Therefore high adventitious buds must be discouraged from forming, and basal dormant buds must be encouraged to grow - hence the injunctions to lop as close to the ground as possible (06.00).

4.3 THIRD CYCLE

After lopping and harvesting the second cycle, the stump will be as in Fig. 4.2. The third generation sprouts will develop on the second generation stumps, (Fig. 4.3): and by the time these are ready for harvesting, the stump complex would initially be as in Fig. 5.

There are two points to be noted here. Firstly, that even if each cycle of sprouts is grown to the same desired diameter as the last before it is harvested, each generation of stumps continues to increase in diameter from the normal addition of concentric rings of cambium.

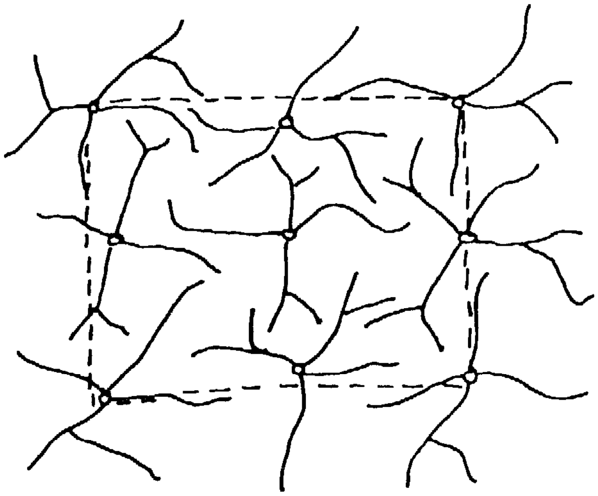
The second point is that this simple pattern implies that the same unit area of ground must support more sprouts at each cycle - in the scheme illustrated, at a cube law rate - and indicates that if we select the optimum shoot/acre stocking rate correctly for the first planting, then at each successive harvest we shall have to grub out two in every three stumps. In other words, we have opportunity to be selective, and to choose to eliminate the less healthy stumps while favoring the progression of the most productive into the next cycle. Seen in this way, it may indeed be more economic to use skilled judgement and hand labour for the culling program rather than to cut out by machine.

I have demonstrated this pattern in triads for emphasis, and assumed that all three sprouts flourish equally. In practice only one or two will usually grow vigorously, but the principles of husbandry remain the same - maintain optimum sprout numbers per unit area.

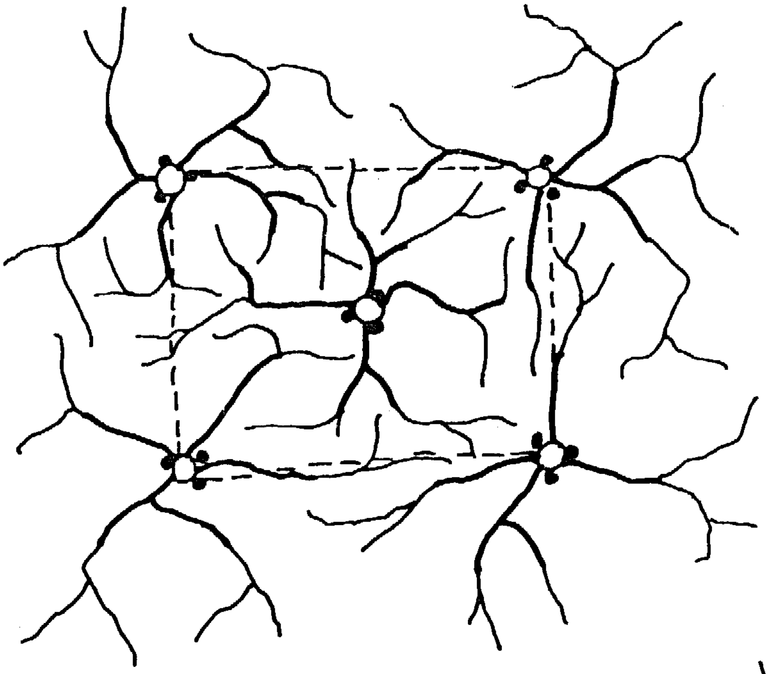
If husbandry - that is, the culling and harvesting - is conducted with the logic that these principles suggest, then culling of sprouts and grubbing-out of stumps will be continued in such a way that the number of developing sprouts per acre is kept constant at the optimum productive stocking rate. By this means the soil volume which had been occupied by the root systems of the stumps just removed will become vacant for infiltration by the remaining root systems. In this way the the surface of the above ground area which is trapping solar energy, and the volume belowground which is absorbing water and micronutrients, will be fully occupied all the time. The root growth pattern which ensues is illustrated schematically in Figure 4.5.

4.4 SPROUTING PROPENSITY

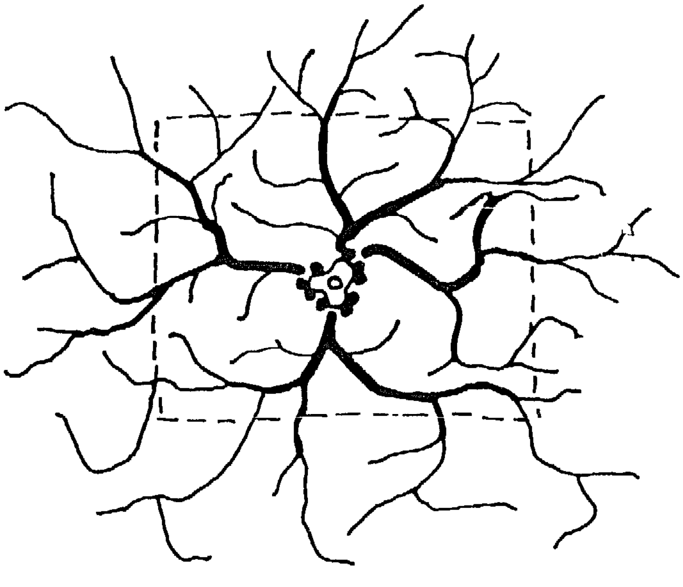
The available information about the sprouting prospensity of the different species is not all in agreement. From what has been said already, it will be evident that this depends not only on species (61.29, p.10) but also on cycle duration between harvests, diameter of stem at harvest, (61.29, Fig. 3) height of lopped stump, age of shoot at harvest, average climate, season of lopping, and severity of the winter at the time of lopping, to mention only the chief variables. These will in turn be perturbed by many sub-variables, for example: prevalence of fungal infection immediately after lopping.



