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energy

THE PRODUCTION OF ENERGY FROM SHORT ROTATION FORESTRY

Report
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SUMMARY

Thirty two species or clones of trees have been tested on a series of soil types over a period of six years. At least one species/clone has been found which gives an economic yield at each location. Broadleaved short rotation species will not survive at moderately high elevations, in exposed coastal situations or peats where the very acid Sphagnum layer remains. In these circumstances conifers at a density of 5,000-10,000 plants per hectare over a 7-10 year period will give a more satisfactory result. On second class agricultural land, Populus species will yield 14-18 t $ha^{-1}annum^{-1}$ as coppice. On mined out peatland, Salix aquatica gigantea is the most promising clone tested to date, but some clones may have possibilities.

In their report, the Forestry and Wildlife Service (FWS) state that with more extensive screening, other useful species would probably be identified, and indeed there is evidence that this is so. Initially one clone clone of Poplar (TT32) was included in the trials, but later experience showed that some of the highest yielding clones can grow on peatland.

In the trials on the harvested ('cutover') peatland at Clonsast, different species/clones were used in the silvicultural experiments e.g.Salix viminalis in the spacing trial, Salix vittelina in the first fertiliser trial etc. It is now known that these were not high yielding clones at that location. An Iteration trial, incorporating the best treatments, was established in 1980 and is giving promising results.

The optimum spacing of plants has not been finally determined. Very close spacing of 1m x 0.3m gave high initial yields, but these are

not being maintained in the coppice cycle. Spacing of 1.5 x 1.5m results in severe weed infestation the control of which becomes an additional cost. A wide range of herbicides can be used on Populus and Salix without ill effect on the trees.

The yield of coppice is 25-50% more than in primary growth. Recovery from cutting was satisfactory for Populus and Salix, but not for Alnus. Some uncertainty also exists in regard to fertiliser treatment especially on peatland, but indications are that an application of up to 100 kg ha^{-1} of nitrogen in the early years is necessary in order to obtain good establishment. Though the species Alnus is not at present cultivated as a forest tree in Europe, some fundamental work carried out indicates that the nitrogen fixing potential of this species is appreciable. The necessary organism Frankia occurs in most soils, but large differences are likely to occur in the nitrogen fixing capacity of strains of the organism. Some species of Alnus coppice erratically but it is possible to overcome this by selection and vegetative propagation.

In the earlier trials willows planted as cuttings showed a high failure rate. Subsequent experience has indicated that better results would have been obtained if either rooted plants or refrigerated cuttings had been used.

A few insect pests occurred, but control measures for those are already known.

Fuel analyses on components of the main candidate species yielded information on s.r.f. moisture content, calorific value, specific gravity ash and volatile contents, as well as the bulk density and particle size distribution for wood chips harvested from these species. Properties differed considerably from 'accepted' values for more mature wood, and variations between and within species were significant. These results on biomass qualities should assist future design and development of fuel handling, storage and conversion systems.

Field storage experiments showed that natural drying occurs in small (less than 2m high) piles or windrows of wood chips, stored during Spring and Summer. Drying is related to ambient air temperature and relative humidity, and climatic measures such as potential evaporation and potential evapotranspiration are good indicators of natural drying capability. In larger piles, where ventilation is restricted, chip pile heating and biological degradation of the fuel occur, and result in dry matter losses of over 1 per cent per month. The more biologically active biomass components, such as leaves and bark, exhibited the highest respiration rates, temperature rises and dry matter losses, during storage.

Economic analyses, conducted using the ENCROP and SALIX systems models, showed that s.r.f. fuel could be produced at a cost of £83/t.o.e. with present yield levels and under medium management costs. At this production cost, s.r.f. could favourably compete with commercial energy sources, including coal, oil and peat. It could also provide better economic returns (of £158/ha/yr.) than present farm enterprises on marginal land areas in the peat, glacial and poorly drained soil categories. Economically, 4 and 5-year cutting cycles and medium planting densities (10,000-13,333 plants per hectare) are optimal over a range of management cost levels and fuel prices. The factors most critical to the economic feasibility of s.r.f. plantations are expected fuel price, management input costs, and biomass yield.

FOREWORD

This contract extends over the period July 1, 1980 to June 30, 1983. Because some important results would become available in the latter half of 1983, it has been agreed that the contract be extended, without additional funding, until December 1983.

The aim of the investigations was to provide specific data on:

(1) The accumulative yield of candidate species on different soil types.

(2) The effect of spatial distribution, fertiliser application, frequency of cutting, and season of harvesting on the yield of dry matter per hectare.

(3) The reduction in establishment costs through the use of rapid methods of propagation through tissue culture in the laboratory and by means of mechanical planting.

(4) The reduction of periodic costs through the use of nitrogen fixing species such as *Alnus* and by making a study of the recycling of nutrients through leaf fall.

(5) The most economic methods of handling and transporting harvested short rotation wood of different dimensions.

(6) Drying and storage of short rotation wood.

(7) The effect of moisture content and particle size on the efficiency of combustion.

Item (5) is partly covered in a separate study [Contract No. ES-E-R-019-EIR (N)]. The direction of Item (4) altered somewhat in order to cope with the problem of poor coppicing in *Alnus* spp. Apart from these, the objectives as set out were achieved.

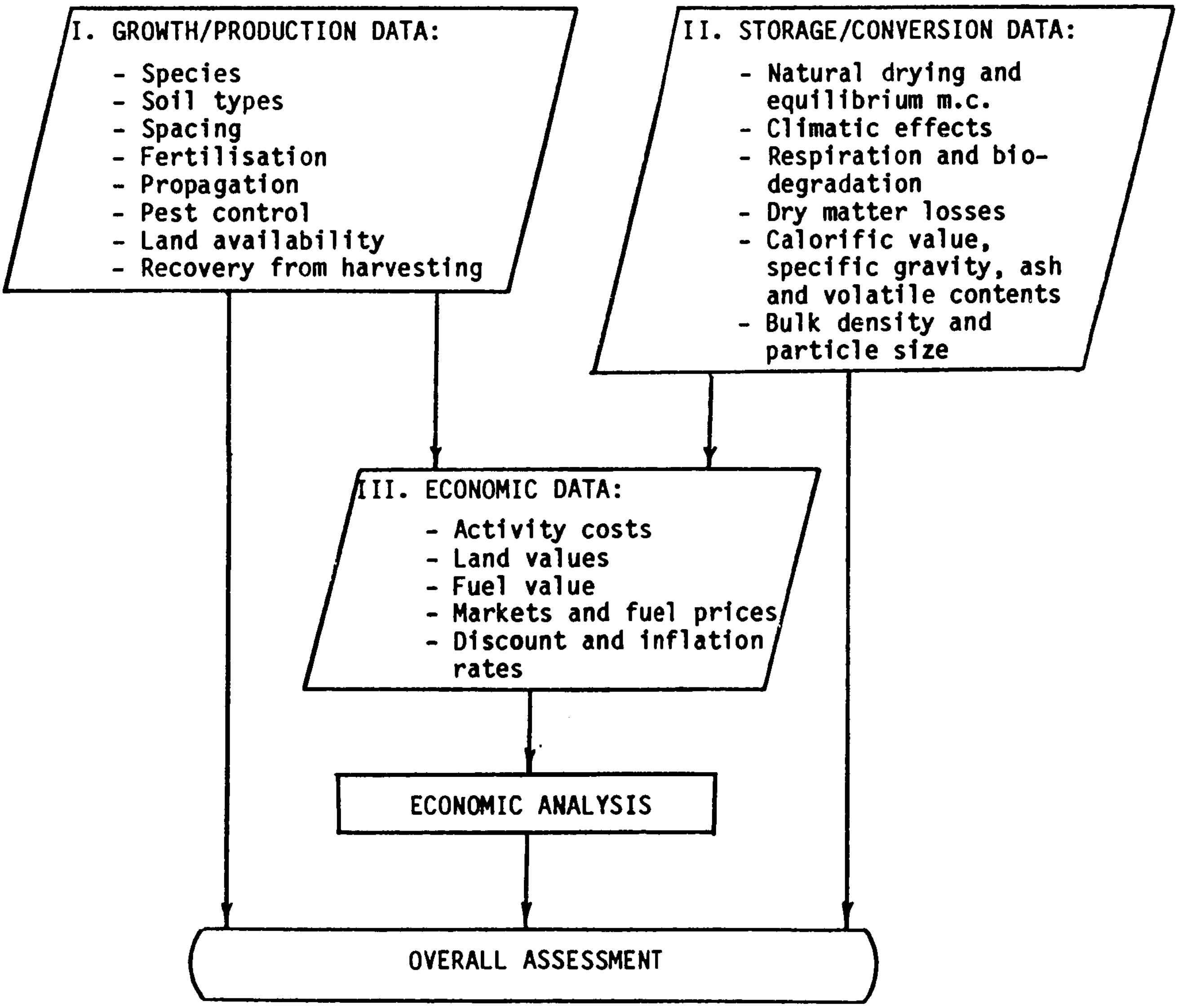
The report is in three sections:

I Growing and land utilisation

II Fuel analysis and storage, and

III Economic assessment.

Figure 1 : Scope of the work



INTRODUCTION

Photosynthesis, which provides a storable form of energy, is one of the best possibilities for exploiting solar energy. Many species of plant could be used, but to be economic, the species must be:

High yielding,

High in dry matter,

Harvestable by near-conventional equipment, and

Not have an alternative market outlet

One of the crops which has attracted attention in the past two decades, and which fulfils these conditions, is short rotation forestry. This consists of growing trees in a bush like arrangement and harvesting the shoots every 3, 4, or 5 years. This has two advantages:

it gives a yield of biomass which is generally about 25% higher than conventional forestry, and

because of the short growing cycle, financial costs are relatively low.

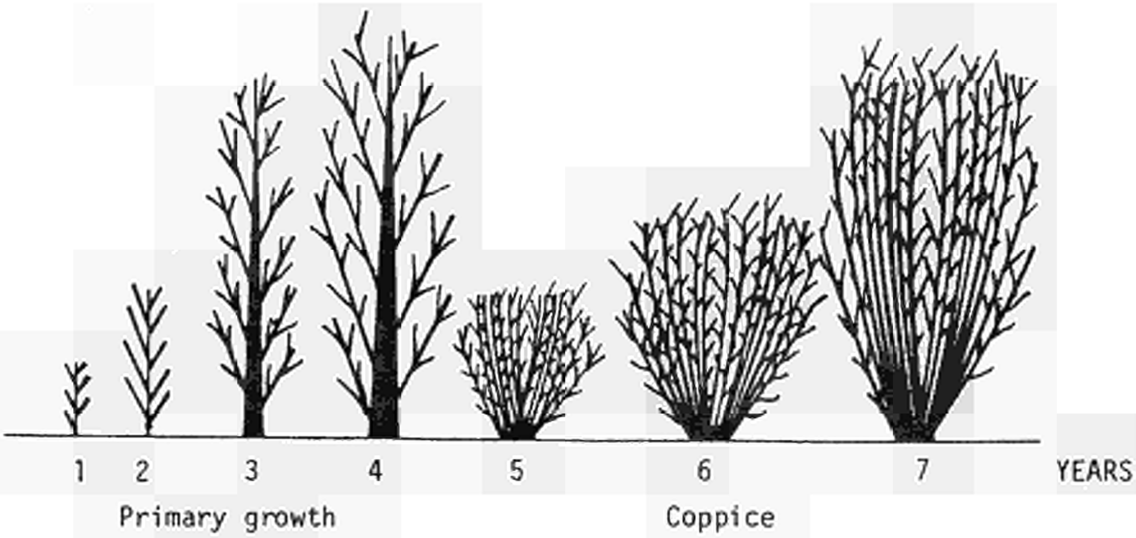


Figure 2: Schematic drawing of short rotation forestry for 4 years primary growth and 3 years coppice growth

Extensive work on the use of coppice as a source of fuel is in progress in the U.S. (1)(2)(3)(4)(5)(6)(7), Sweden (8)(9), Canada (10), and France (11) and many other countries (12). The main species used in the U.S. (Platanus occidentalis) grows poorly in Europe but other coppicing species such as poplar (Populus spp.) and willow (Salix spp.) have given promising results in Northern Ireland (13), Sweden (9) and France (11). [References to this section are listed on pages 50-52].

A feasibility study carried out in 1977/78 (14) indicated that with oil at $12.70 per barrel, short rotation forestry would be a cost effective source of fuel if a yield of 12 t $ha^{-1}annum^{-1}$ could be obtained. Since then, oil prices have escalated considerably, so that short rotation forestry is now competitive at a much lower yield, despite some increase in its cost of production.

The most effective way of costing short rotation forestry at varying input costs, against oil, which is also fluctuating in price, is by means of a systems analysis. In the feasibility study mentioned above (14), certain projections and assumptions were made regarding yield, input costs, land availability, and properties of the fuel to be produced. During two research programmes in this series, these assumptions have been tested in field trials and laboratory investigations. A preliminary report was publised in 1980 (15). The present report gives the updated experimental results, and also the cost of energy as determined by systems analysis based on this data.

SECTION 1

GROWING AND LAND UTILISATION

TYPES OF LAND POTENTIALLY AVAILABLE FOR BIOMASS PRODUCTION

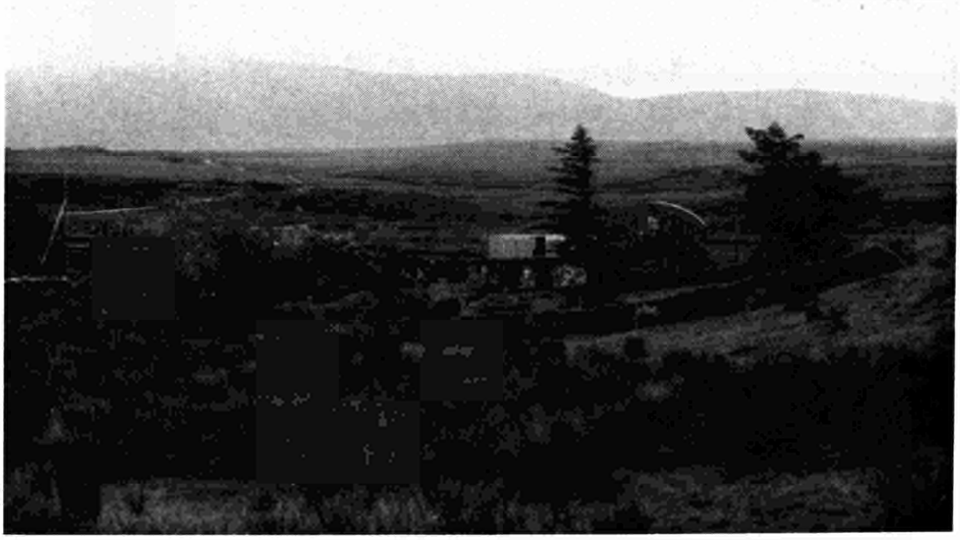
M. Neenan, An Foras Taluntais, Oak Park, Carlow.

It has been shown (14) that 2.34% of the land area of Ireland if planted to wood energy crops, could provide 10% of the energy requirements. The main types of land which could become available for this purpose are mountain land, abandoned farmland and peat.

Mountain land: This covers nearly 22% of the land area of Ireland. It consists of thin soils with rocky outcrops. The elevation is between 200 and 1,000 metres over sea level. The quality of the soil varies with the geological composition of the rocks. The most abundant series of these soils is on Old Red Sandstone. These areas are used for extensive grazing with sheep and for conventional long-cycle forestry. A typical landscape is shown in Plate 1.

PLATE 1 : Typical landscape in podsolised mountain soil near Kilfinnane.