FIRST CYCLE



SECOND CYCLE



THIRD CYCLE

FIGURE 4.5

Conifers do not sprout after lopping at merchantable size; but it is worth noting that some species at least will sprout from the stump year after year if they are browsed when small (61.28).

Almost all hardwoods sprout well after lopping (hickory is a notable exception) (62.33). Table 2.1 lists species that have been reported in published literature.

Our native chestnut, which was as widely coppiced in the USA as its European conterpart was on that continent, succumbed to a fungus infection introduced on some European inportations in 1912; by 1920 our native species was practically extinct. It sprouted freely from young and from intermediate diameter stumps, but not so well from fully matured trees. Redwood (Sequoia sempervirens) exceeds the sprouting propensity of chestnut, and retains this ability to a great age (1000 years or more). In parallel with this, its sprouts grow away extremely fast as compared with its seedlings: 2 - 6 feet in the first year as compared with around 7 inches (60.19, pg 9). I have found no record of deliberate coppicing of redwood on a short-term cycle, which is strange, since it would seem to be especially well suited to this: mean annual increments of up to 6000 board feet/acre/year of merchantable timber has been recorded (25.29, pg. 100); this represents 10 tons/acre/year, or a total fuel wood productivity, when we include branches, of 15 tons/acre/year; and trials have shown that the normal growth rates can probably be doubled by good husbandry (25.29, pg. 161).

4.5 THE ROOT SYSTEMS

After the first harvest all the new sprouts grow fast, by using the food stored in the root which was supplying that region of cambium. Those which are on the main-stream of a root will grow away faster than those which are poorly situated in relation to the sap-flow. Competition will produce some natural lopping; but it is beneficial during the second cycle to reduce the number of sprouts per stump to two or at most three, depending on the evident root formation. When the surviving shoots are well grown, each will have developed its own root system, and radio-tracer techniques show that these root units are independent of each other (62.63); in other words, each is a distinct tree; the units from any one stump constitute a clone.

For any plant, while the soil is moist, the root-hairs absorb water freely; but as water is progressively withdrawn, and conditions begin to approach wilt-point, the roots extend, new rootlets and root-hairs grow, and the older ones in the dry zone die and are eventually bio-degraded. When the soil becomes wetted again, new roots with their root-hairs develop nearer to the main stem, and the peripheral root growth stops, and may die back to a greater or lesser extent. These new proximal root systems will absorb some of the products of biodegradation of their predecessors, either directly or after passage through the soilorg metabolic sequence. In much the same way, when the seedling is lopped, and also when the second cycle shoot is lopped, the distal roots die off, and new ones form proximally in association with the newly developing sprouts.

This general picture of root formation is overlaid by another one of equal significance: in general terms, the main roots and their subdivisions develop in step with the main branches and their subdivisions, so that any one radial segment of a shoot surface is almost in continuous relationship with any one rootlet: the organization of a complete tree can be visualized, in some ways, as comparable to the wiring harness of an electrical equipment. When the shoot, or one of its main branches is lopped, its associated root has no further source of photosynthetic nutrient, and its water and micro-nutrient take-up has nowhere to go. There is thus a considerable die-back of the large root system after lopping a large shoot, even when it sprouts freely; but if the shoot is lopped while still small, a bud may obtain sufficient nutrition from the root reserves to grow away quickly, and may then be able to photosynthesize sufficient sugars to feed the root-system before it suffers severe die-back. In that case, the shoot can reserve most of its photosynthetic activity to furthering it own growth, and will need to divert but little to forming a new root system - it need only provide the basal metabolic needs of the old root instead of having to bio-synthesize new root mass. Coppicing husbandry seeks to optimize this strategy for storing new photosynthesate above-ground, and reducing the demand below-ground. Short cycles (3-5 years) secure this.

It has been reported for apple orchards that, under such conditions of dense root occupancy of the soil volume, roots from neighboring trees that cross over each other will graft together as they increase in diameter with their annual concentric growth. I have not yet found any evidence reported that nutrients flow freely from one to the other, thus suggesting the formation of a true syncytium, although there is no reason to suppose that this could not occur. On the other hand, fungal root infection certainly could spread from one tree to another across this (apparent) union. Indeed, transfer of water and some solutes could occur across this gap, even if true syncytial communication does not occur; the fascinating mechanism whereby the cotyledons of the germinating chayote fruit transfer water and nutrients from the storage testis to the growing seedling provides such an example.

In this way an infection can spread quickly through the densely planted coppice: planting in bands of different species will reduce this risk.

4.6 SENESCENCE

It has been suggested that although the new shoot system necessarily has some of the attributes of youth, it is being supplied by a root system of a definite age, which will reach senescence at about the same time as it would had the tree been intact throughout the period; and that therefore the productivity of the stool will diminish as that time approaches, and death will occur at the fore-doomed time. But this is maybe an unnecessarily anthropocentric concept. For all practical purposes, a tree is a new structure each year, thinly spread over and around last year's tree. In this view of the model, a tree is more analogous to a coral reef than it is to an animal; and so long as the coral reef continues to receive nutrients, and other factors are suitable, it will continue to grow. A climax forest eco-system has attained steady-state for all its essential micro-nutrients, which recycle from the leaves to the roots and back again during precipitation, leaching (34.30), and leaf fall (34.71); small losses in the water and soil are replaced by wind-born dusts and by solubilisation of soil constituents. I have already described how the root system itself is renewed not only at each harvesting, but at each dry-wet weather cycle. Under these conditions, if there is no interference other than felling and laying the entire biomass on the forest floor, juvenile vigor may be able to continue indefinitely conjoined with mature stability. It is only when the crop is removed, with its stored micro-nutrient reserves, that the eco-system will become repidly depleted, and then re-growth dimish and finally cease after a number of cycles which will depend upon local circumstances. However, this can be prevented. If the wood is destined for fuel, as in a boiler for generating electricity, the micro-nutrient pool can be maintained after harvesting by returning the furnace ash to the harvested site. At the same time the soil energy reserve can be maintained by scattering a proportion of the harvested chips back onto the surface of the soil during harvesting. And both micro-nutrients and energy can be sufficiently topped-up by applying municipal refuse to the soil, as I describe later.