<u>Abandoned farmland</u>: This covers a wide range of soil types, but the most important category is that which has been abandoned in relatively recent times. The largest category of soils in this series are the Drumlins which constitute 3.66% of the land area. Many of these soils are impermeable, and suffer from poor drainage. They are generally at elevations below 100m.



Plates 2 & 3 : Land which, due to difficult soil conditions, is ceased to be farmed.

<u>Peatland</u>: In Ireland, the term peatland or bog covers a wide range of soil and ecological conditions. According to Hammond (16) there are 3 types of bog in Ireland, Raised, Fen and Blanket bog. The Raised bog, which is the type used for commercial peat production, is often a secondary development from a valley bog or a fen. It can have a depth of 3-8 m. Most of the industrial peat production is on the Raised bogs in the midlands.

FIG.3 : Peatland types in Ireland (courtesy of the Irish Geological Survey Office).

Blanket bog follows the contour of the ground and so extends to high elevations. Its depth is usually 3m or less. There are two sub types within this category, Low Level Atlantic which covers up 150 m O.D., and High Level Mountain peat which reaches a height of more than 300 m O.D.

Peat is classified according to the botanical composition of the plants from which it is formed, and to the extent to which it is decomposed. The latter is measured on Van Post's scale of 1 (least decomposed) to 10 (wholly amorphous). The main layers of peat in a typical Irish midland bog are (17):-

Top

Sphagnum	(Moss)
Eriophorum	(Cotton grass)
Calluna	(Heather)
Carex	(Sedge)
Cladium	(Common sedge)
Phragmites	(Common reed)
Wood peat	(Birch, alder)
Marl or clay	

Bottom of bog

Fig. 4 : Typical horizons in an Irish raised bog, and
Plate 4: Surface contour after peat has been harvested by hand.

The most important constituent of Irish bogs is Sphagnum, of which there are several species. In the blanket bogs in the west, Sphagnum is less continuous and the hollows are dominated mainly by other species. Most of the soils which have been reclaimed consist mainly of woody peat zone (Fig.5) layers underneath the Sphagnum. This is a matter of critical importance.

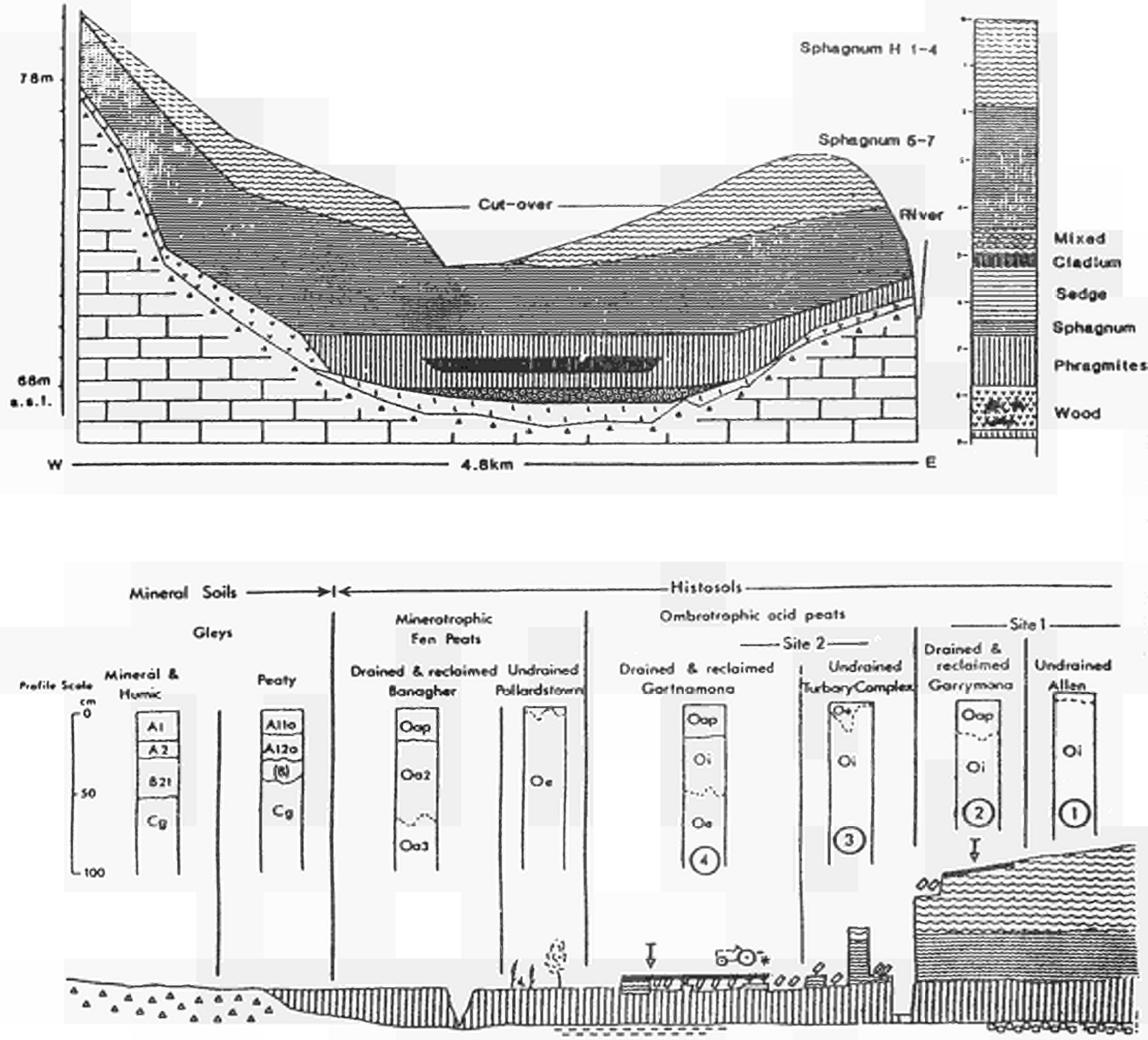


FIG. 5 : Schematic cross section of typical Irish midland bog. (Hammond, ref.16).

Industrial peat production in Ireland

It is inherent in the formation of peat that each successive layer from bottom to top is lower in mineral matter; as a species dies it is replaced by a less demanding species, until eventually only Sphagnum will survive. In peat harvesting, the process works in reverse, the deeper layers being more amenable to cultivation.

Beginning about 1950, a series of peat burning stations were established in Ireland. The peat is now being depleted and supplies will be exhausted early in the next century. In harvesting the peat, the top layer of relatively undecomposed Sphagnum (Van Post scale 1-4), (See Fig.5) is first thrown aside, and then two layers of sod peat are taken off. This depletes most of the peat. Afterwards the milled peat is harvested. This consists mainly of Sphagnum which originally formed the topmost layer. When the peat level is reduced to about 0.5m from the bottom of the bog, harvesting must cease. The remaining soil will consist mainly of woody peat. If the layer of Sphagnum is not fully removed, or if it is buried by cultivation during harvesting, the soil becomes extremely variable and its performance for supporting plant growth is unpredictable.

Types of peat on which trials were located

It has been shown (18)(19) that many coniferous species of trees can be grown on cutover peatland, provided ample fertiliser is applied in the initial years. In this investigation, four types of peat were used:

(a) Valley peat with Sphagnum remaining (Derrycoffey, near Tullamore, Co. Offaly),

(b) Valley peat with the Sphagnum completely removed but otherwise uncultivated (Clonsast, near Portarlington)

(c) Blanket peat unimproved except for fertilising and drainage (Knockalough, Ross forest, West Galway)

(d) Blanket peat which had been reclaimed to poor quality grassland (Glenamoy, Co. Mayo).

Selection of species and sites

There were a large number of species which could be considered as having possibilities for short rotation forestry (20)(21)(14). In collaboration with the State Forest & Wildlife Service (FWS), and with K.G. Stott of the University of Bristol, the number of species was reduced to twelve for the initial trials. These were tested on the soil types mentioned above, and on low grade agricultural mineral soil at Oak Park, Carlow. Planting was in the spring of 1977. Bord na Mona (the National Peat Development Authority) kindly provided an 8 ha site at Clonsast, near Portarlington, Co. Offaly on land which had been mined for peat production. Several additional species, as well as fertiliser and spacing treatments were tested on this soil from 1978 onwards. The geographical location of the various trials is given in Fig.6.

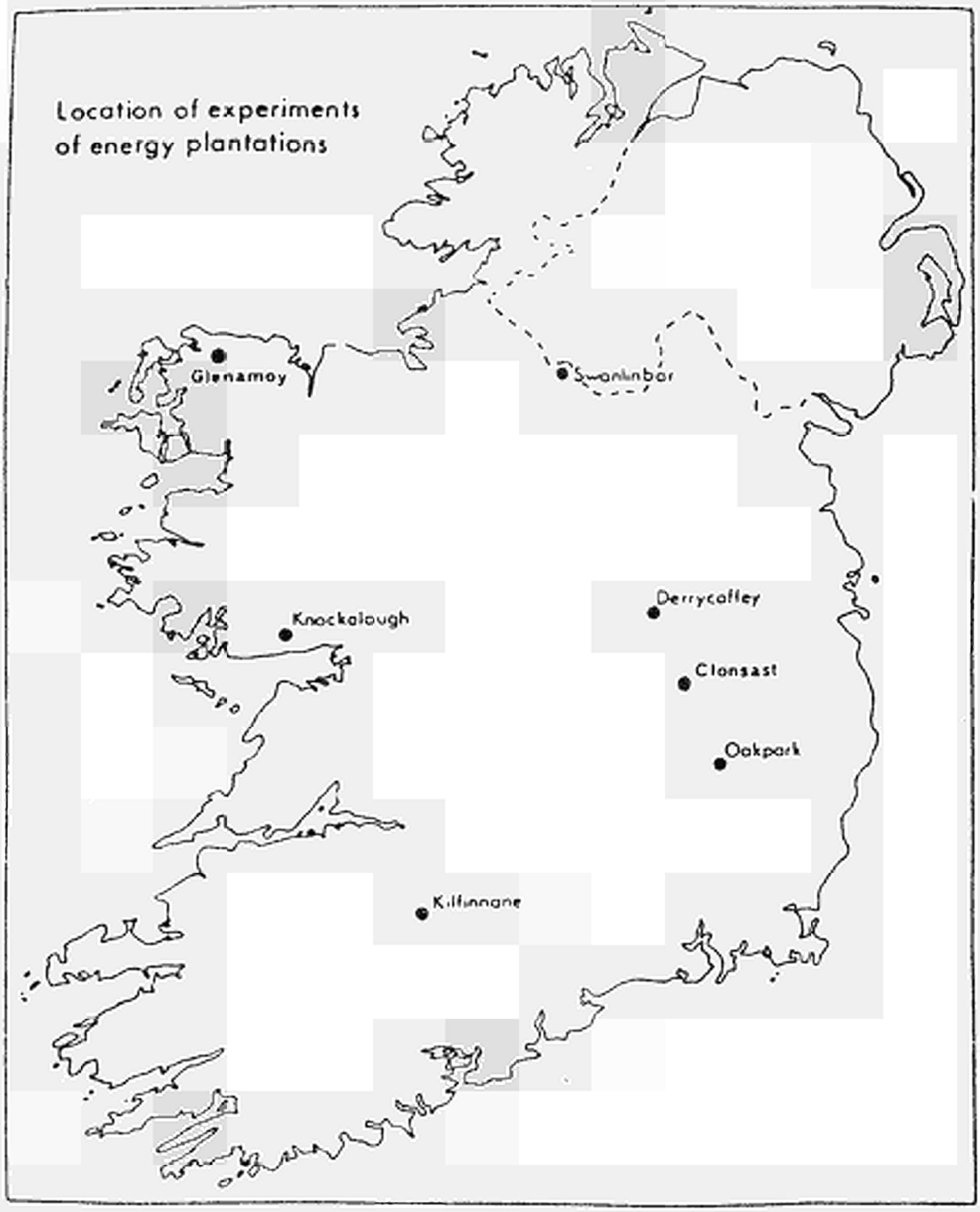


FIGURE 6 : Geographical location of trials on short rotation forestry.

TABLE 1 : List of candidate species and reasons for their inclusion

Latin Name	English Name	Reason for inclusion
Alnus cordata	Corsican Alder	Fixes nitrogen, used for wind screens
Alnus glutinosa	Black European Alder	Fixes nitrogen, grows in wet soils
Alnus incana	Grey European Alder	Fixes nitrogen, grows wild in Europe
Alnus rubra	American Red Alder	Fixes nitrogen, has given good yields in Europe
Betula pubescens	Birch (warty)	A weed in peatland in N.Europe
Castanea sativa	Spanish chestnut	Good reports in literature
Eucalyptus dalrympleana	Eucalyptus	High yielding, has survived 14°F
Eucalyptus gunnii	do.	High yielding, has survived 0-5°F
Eucalyptus johnstonii	do.	High yielding, has survived 6°F
Fraxinus excelsior	Common Ash	Coppices, has high dry matter content
Larix decidua x leptolepis	Hybrid larch	Tolerates thin soils
Populus trichocarpa "Fritzi Pauley"	Hybrid Poplar	N.American clone. Widely grown in Europe
Populus trichocarpa x P.tacamahaca "TT32"	do.	U.K. clone, widely grown in Ireland
Populus trichocarpa x P.deltoides "Rap"	do	Recently bred Dutch clone, high yielding
Pinus contorta	Lodgepole Pine	Most widely grown species in Ireland Yield known for most areas.
Picea sitchensis	Sitka spruce	do.
Salix daphnoides	(No common name)	Tolerant of exposed windy situations
Salix x dasyclados	do.	High yielding in Britain & N.Ireland
Salix aquatica gigantea	do.	do. in peat or wet soils
Salix smithiana	do.	Promising results in Sweden
Salix viminalis (Lough Neagh)	Basket Willow	Species is widely grown in Europe
Sorbus aucuparia	Rowan	Grows wild in peatland

SOIL TYPE BY SPECIES TRIAL ON LOW GRADE AGRICULTURAL LAND

M. Neenan & J. Devereux, An Foras Taluntais, Oak Park, Carlow.

This experiment was designed to gain some preliminary information on species, spacings and type of planting material. The species were selected on the basis mentioned in Table 1 above.

Materials & Methods

The location was the Agricultural Institute farm, Oak Park, Carlow, where the soil type was a sandy loam derived from limestone glacial till. Drainage was impeded, so that the soil was only marginally suitable for agriculture. Elevation was approximately 61m above sea level and mean annual rainfall 921 mm. The area was ploughed at 1m intervals and planting was carried out from 9 to 21 March 1977.

Plots were single rows of 100 m length, replicated three times. The trial is mainly concerned with coppicing species, but some conifers are included as controls, since their yields on many locations was already known. The list of treatments, and percentage establishment is given in Table 2.

At planting time, fertiliser was applied at the rate of 37 kg ha^{-1} of nitrogen and phosphorous and 74 kg ha^{-1} of potassium. In 1979, an application of 207 kg ha^{-1} of nitrogen was applied, and in 1982 and 1983, an application of 25 kg ha^{-1} of nitrogen and phosphorous and 50 kg ha^{-1} of potassium was applied to the plots which had been coppiced.

Weed control was maintained by 1 or 2 applications of paraquat per annum with occasional cutting of perennial weeds.