4.7 HARVESTING

Harvesting coppicewood for use as fuel will in most instances be done by machinery which converts the biomass to chips as it travels down the rows. This machine will need to be designed to meet certain basic criteria, which are well recorded in the literature of hand-harvesting, so that the yield from the next cycle will not be reduced.

For best sprout formation for the next cycle, harvesting must be done only during the first 2/3 of the dormant period. This insures that the vestigial buds can mature sufficiently for early growth in the spring. Lopping must be done close to the ground at the first cycle, and as close to the base of the sprouts on subsequent cycles as possible. The bark must not be torn away from the stump edges during lopping. After a number of cycles the enlarged rim of the stump will be knotted and gnarled; it must then be trimmed back evenly almost to ground level. Fungus infection of the center of the stump should be discouraged for as long as possible. This is achieved by obtaining a sharp cut, as by an axe or hook in preference to a saw; and the cut should be lower at the outside than in the center, to shed water. Care must be taken not to shake the tree while lopping, since that would damage the roots; this means that for large-diameter sprouts a saw-cut may be better than repeated blows of an axe.

A large-scale coppice is at all stages of the cycle a highly abnormal eco-system, and some novel husbandry techniques may be needed. For example, it is likely that higher sustained yields will be obtained over a period of several cycles if each row is cycled on the contour and out of phase with its neighbors: on a 3-year cycle this would mean that the 3rd year growth can protect the neighboring first-year regrowth from sharp winds. It will also provide much better erosion control and protection from avalanche or rockfall.

4.8 SOIL PREPARATION

Aeration and Drainage

For all these practices the soil should be well prepared beforehand, preferably one full year in advance. The soil should be dug to at least 24" depth, to assist deep root-run for water, in such a way that the A and B horizons remain at their proper levels. The ardous technique of achieving this with a spade, by double-trenching, was well described in 1825 by Cobbett (62.24, pg. 31) who with his characteristic attention to practical detail, advises that the laborers are paid by the day, not by area trenched, to ensure that they dig deeply and carefully.

Enrichment

Into the topsoil should be mixed a good woodland type compost. This should have been prepared a full year ahead, and should if possible contain a significant proportion of chips of the same species as the nursling being propagated.

A portion of those chips should be derived from roots of well-established trees of that same species, or else they should have been seeded with mycorrhizal and rhizosphere micro-organisms by using leaf-litter collected from beneath well-established trees of that species.

If proper attention is given to the species' needs for provision of commensal soilorgs, the precise composition is probably not important: other basic cellulosic materials for the compost mix are likely to be just as successful, providing that they are matured and seeded with commensals: composted urban refuse, which had a brief explosion of enthusiasm in the 1960's, is likely to be re-introduced soon with greater success now that the biological processes involved are better understood, and that more robust and reliable shredders are available. The program for incorporation of raw shredded refuse with agricultural sopsoil that is now being used as the sole disposal method for solid waste at Odessa, Texas, a city of 100,000 people, is a variation which is expected to be as effective as compost in improving the soil, and it also offers important savings both in dollars and in energy over composting (63.30), as I describe later.

In temperate climates with 30 inches or more annual rainfall, an application rate equivalent to 10 dry tons/acre, well mixed into the nursery furrow throughout a cross-section of 12" x 12" should be adequate; in hotter and in drier climates the rate should be increased.

Weed Control

No matter what propagation technique is used, the over-riding requirement in good soil is weed control during the first 2 years, while the nurslings are under 8 foot high. Since both the taller unwanted competing weeds and the desired nursling trees are dicotyledon, herbicides will be recommended only under special circumstances. Surface discing to destroy the weeds will form a surface mulch; this will further encourage the surface feeding rootlets which are normal to most trees, but the next discing will destroy most of those along with the next crop of weeds - a self-defeating program. Thus continuous control by hand-labor is preferable.

But if the area planted is too great or if labor costs are too high (as they mostly will be in technologically developed countries) it may be better to omit hand-weeding, and to mow the weeds frequently between the rows, as close to the growing canes as possible; this will hold down most of the weeds that are competing for light, and the close-cropped cover that is competing for nutrients in the soil will be recycled by conversion to mulch and then to humus by the repeated mowings. But great care will have to be taken not to damage the bark on the stumps, for that would destroy the root-shoot continuity at that point. By the end of the second year in a new plantation, the canes will have developed sufficiently to outstrip the weeds, and groundcover will die back. However, weeds cannot be lightly dismissed: on Dr. Kardos' trial woodland in Pennsylvania I saw herbaceous weeds 8 - 10 foot high in a clearing in his woodland test area which had previously been generously supplied with nutrients from treated effluent sewage water; they totally suppressed tree shoot growth (40.47).

5. AN ALTERNATIVE TO LANDFILLS AND SEWAGE PLANTS

The proposal that a coppicing program be combined with a program for disposal of urban wastes (B3.86) will be seen to have many advantages when examined with these factors in mind. Refuse contains a wide spectrum of metals, and no matter how thoroughly it is sorted, and the valuable recoverable metal constituents are first removed, a fraction will survive in the residuum and be available as micronutrients. Furthermore, this residuum is almost entirely of plant and animal origin - that is, it is biodegradable by the soilorgs, and so can provide the energy source that they need. Indeed, since these residues are some 60% paper, and since paper today is largely wood pulp, the solid waste stream can be considered as a homogenised forest litter surrogate inoculated with a broad spectrum of essential trace metals. This refuse is laid directly onto the soil surface after harvest or after the first year regrowth. This refuse can either be raw or treated only by shredding and removal of the marketable constituents, and allowed to compost on site; or it may be pre-composted before application. In either event, it will be covered by normal litter-fall during the next growth season, and quickly assimilated.