TABLE 2 : List of treatments and percentage survival of original plants 3 years after planting

Species	Age of plants*	Spacing (m)	% survival (3 years after planting)
Alder (Italian) (Alnus cordata)	2 + 1	1.0 x 0.61	65
Birch (Betula pubscens verrucosa	1 + 1	1.0 x 0.61	55
Chestnut (Spanish) (Castanea sativa)	1 + 1	1.0 x 0.9	69
Eucalyptus (Eucalyptus gunnii)	1 year old potted	1.0 x 0.61	47
Ash (European) (Fraxinus excelsior)	2 + 1	1.0 x 0.61	87
Poplar Fritzi Pauley (Populus trichocarpa)	0 + 1	1.0 x 0.3	94
Poplar hybrid Rap (Populus deltoides x P.trichocarpa)	0 + 1	1.0 x 0.61	89
Poplar hybrid Rap (do.)	Cuttings	1.0 x 0.3	31
Spruce Sitka (Picea sitchensis)	2 + 1	1.0 x 0.61	80
Willow basket (Salix viminalis Lough Neagh)	Cuttings	1.0 x 0.61	56
Willow basket (do.)	Cuttings	1.0 x 0.3	62
Willow hybrid (Salix aquatica gigantea)	Cuttings	1.0 x 0.3	66
Willow hybrid (Salix x dasyclados)	Cuttings	1.0 x 0.3	77

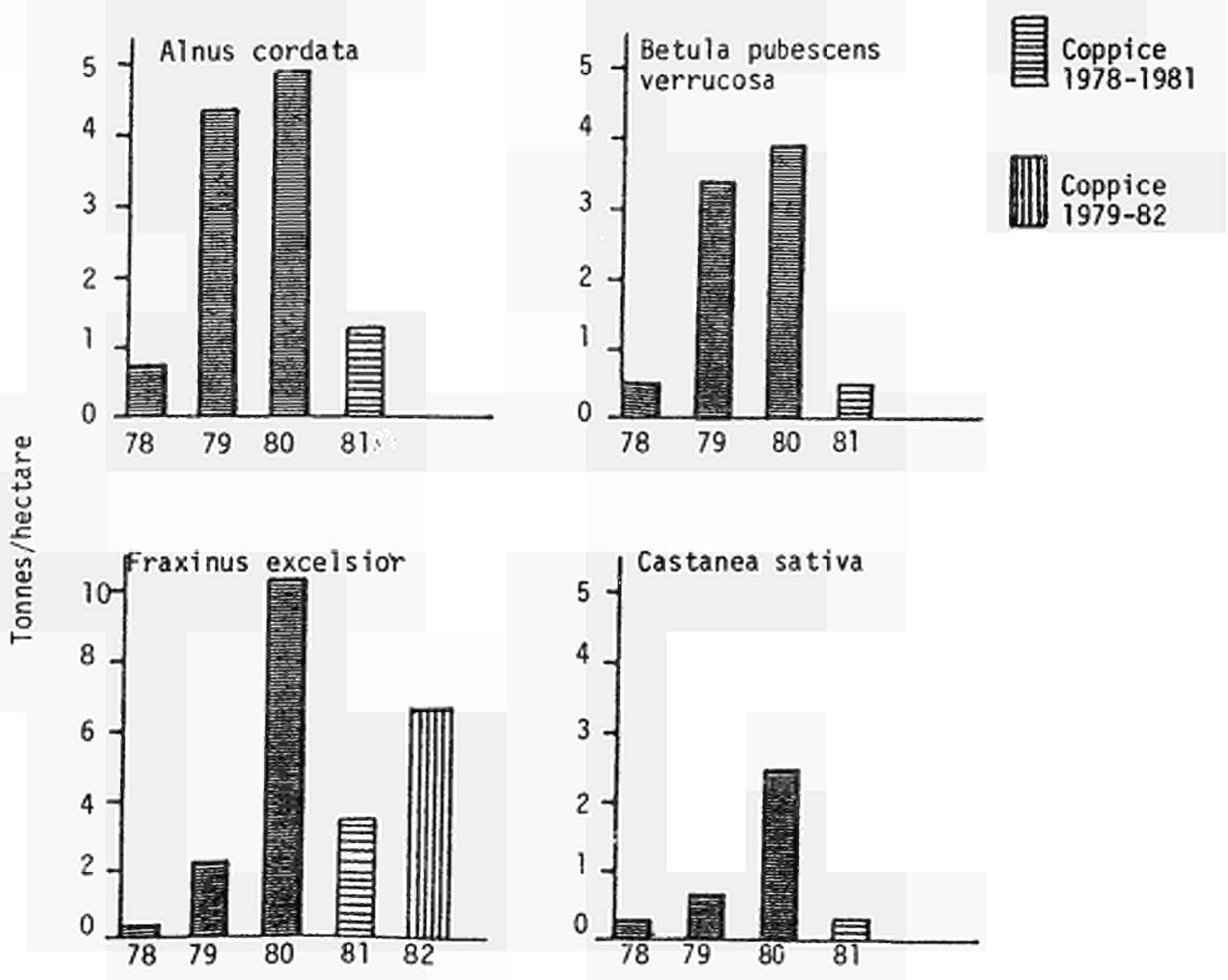
* The first number refers to the number of years in the seedbed, the second number gives the number of years after transplanting

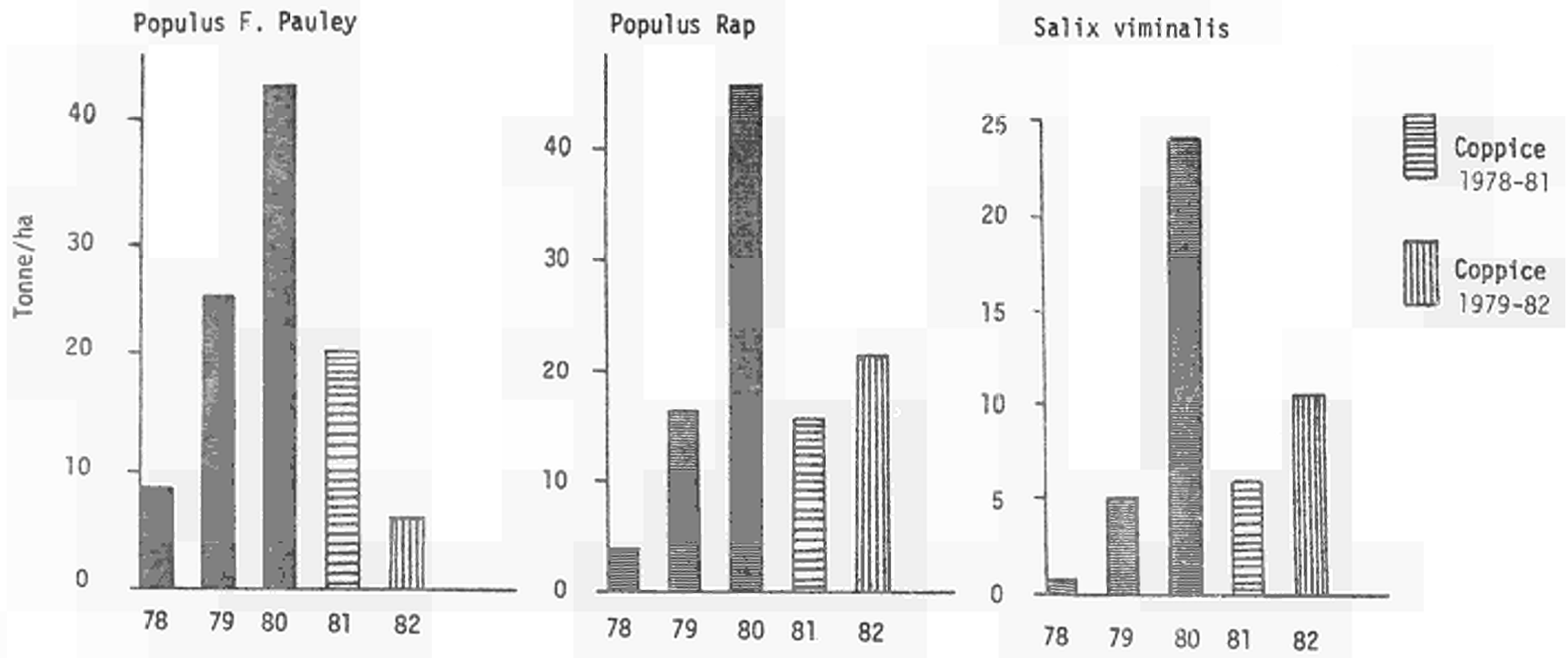
Harvesting took place soon after leaf fall in the years mentioned. One block of the experiment was harvested (except for the conifers) in each of the years 1978, 1979 and 1980. The plots previously harvested in 1978 were again harvested in 1981 to give the first coppice yields. At each harvesting the entire plot was cut down using hand tools, weighed in the field and an alliquot taken for dry matter content.

Results

The results are given in Fig.7.

FIG.7 : Yields of clones grown on second class agricultural soil at Oak Park, Carlow. The yields for 1978 to 1980 are accumulative for 2-4 years primary growth. Yields for 1981 and 1982 are equivalent annual yields of coppice.





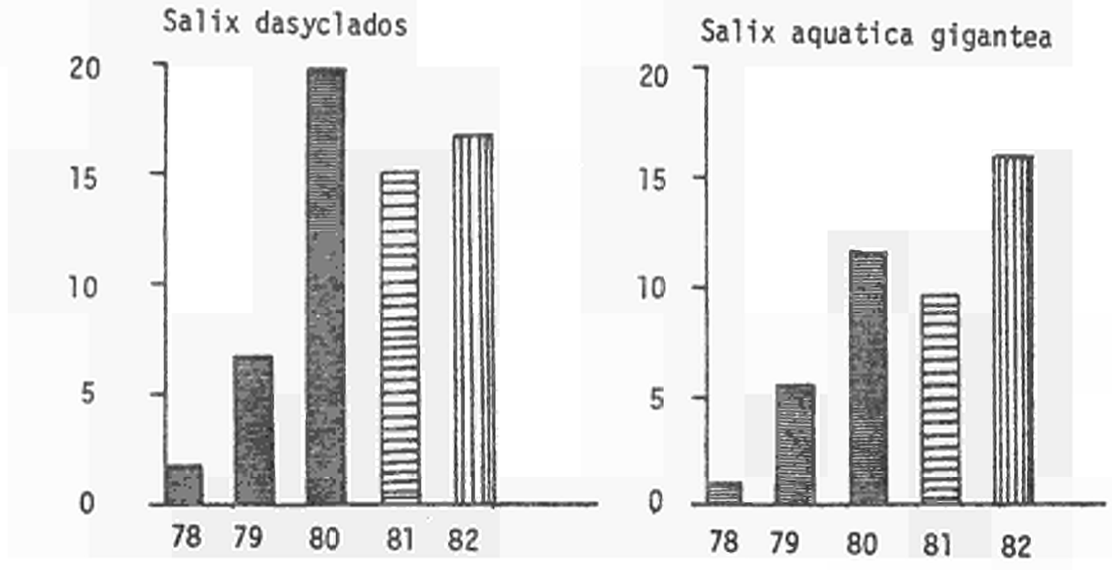


FIGURE 7 : Yields in t ha^{-1} of D.M. of clones grown on second class agricultural soil at Oak Park, Carlow. The yields for 1978 to 1980 are accumulative for 2-4 years primary growth. Yields for 1981 and 1982 are equivalent annual yields of coppice.

The Salix clones were all grown from cuttings, the Populus from rooted plants.

Discussion of results

Although the experiment was not laid out in a form which permits statistical analysis, the yield differences are so large that they are meaningful.

The main feature of the results is that a yield of 18 t ha^{-1} $annum^{-1}$ has been obtained with hybrid poplar. Salix dasyclados, grown from cuttings, yielded 15.3 t $ha^{-1}annum^{-1}$ at this site. For both species, the target yield of 12.0 t $ha^{-1}annum^{-1}$ has been exceeded.

Because establishment from cuttings was only about 60% (due to losses at planting), comparisons of cuttings and rooted plants are not valid. A higher planting density (1.0 x 0.3m) gives a higher initial yield but after the first coppicing there may be considerable die back especially if the initial coppice is too long delayed (see Populus Fritzi Pauley in Fig.7).

Three species, Alnus, Betula, Castanea, and Fraxinus gave poor results. This might indicate that they require a long period to become established. Fraxinus improved substantially in 1982. Alnus cordata, Betula pubescens and Castanea did not recover well from coppicing. Eucalyptus gunnii which was killed back by the frost in 1979, was removed from the trial, but has survived in an adjoining area. However its performance is unreliable.

The yield from the conifers has not yet been determined, but from height measurements, the results should be somewhat better than those obtained in the Forestry & Wildlife Service experiment at Derrycoffey, i.e. more than 51.0 t ha^{-1} over 6 years.

PLATE 5.

(a) Three year old coppice prior to harvesting.

(b) Chipping coppice wood in preparation for laboratory tests.

SPECIES BY SOIL TYPE INTERACTION TRIALS AT FOUR CENTRES

R. McCarthy & L. Condon
Forest and Wildlife Service of the Dept.of Forests and Fisheries, Dublin

The purpose of this series of trials was to assess the potential of different species for the production of biomass-energy on land types described above. Four sites were chosen as being representative of these areas.

(1) Mountain land: This was located at Kilfinnane on the borders of Counties Limerick and Cork (Fig.6). The soil was a podsolised Old Red Sandstone which had been used for grazing (mainly with sheep). Conventional afforestation has been successful on the better slopes.

(2) Abandoned farm land: This was a surface water gley on a drumlin located in the Swanlinbar area of County Cavan. Some of this land is currently used for agriculture (cattle and dairying) but with a low level of return. Such soils are very suitable for high production conventional coniferous forest species.

(3) High-level midland bog: These are currently used for the industrial production of peat for electricity generation and peat briquette manufacture. This particular site which is at Derrycoffey, Co. Offaly had not been harvested for peat, so the trees were growing on Sphagnum. However, intensive artificial drainage had been carried out.

(4) Blanket peat: Large areas of this soil occur along the exposed western seaboard and at high elevations on the mountain ranges. The main uses are local peat production and afforestation. This

site was at Lake Knockalough (which is part of Ross forest) in Co. Galway. The site was drained prior to planting.

Materials and Methods

The layout and treatments have been given in previous publications (15)(22). Due to the short notice of this experiment, some difficulty was experienced in procuring good quality plants of some species. Planting was later than would normally be recommended. The problem was further compounded by the occurrence of a long dry period in May and June of 1977. This gave poor establishment of several species; *Salix* in Tullamore and Kilfinnane and conifers at Swanlinbar.

At the end of the 1982 growing season 15 representative trees (5 trees per replicated plot) were selected across the stem diameter (at 1.3 m) range to provide samples for determination of dry weight production. Samples were oven-dried at 105°C for 48 hours.

Results

As indicated in previous reports (27)(28) the species gave widely different results on the various soil types.

Kilfinnane site - Podsolised Old Red Sandstone:

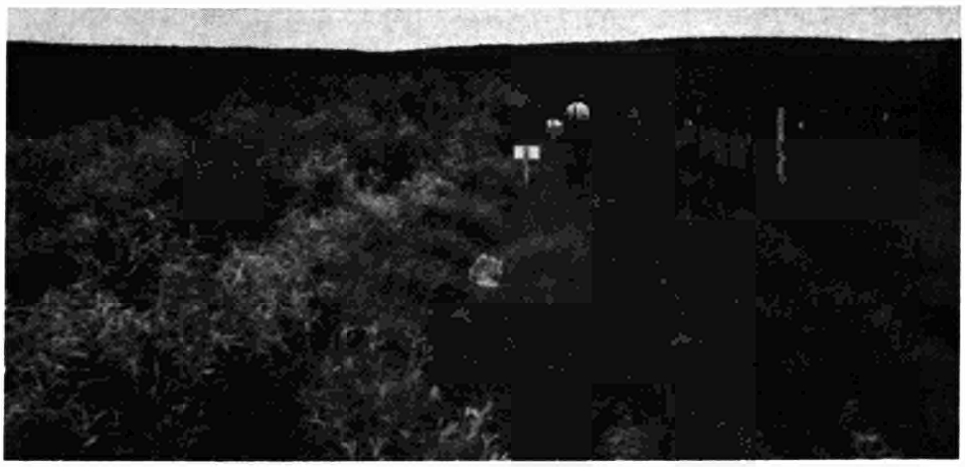
Alnus, *Populus* and *Castanea* survived, but only *Pinus contorta* and *Picea sitchensis* gave an economic yield (Table 3). *Larix* also survived, but is not a high yielder. A major problem at this site is the presence of boulders which become exposed in the course of ploughing. This would render mechanical harvesting virtually impossible. Previous experience by the FWS clearly indicate that plantations cannot be established without soil preparation. This land type has therefore limited potential for short rotation crops.