TABLE 5.1
COMPOSITION OF SUBURBAN REFUSE, BY WEIGHT

Paper and packaging	60%
Food wastes	10%
Garden refuse	10%
Metals	10%
Inerts (including plastic)	10%

In the same way treated sewage effluent, both sludges and water, are a welcome addition to a coppicing program, not only for their nitrogen content but also for the micro-organisms which they contain. If they also happen to contain dissolved metals to excess (as, for example, chromium or mercury) the prime source of this pollution should be restrained, since not only could these metals be vaporized when the wood is burned, and so contaminate the stack gases, but they are also too precious a resource to waste heedlessly.

Some figures may illustrate the benefits. We will assume a city of 100,000 people; that they allocate 300 km^2 for coppice; that they each generate 500 litres of sewage daily, and 1 tonne of domestic refuse each year; that the coppice is harvested on a 5-year cycle; that sewage and refuse is landmixed into agricultural land for 215 days of the year, and onto the coppice for 150 days: then the sewage will be applied at a rate of 125 mm/year (additional to the natural rainfall of 750 mm or more, so it is a useful addition), and the refuse will be applied at a loading rate of 0.685 tonnes/ha (in a mature deciduous forest the litter-fall is about 3-4 tonnes/ha/yr. (34.43, 35.30). Both of these loadings are well within the capabilities of the eco-system to digest; indeed, we could be glad to have that loading every year. These figures will increase proportionately if harvesting is on a 4 or 3 year cycle.

Obviously this program has multiple benefits: the waters are efficiently cleansed ("the living filter" concept, 40.47), the nitrates in the sewage stream are used productively instead of recklessly wasted (10.04), and the demands for landfill sites, the costs incurred by them, and the nuisances that occur from them, are all eliminated (63.30). Indeed, it may well be possible in the future to reduce of even to eliminate the traditional sewage treatment procedures if adequate isolation of the public from the application site can be secured. (62.48)

To use the coppice as an ultimate sink for city refuse and sewage, and to provide clean fuel and clean water in return, will provide considerable savings both in capital and in running costs over present practices. The resulting enhancement of the environment and provision of afforested recreation areas are attractive spin-off benefits.

6. PROPAGATION

Propagation can be by seed, by cuttings, by plashing, and by layering.

6.1 SEED

Seeds planted in a nursery bed should be lifted at the end of the first or the second year, according to species and size; the main tap-root should be trimmed to 4 inches and the side-roots shortened; this encourages a balled fibrous rooting pattern, and makes it much easier to transplant in the second or third year. A swifter, cheaper method, but not so good, is to leave the seedlings in the bed, and to draw by tractor a sharp root-cutter, set a 4 - 5 inch depth, below surface level. At the same time, the stem should be cut at 2 inches above ground-level, with a single strong sweep of a sharp knife - not by secateurs and not by cutting against a surface, since both these techniques will crush the tender bark. The following spring, one or more dormant buds at the root collar level will sprout vigorously. All except one should be rubbed off at an early stage. By the end of the second year of this sprout (that is, the third or fourth year of seedling root) the sprout may be some 8 - 15 feet high, whereas the unlopped seedlings will be only 4 - 8 feet, even though they have not been checked by this lopping. (62.24, 61.28). The original seedling stump should now be trimmed off close against the sprout, which will soon grow around and encorporate it into its center. Planting out to final site will be at the fourth year; and first harvesting may be made in 3 - 5 years after, that is, 6 - 9 years after germination.

6.2 CUTTINGS

Cuttings should be of well-matured one-year canes, some 8 - 24 inches long, planted slightly sloping to the vertical, with 2 - 6 inches above ground. (62.24b, pg.90). They must be planted in an open hole or trench; they must not be pushed into the soil, for that drives soil particles between the wood and the bark, and so splits the cambium layers. For some species it may prove advantageous to score or to twist the canes, as described below for plashing, before cutting into shorter lengths. In the nursery they should be root-pruned and the sprout cut back as for seedlings; but if set out in the plantation then only the sprout should be pruned. In all other respects husbandry is as described above for seed.

6.3 PLASHING

This is a term used for laying long lengths of cane horizontally under the soil level. Well-matured canes of current season growth are used. The tops are trimmed off at about half inch diameter, and the bottoms at about 1 inch diameter, resulting in a cane some 3 - 5 feet long. These are laid end-to-end in shallow trenches in soil prepared and enriched as I have already described. They are placed some 3 - 5 inches below soil level, and covered over.