PLATE 6 : Kilfinnane trial after 2 years grown showing moderate growth of Pinus contorta and poor growth of the broadleaved species (nearer the camera). Note the rocky nature of the terrain.

Knockalough site - Blanket Peat:

Castanea, Betula and some Alnus plants survived in 1982, but yields were negligible. The coniferous species made only moderate growth. It is concluded that the problem is due mainly to exposure to high winds from the Atlantic.

PLATE 7 : Trial at Knockalough showing (above) poor growth of Pinus contorta and (below) near total failure of broadleaved species, Sept. 1983.



Tullamore - Raised Virgin Bog:

Populus failed, Salix survived but gave no economic return. Castanea survived better than Salix, while Betula and Alnus grew but gave yields which were uneconomic. The best result was 8.5 t ha^{-1} $annum^{-1}$ from Lodgepole pine. This includes foliage, which in a commercial operation might not be recovered. The yield results are given in Table 3.

(a)

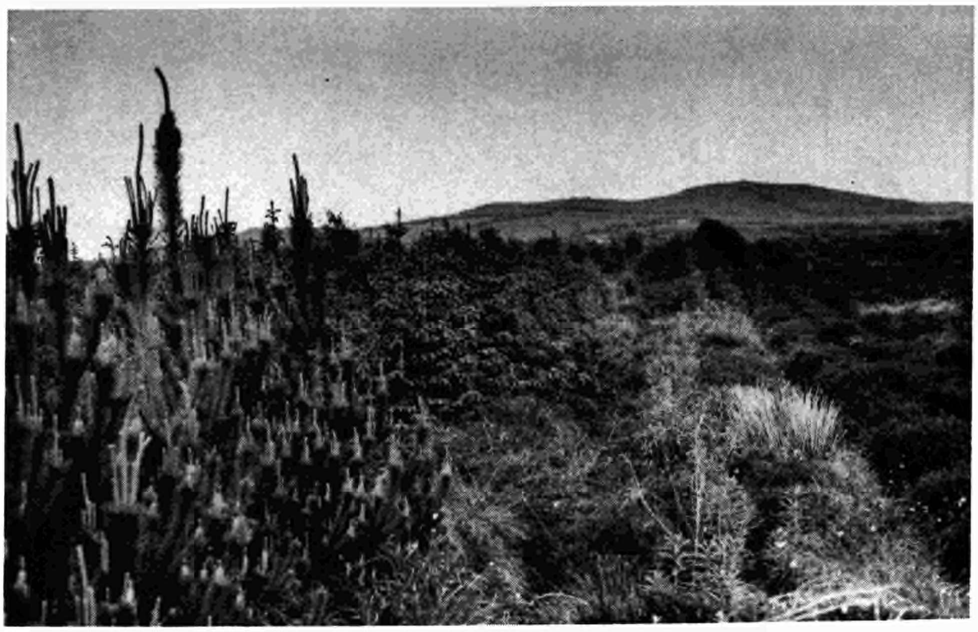


PLATE 8 : (a) Poor growth of Salix (right) and excellent growth of Pinus contorta and Picea sitchensis

(b) Survival but poor growth of Alnus and Betula spp.

(b)

Swanlinbar site - Gley:

This experiment suffered most severely from the dry period of planting. Establishment of the coniferous species was not entirely satisfactory and yields were well below those normally obtained on this site (i.e. 26 m^3 $ha^{-1}annum^{-1}$ = 14 tonnes ha^{-1} $annum^{-1}$ approximately). Populus and Alnus established, made only moderate growth in the early years, but have begun to show promise from 1982 onwards. Salix survived well but suffered severe competition from weeds (Juncus spp.) after coppicing. Alnus rubra showed a susceptibility to wind damage. Although the soil was suitable for Populus, the elevation was possibly a limiting factor.

PLATE 9 : Trial at Swanlinbar showing Populus and Alnus in the autumn of 1983. Note abandoned homestead in foreground.

TABLE 3 : Above ground dry matter (tonnes/hectare) after 5 and 6 growing seasons respectively (mean annual dry matter increments in brackets). In the case of conifers the yield includes the foliage. All data refer to single stems, not coppiced.

	Soil Type					
	O.R.S.		Gley		Raised Bog	
Species	5 yrs.	6 yrs.	5 yrs.	6 yrs.	5 yrs.	6 yrs.
Lodgepole pine	18.4 (3.7)	34.4 (5.7)			17.6 (3.5)	51.0 (8.5)
Sitka spruce	13.1 (2.6)	28.2 (4.7)			10.8 (2.2)	22.2 (3.7)
Alder (*A.rubra*)	F		6.7 (1.3)	12.8 (2.1)	F	
Poplar T (MB)	F		14.7 (2.9)	17.1 (2.8)	F	
Poplar TT 32	F		6.9 (1.4)	8.8 (1.5)	F	
Willow (*S.aquatica gigantea*)	F		8.2 (1.6)	7.8 (1.3)	F	

F = Failure

Discussion

The results indicated that the performance of many species which has proved satisfactory on better quality sites of a similar nature were severely limited by lower nutrient status and/or adverse climatic factors such as elevation and/or exposure.

On 3 out of the 4 sites, the performance of the broadleaved species was unsatisfactory. This can be attributed to some extent to poor establishment due to the late planting in 1977, but is mainly due to the nature of the soils. It seems reasonably certain that the high yielding *Salix* species will not survive at elevations in excess of 100m, and at lower elevations, where exposure is severe as at the Ross site. Populus will not grow on unimproved peat i.e. when there is a deep layer of very acid Sphagnum. Betula survives in many locations, but despite fertiliser and other treatment gives an uneconomic yield. This is different to the situation in Scandinavia, where Betula is regarded as a promising species for biomass.

On these marginal soils Pinus contorta (Coastal type) is clearly the best performer. With very dense planting (5,000 to 10,000 plants per ha) satisfactory results can be obtained in 7 to 10 years. More recent experience by the FWS would suggest that the lower population will give a satisfactory result with a rotation period of 10 years or less.

It should be noted that in any form of forestry, time is important; for example on the raised bog site the mean annual increment increased to 8.5 t ha^{-1} after six years as compared to 3.5 t ha^{-1} during the first five years. In general, a satisfactory result can be expected in a period of 7-10 years.

The results to date would suggest that although there is a large area of land available, much of this is not suitable for short rotation coppice forestry, but reasonably good results can be obtained with coniferous species at a density of about 5,000 trees per hectare. It should be emphasised however that only one trial was carried out on each soil type. It is probable that with more extensive trials and better weather conditions in the year of establishment, that yields could be substantially improved.

COMPARISON OF SPECIES ON HARVESTED PEATLAND

M. Neenan & J. Devereux

Apart from a large scale trial with conifers initiated by the State Forest Service in 1955 (18), there is little information on the suitability of broad leaved tree species on virgin peat. Accordingly a series of trials was undertaken on typical mined out peatland, beginning in 1978.

Materials and Methods

Six trials were established on harvested peatland on Bord na Mona property at Clonsast, Co. Offaly. In most of the area, approximately 0.5m of woody peat remained; this was underlain by calcareous clay. Elevation was 73m O.D. and rainfall 820 mm annually. The area was limed bringing the pH to 6.4 on the surface. Subsequent experience indicates that much less lime would have sufficed.