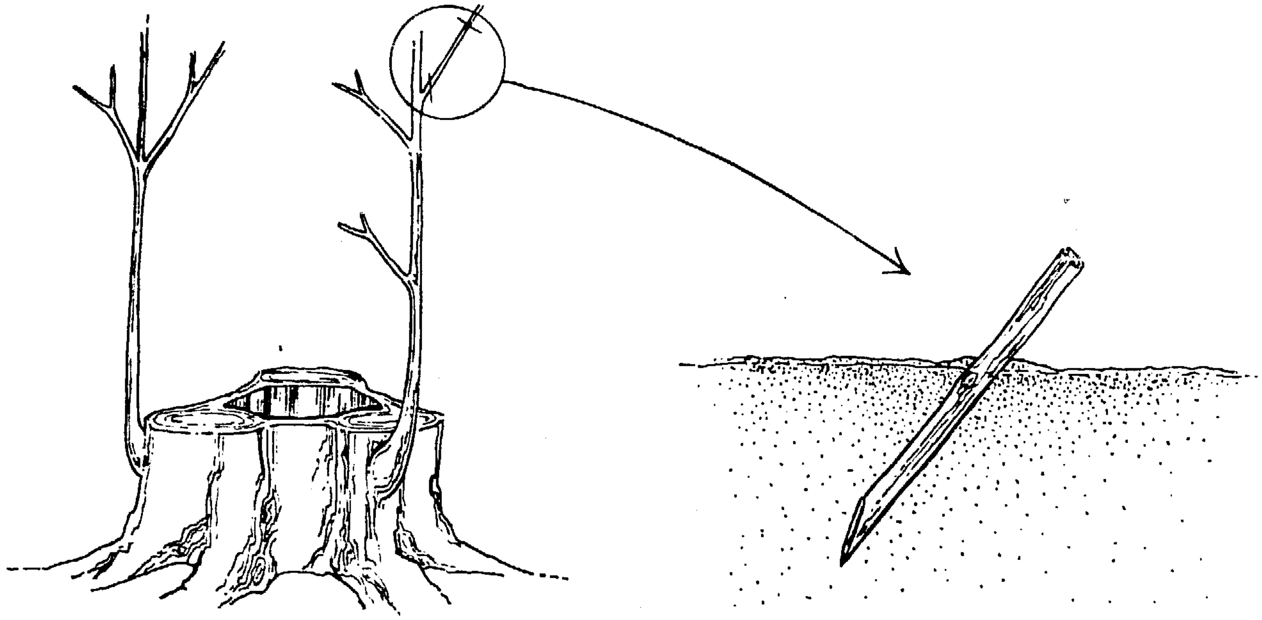


FIGURE 5.2 TAKING A CUTTING

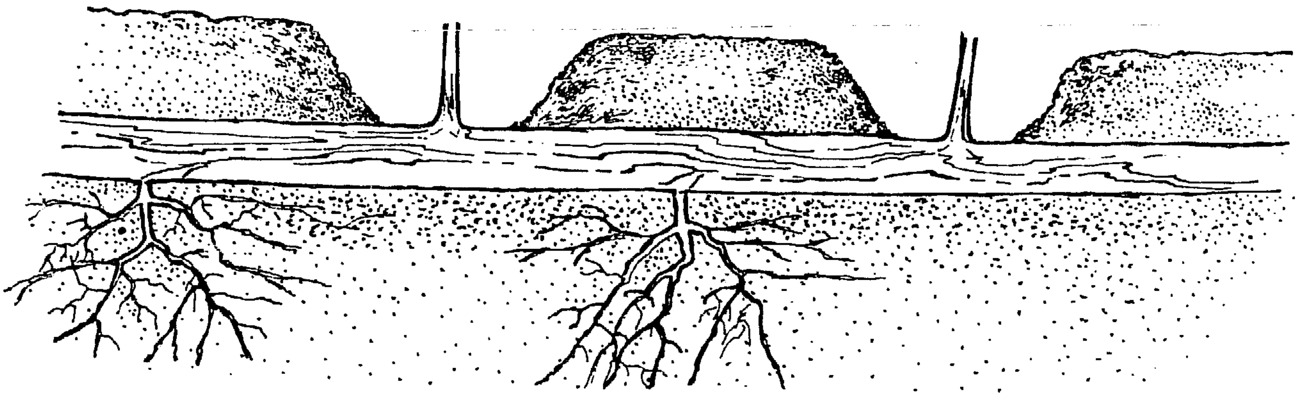


FIGURE 5 . 3 PLASHING

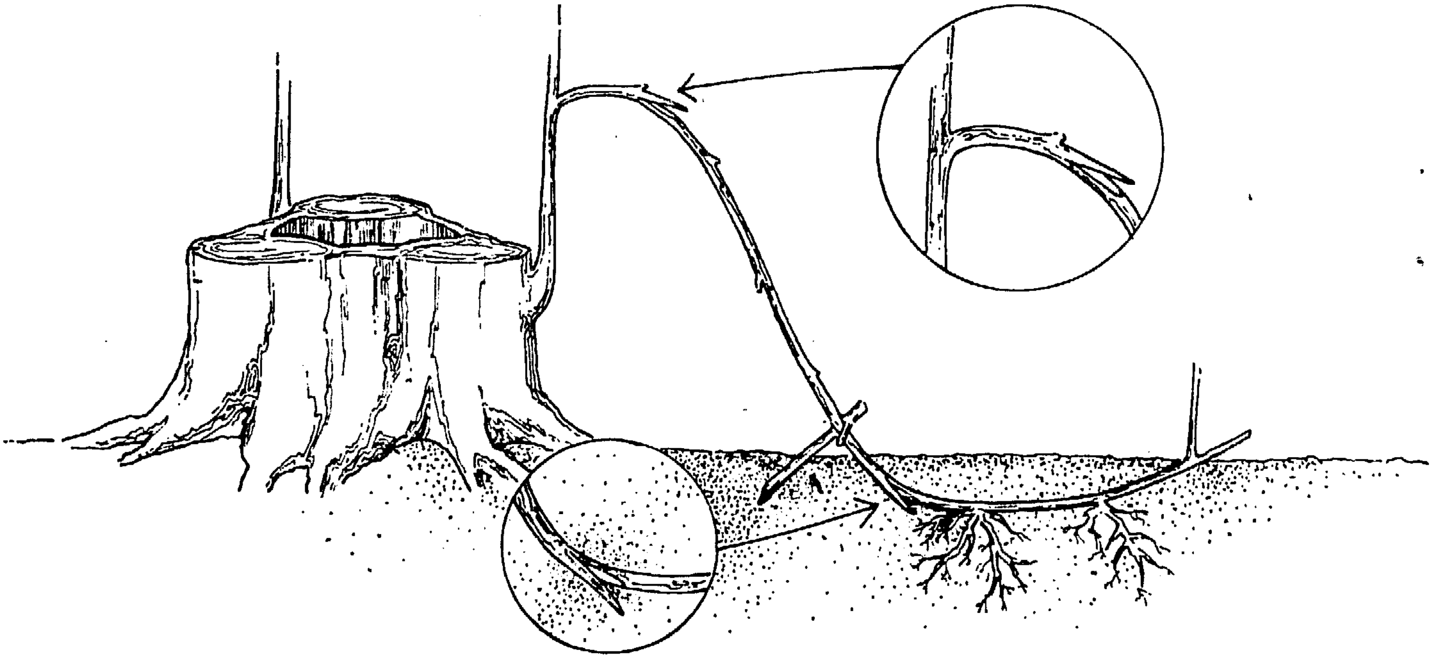


FIGURE 5.4 LAYERING

Sprouts grow from the dormant axillary buds, and roots form at the base of those sprouts, and at the bottom cut end of the canes. The greatest number of sprouts form at the top half of the cane (62.31). This results in uneven spacing of the sprouts, which is undesirable. However, adventitious buds can be encouraged to form all along the cane, by two techniques. One is to split the bark longitudinally with a sharp knife down to the cambium layer, at several points along the entire length of the cane; the other is to grasp the ends of the cane firmly, one end in each hand, and give it a sharp spiral twist; this ruptures some of the cambial cells under the bark without resort to the knife. Not all species will respond to this treatment, but it is the preferable method of the two since it maintains the integrity of the bark and so offers less opportunity for infection by pathogenic fungi. Sprouts will form freely along the whole length. In some species shoot spacing can be further controlled by removing the topsoil over the cane for 6 - 8 inches at selected intervals; sprouting is favored at those parts which receive daylight, while roots are favored at the fully covered parts.

6.4 LAYERING

Layering is usually applicable only in an established coppice. Where the forester observes an area where a stump has died, he bends nearby canes over, buries them as for plashing, and pegs each down with a crook. Care should be taken to maintain continuity of the conducting layers from roots to cane; when the cane is of larger diameter, and bending down to soil level could tear it off the stump, the upper face can be slashed longitudinally to half diameter to assist bending. It is practical to perform this while harvesting, when that is done by hand; where mechanical harvesters are used, layering will best be done a year or two before harvesting, so that the new sprouts will be lopped automatically at the end of their first or second year's growth (see 1. above). This slashing technique, so extensively practiced in Europe for the woven live hedge, has the merit that the layered cane remains in live continuity with the parent stump, and its own root system, and so can and does form sturdier sprouts than before the root development would be able to support if the cane were free planted - plashed. I have not read anywhere of applying the bark-slitting technique which I have just described for plashing, to the layered cane; it should give prolific sprouting. Under modern conditions layering may prove to be the best way of establishing large nursery stocks quickly, and of protecting them from the vagaries of sudden drought and other uncontrollable variables.

One other point of interest - the slashed edges also sprout prolifically, so establishing the next generation of canes while the previous one is still being layered.

Once the new sprouts have developed their own root systems, the slashed section is severed, as also is the cane between each sprout; and the shoots are now treated in the same way as are seedlings.

6.5 SEEDLING AND SPROUT VIGOR COMPARED

An alternative strategy to coppicing would be to plant seedling or seed and to pull it up, root and shoot, after 3 - 5 years and then plant anew. But the biomass yield by this practice are not nearly as great as by coppicing, since a number of factors combine to provide a large increase in productivity of the sprout as compared with the seedling. (i) As a direct result of the advantage given to it by the large food reserve available early in the spring from the roots stores, the thick sturdy young sprout is able to develop leaves which are larger, in greater number, and quicker, than can the emerging seedling. (ii) Its leaf area, and therefore its rate of photosynthesis, is greater, and it can therefore photosynthesize more, as this competitively beneficial spiral is developed. (iii) The photosynthesate can be entirely devoted to building up more pre-existing shoot, since the roots already exist. (iv) No energy need be expended in forcing roots through the soil; channels already exist. (v) The leaf and root system is in equilibrium with its competitors - that battle is already won, and there is no need to divert photosynthate into making allelogens or other defensive/offensive mechanisms.

6.6 ALTERNATIVE STRATEGIES

The quickest and probably the best way to optimize yield from any given soil will likely be to work with local woody species, to select the ones that are most productive under coppicing management, and then to find out the planting and harvesting conditions which suit them best. This strategy will likely be better than importing exotics and trying to alter circumstances to suit them. We should probably avoid irrigation and fertilization as being energy-demanding short-term, and counter-productive long-term. We also should take a hard look at the relative merits of accepting low yields out of small areas. Huge areas of semi-arid land are available which already grow mesquite, creosote-bush, and saltbush. Mesquite is a woody legume which nitrofixes, and is notorious for its sprouting propensity; much work has already been done on Atriplex, and especially on its C3 and C4 varieties (62.54). Perhaps we should start selecting for these semi-arid regions not on the criterion of productivity per hectare, but on productivity per liter of water or per millimeter of annual rainfall ("photosynthetic water-use efficiency"), as is already being adopted for range grasses (34.58), but xerophytes require much less, and C4 varieties require only 1/5 as much per gram dry-weight for photosynthesis as do their C3 relations (62.54).

7. DISCUSSION

The information which I have given is gathered in part from practical guides to sylviculture and to farm husbandry which were written in Europe and in the USA during the Nineteenth Century, which I have blended with modern scientific knowledge of plant physiology and with modern sylvicultural research reports. In some ways these do not readily mate together, for much of the earlier advice on husbandry is based on long father-to-son experience working with cheap hand-labor and no machinery, and with marketable fuel very much in mind; while modern work is predicated on free use of agro-chemicals and machinery, with paper-pulp in mind; hence any advice which entails personal attention to individual sprouts may, in practical terms in the USA, be irrelevant today. The older experience and advice is nonetheless sound, and it may be applicable in other countries on a large scale; it may also be valuable in the USA in nurseries and in trial plots, especially where swift buildup of high-yield clone stocks is desired and the value of the harvest justifies extensive hand labor; it is therefore worthwhile to include it here.

There are many avenues for increasing coppice yield, and these can be the more successfully pursued and evaluated now that we have so much more insight into the physiology of soil and plants, and into the energetics of photosynthetic transduction pathways. In hotter, drier areas the merits of the C^4 pathway will be explored: for example kenafe (Hibiscus canabinus) has already come to the forefront as a high-yielding crop which works efficiently either by C^4 or by C3 pathways, depending on local conditions. (62x62). Doubtless there are woody relatives of this species which either already have this ambivalence, or in which it can be developed; and intermediate species have been reported recently (63.31.) More sophisticated planting programs may give higher yields: for example, interplanting lower yielding but nitrofixing alder, false acacia or mesquite with other, main crop high yield species. Commercial attention so far has been given almost exclusively to developing improved coppicing varieties of species that are presently grown for their stems; attention should also be given to species which do not normally form stems, but which thicket readily; these are predominantly found at the edge of the woods, in the forest-field ecotone; for example, hazel (Corylus avellana), was extensively coppiced in the past to provide barrel-hoops (62x60); now we should try lilacs (Syringa sp.) which sucker profusely, and redbud (Cercis canadensis) which thickets well and which, being a legume, also nitrofixes. The advantages of planting beech as a transient nursery shield to young conifers are well known, and it is an accepted silvicultural practice. But the possible advantages of planting conifers as a permanent nursery shield to coppices remain to be explored and evaluated; many advantages are foreseeable; wind shield to the tender young first-year sprouts after each harvest cycle, nitrofixing on the phyllosphere (37.11) and by the epiphytes on the mature conifer bark (38.01), and the eventual high-quality timber yield of these conifers themselves. There is no danger that their seedlings would take over the hardwood coppice; coppice forms a light-excluding canopy quickly, and conifers require a higher light intensity than do hardwoods; further, any conifer seedlings that did survive would be killed by the next cycle of harvesting, since conifers as a class do not sprout except when very small. The virtues of coppicing for flood-control offers new dimensions to the Corps of Engineers: tree roots and shoots are far more resistant to flood-waters than is concrete; they are largely self-repairing after damage, and they are more aesthetic. Channel verges should be planted to coppice not on the contour, but herring-bone with the apex upstream, so that silt and debris get washed and held higher up the bank while the flood rises, and so leave the water clear as the flood subsides. On a 4-year cycle, harvesting will be done on every 4th row, to maintain this comb effect along the banks. But perhaps the greatest advance will be from the combination of coppicing and urban wastes disposal, especially on land ravaged by opencast strip-mining, on the landmix principle (40.48). Following the lead provided by, for example, Germany, legislation now existing or pending at state and federal levels in the USA will make it mandatory to restore the fertility of land and the purity of the waters to standards as good or better than were found previously in that particular locality. The topsoil on these lands will benefit immediately by being loaded with biodegradable urban wastes, and conversion to coppice will then provide an inexhaustible fuel reserve to replace the fossil fuel seam that has been removed.

Opencast mining companies do not yet appreciate the long-term profits that they can obtain for their shareholders by an integrated approach to using their real-estate: the powerful machinery which they routinely use enables them to sculpt lakes and hills as they mine. If they make these to a plan instead of, as at present, haphazard, they can plant fuel forests, build new cities on the lakes and supply electricity to their populations from generators fueled by their forests and cooled by their lakes; designed on the agro-city principle, these cities will be in positive energy balance (23.04, B3.85).

Coppicing is an attractive program for LDCs which have no ready source of fossil fuel, have reasonable rainfall, and have a need to introduce electrification. Their peoples are accustomed to agriculture, and can plant out the seedling nurseries, and later the plantations, by hand: the sympathy, the skills, and the man power are all available. Once the large-sized coppice is well established, and the benefits of the resulting electrical supply and the accompanying trend to urbanization begins to drain workmen from the land, the higher overall income level and technical skills pool will also have developed enough for a transition to increasing mechanization of management to occur smoothly. And of course the actual capital requirements for the coppicing program both in technology and in currency are well within the range of the poorest LDC.

8. GLOSSARY

Bole	See stem
Cane	A 'reasonably' straight length of shoot, free from side branches. A side-branch, by this definition, can also be a cane.
Coppice, Rough	An existing mature forest is felled for timber, and allowed to regenerate spontaneously by sprout and by seed. Thereafter it is clear-felled at shorter intervals for coppice-wood.
Coppice, Row	Nursery stock is planted at close intervals in regular lines for routine short-cycle harvesting.
Cycle	The period of time between one harvesting and the next; usually 3-5 years for fuel and pulp, 4-10 for stakes, and 8-50 for poles.
Lop	The removal of a shoot or a branch by normal process, by accident, or by design, e.g., by die-back, browsing, windblow, fire, axe, saw - or in any other way.
Nitrofix	The program by which atmospheric nitrogen is combined with other elements into compounds that are assimilable by plants: e.g. by soilorgs, by algae and lichens, by legume nodules . . . and by industrial factories. Hence nitrofixate: any nitrogen-containing compound which is assimilable by plants: e.g. ammonia, sodium nitrate, amino-acids . . .
Nursling	The propagate tree while in the nursery, and during planting into its final position in the plantation. This term therefore includes a seedling grown from seed if the seed is planted in its final position in the plantation - i.e., it will not be transplanted.
Overstory	The treetop leaf-cover; considered either as an energy transducing mechanism for ultimate storage in wood, which can be harvested; or as a ground-shading system.
Phosyn	Photosynthesis, hence phosynthate
Pole	A harvested cane with a minimum diameter of 1 inch, and of any maximum diameter, and of any length as may be required.
Seedling	The maiden growth from the seed. By this definition a mature tree can still be a 'seedling'.
Seedling Sprout	The growth from a seedling which was lopped while less than 1 inch diameter.

Shoot	The above-ground stem and branches, with or without leaves; this term applies to maiden (seedling) growth and to sprout growth.
Soilorg	I know of no word that is acceptable to soil microbiologists and also to plant biologists to indicate all the organisms - virus, bacteria, actinomyces, fungi, nematodes, worms, soil-dwelling insects, soil residing pupae, worms, . . . that contribute to the multitudinous and complex bio-degredation and biosynthetic pathways in the soil, on which plant roots are in a sense saprophytic, and with which they are in another sense symbiotic. I offer the word 'soilorg' to fill this need.
Stem	The primary growth of seedling or sprout from origin at ground or stump up to the first significant side-branch. Also called the trunk or bole.
Stool	See stump; stump is usually used for long-rotation husbandry, stool for short-rotation, and especially for osiers (willow for basketry).
Stump	The original seedling root and lopped shoot remnant, but not the sprouts growing from them.
Sucker	A sprout that grows from a root.
Trunk	See stem
Understory	The ground-level plant growth, viewed as an energy transducing mechanism which cannot normally be harvested; or as the system which uses the energy which escapes through the overstory. In this sense the primary photosynthetic overstory/understory biomass ratio can be seen as an index of the efficiency of the management of the energy plantation. The understory can be coppice, while the overstory produces timber - the coppice-with-standards husbandry.

9. NOTES AND REFERENCES

This report is abstracted from a larger study now in progress. The quantity of references cited in this paper would take up an unreasonable space to print here. I will gladly send them to anyone who enquires with a self-addressed stamped envelope.

It is a pleasure to record here my extreme indebtedness to the excellent service so willingly given by a number of librarians, many of whom went far beyond the bounds of normal responsibility to furnish my recondite requests, and to give me access to rare and valuable records; and especially to Henry Gilbert, National Agricultural Library, USDA; Tom Hussey, Library Assistant, Yale School of Forestry; Dr. Hennings and Mr. Linnard, Commonwealth Forestry Bureau, Oxford, England; Stephanie Norman and Mary Baykan, School of Public Health, University of Texas; also to Ray Wilson who drew the diagrams, to Polly Wallace who typed the texts, and to Fox & Jacobs who generously provided resources.

10.1

TABLE 2.1
Species Reported as being Coppiced

LIST OF SPECIES:	COUNTRY	REFERENCE
Acer rubrum	Canada	41a1
Alder, see Alnus		
Alnus sp:	Germany	9
glutinosa	Germany	28b5
Ash-leaved Maple		62.24
Ash, see Fraxinus		
Aspen, see Populus tremuloides		
Babul	India	5
Bamboo, see Phyllostachys		
Beech, see Betula		
Betula sp.		9
	Finland	25a3
	France	42b3
Betula (pollarded)	U K	9
	Switzerland	14
	Switzerland	28a4
Birch		9
Black Cherry, see Prunus serotina		
Black Poplar	Rumania	47a5
Blue Gum, see Eucalyptus globulus		
Black Cottonwood		52.01
Cassia siamea	Tanganyika	14a1
	Caribbean	40b4
Castanea sativa	U K	18a2
	U K	40b4
	U K	41a3
	Italy	41b1
	Portugal	41b5
Chestnut, see Castanea sativa		
Chestnut oak, see Quercus montana		
Chil	India	6
Carpinus orientalis	Yugoslavia	56a1
Carpinus betulus	France	32b4
	France	35b3
Casuarina equisetifolia	West Bengal	58b2
Corylus abellana	U K	29a3
	Denmark	49a4
Cyclobalanopsis myrsinaefolia, see Quercus		
Conifers (sic)	Germany	6
Cottonwood, black		52.01
Crab-apple		62.24

Dogwood	USA (Appalachia)	66b1
Eucalyptus	Australia	6
E. camaltulensis	Israel	59b1
E. globulus	Spain	18a3
	South Africa	67a2
E. marginata	Australia	20b1
	Australia	66b3
E. saligna	South Africa	38b2
	South Africa	52a3
E. piminalis	Australia	54b2
E. roostrata	Israel	20
Fagus sylvatica (pollarded)	U K	9
	New Zealand	9
Ficus elastica (pollarded)	Malaya	13
Fraxinus excelsior	France	52a5
F. ornus	Yugoslavia	56a1
F. pennsylvanica	Rumania	47a5
F. americana		62.24
Hazel, see Corylus		
Holmoak, see Quercus ilex		
Hornbean, see Carpinus betulus		
Ironwood, see Ostrya		
Jarrah, see Eucalyptus marginata		
Laguncularia racemosa	Caribbean	18a5
Lime	France	32b3
Locust, see Robinia Pseudo-acacia	Caribbean	18a5
Liriodendron	USA FA	72/33.490/62
Laura nobilis	Russia	20
Mangrove, see Laguncularia		
Micromeles	Japan	28b2
Morus alba	Italy	18b1
Mulberry, see Morus		
Oak, see Quercus		
Osier	International	9
	Rumania	47a5
Ostrya virginiana	Virginia USA	20a5
Phyllostachys recticulata	Japan	38a4
Platanus occidentalis	USA	54b3
Populus tremuloides	France	32b3
	USA	54a1
Prunus serotina	USA	67b1
Pinus leipphylla	Rhodesia	16
Prosopsis spicigera	India	21

Quercus (sp.) (Tanbark)	France	2
	Germany	3
	Scotland	35a1
Q. alba	U K	18b4
Q. cerris	Bulgaria	50b1
Q. crispula	Japan	28b2
Q. dentata	Japan	43a4
Q. frainette	Bulgaria	50b4
Q. ilex	Italy	18b5
	France	53a1
	Montana	67b4
Q. myrsinaefolia	Japan	64b2
	Japan	45a4
	Japan	56a2
Q. pubescens	France	43a1
Q. serrata	Japan	28b2
Q. suber	Portugal	54b5
	Portugal	67b5
Red Maple, see Acer rubrum		
Robinia pseudocacia	Hungary	55a1
	Italy	66a1
	Yugoslavia	66a2
	U K	6224
Rubber, see Ficus		
Sal	India	5
	India	66a3
Salix		
Sweetgum	Mississippi	20
Sycamore, see Platanus occidentalis		
Teak, see Tectona	Rumania	47a5
Tectona grandis	India	5
	India	30a2
	India	38b5
	Caribbean	40b4
Tulip-tree, see Liriodendron		
Willow, see Salix		
Willow (pollarded)	Rumania	57a1
	Switzerland	2
Yellow Poplar, see Liriodendron		

10.2

TABLE 2.2
Countries Reporting Coppicing

Africa, East
Africa, South
Angola
Australia
Bulgaria
Canada
Caribbean
Denmark
France
Germany
Great Britain
Hungary
India
Israel
Japan
Yugoslavia
Malaya
Morocco
New Zealand
Nigeria
Poland
Portugal
Rumania
Russia
Spain
Switzerland
Taiwan
Tanganyika
Turkey
West Bengal

These names are listed as given in the published documents, and not by their modern names.