No.1 Trial: In April 1978 rooted plants were spaced at 0.61 x 0.61 m. Plots were single rows of 50 plants each and there were 6 replications of each treatment. Establishment was approximately 90%. The species were: *Alnus glutinosa*, *Eucalyptus dalrympleana*, *Eucalyptus gunnii*, *Populus* hybrid TT32, *Salix daphnoides*, *Salix smithiana*, *Salix viminalis*, *Salix vittelina* and *Sorbus aucuparia*. The severe frosts of 1979 reduced the population of *Eucalyptus* to less than 40%, and these species were removed to another part of the field and replaced by two other species, *Salix aquatica gigantea* and *Salix daphnoides*. *Salix vittelina* which had become diseased, was replaced by *Alnus incana*. It was apparent that the original spacing was too close to provide a valid comparison of the species. After 2 years growth, every alternate plant in 4 blocks was removed (and planted in a new trial, described below). The plants in the 4 blocks were cut back and fertiliser applied at a rate/ha of 88 kg of nitrogen and phosphorous, 176 kg of potassium, 45 kg of copper sulphate and 2.5 kg of boron. Weed control was maintained by application of 'Casoron G' in 1979, and by paraquat in subsequent years. Harvesting was by means of hand tools, after all the leaves had shed. Samples were weighed in the field and taken to the laboratory in plastic bags where they were dried for 24 hours at 104°C.

The first harvesting from Trial No.1 was made at the end of 1981. The yield of all species was too low to be of interest.

No.2 Trial: In April, 1980 the plants (Eucalpytus excepted) which had been removed from the No.1 trial were planted in a new experiment spaced 1.83 x 1.83m. Each plot was 17 plants in length and there were four replications. Fertiliser and weed control were as in the previously described trial. Establishment was satisfactory. Harvesting procedures were as already described.

TABLE 4 : Yield of dry matter from eight species grown as coppice on mined out peatland. First coppice yield from plants in situ, taken at end of 1982.

Species	Yield t ha^{-1} (3 years growth)	Species	Yield t ha^{-1} (3 years growth)
Alnus glutinosa	14.2#	Salix daphnoides	9.3
Populus spp. TT32	8.4	Salix smithiana	5.9
Salix aquatica gigantea	25.1#	Salix viminalis	46.5
Salix dasyclados	5.3	Sorbus aucuparia	19.4

Transplanted in 1980 - little growth in the year of transplanting

No.3 Trial: This was laid down in the same area in April 1980. Five species, Salix viminalis (1 year old), Salix vittelina, Pinus contorta, Picea sitchensis and Picea excelsior were planted at a spacing of 1x1 m. Fertiliser treatment was 38 kg of nitrogen and phosphorous and 75 kg of potassium per ha. This trial has not yet been harvested, but visual observations indicate that Pinus contorta and Salix viminalis are the best of this series.

No.4 Trial: Four species of Alnus - A.cordata, A.glutinosa, A.incana and A.rubra, were planted in the spring of 1980. Plots were 4 rows wide and 18.3 m long with 4 replications. Spacing between plants was 1.83 m each way. Fertiliser was applied as in the previous trials, and weed control was maintained by two applications of paraquat. The plots were coppiced at the end of 1981. There was an unexpectedly high mortality for three of the four species. The results are given in Table 5.

TABLE 5 : Survival of Alnus species from coppicing on mined out peat at Clonsast, Co. Offaly, after two years growth.

Species	Survival % after coppicing 1981
Alnus cordata	18
Alnus glutinosa	67
Alnus incana	28
Alnus rubra	6

Discussion of species trials at Clonsast

A number of species can be eliminated as being unlikely to give economic yields. These include Eucalyptus and Sorbus. Two Salix species, S.viminalis and S.aquatica gigantea, were promising, while two other, S.smithiana and S.vittelina, gave very poor results. Salix dasyclados gave poor results on peatland. This could be due in part to damage from flea beetle which is particularly severe in the Clonsast area.

The results for Alnus are of special interest since this species has the capacity to fix nitrogen. It is clear that two of the species which are otherwise promising, A.rubra and A.cordata, are very poor in coppicing ability (Table 5). The other two Alnus species are variable in this respect. The variation appears to be genetic. Since the species is difficult to propagate vegetatively, a special study was made on this problem. This is described below. The outstanding feature of these results is that Salix a.gigantea is substantially better than any other clone in these trials.

No.5 Trial- Iteration trial: In the earlier trials only one clone of poplar, TT32, was used. This has proved unsuitable on peatland. However an unscheduled planting of another clone, Fritzi Pauley, in the same area gave promising results, indicating that some clones could tolerate peat conditions. This has later been confirmed with other clones.

A trial was laid down in 1981 with the species/clones and silvicultural treatments which had shown the best promise hitherto. The species used were Populus trichocorpa Fritzi Pauley, Populus hybrid Rap, Salix aquatica gigantea, Salix dasyclados and Salix viminalis. Spacing was 1.2 x 1.2 m. Plots were 4 rows wide and 108 m long and replicated 4 times. In view of the soil variation which occurs, two blocks were deliberately located on the worst type of soil i.e. where the peat has been totally removed leaving only a marl subsoil. The other two blocks were on the more normal type of soil i.e. where about 0.5m of peat remained. Fertiliser application was 37 kg ha^{-1} of nitrogen and phosphorous and 75 kg ha^{-1} of potassium applied in 1981 and 1982, plus a top dressing of 90 kg ha^{-1} of nitrogen in 1982. The trees were pruned to near ground level after planting. A sample harvesting of 16 trees from each plot was made in the autumn of 1983. The results are given in Table 6.

TABLE 6 : Yields from iteration trial on two types of harvested peat soil at Clonsast. Results are for 3 seasons growth in tonnes D.M. per ha.

Species	% D.M.	Soil mainly calcareous marl	Soil with 0.5m peat remaining
Salix a.gigantea	46.3	16.7	73.8
Salix dasyclados	45.9	7.2	27.2
Salix viminalis	47.0	3.3	23.8
Populus Rap	44.3	16.2	36.6
Populus F.Pauley	46.7	12.4	20.6

Discussion of Trial No.5

The results for 3 seasons growth (Table 6) show very large differences due to soil type. Yields on calcareous marl were only one third or less than those obtained where 0.5m of peat remained. This explains many results so far obtained on peatland. Once the problem has been recognised, it can be avoided in future peat harvesting operations.

The yield on the better soil (24.6 t ha^{-1}) were substantially higher than might have been expected even allowing for the fact that spacing, fertiliser application and weed control had been optimised. Bearing in mind the small size of the sample (16 trees per plot), there is the possibility of a substantial sampling error. However, much higher yields have recently been recorded in the somewhat similar climate (49°N) of Washington State with hybrid poplar (29).

It is interesting to note that the yield of poplar, although inferior to Salix aquatica gigantea, is promising. Bearing in mind that many hundreds of poplar exist as compared with a possible two clones of Salix aquatica gigantea, it seems likely that its yield can be substantially increased through the use of genetically improved clones.

EFFECT OF CULTURAL PRACTICES ON THE COST OF SHORT ROTATION FORESTRY

M. Neenan

(1) Cost of establishment

The cost of establishment is determined by three main factors, the cost of plants and planting operations, the establishment obtained, and the density of planting. The cost of plants and planting is dealt with in Section III below.

The foregoing series of trials has provided a number of useful observations regarding the percentage of plants which survive one year from planting. These are summarised in the present paper.

TABLE 7: Results from rooted plants

Species	Soil type	Date of Planting	Minimum % Establishment
Alnus cordata	Mineral	1 April 1977	65
Alnus incana	Peat	7-10 April 1978	82
Betula pubescens	Mineral	1-5 April 1977	55
Castanea sativa	Mineral	5 April 1977	68
Fraxinus excelsior	do.	7 April 1977	80
Populus trichocarpa FP	do.	13 April 1977	80
Populus " Rap	do.	30-31 March 1977	89
Picea sitchensis	do.	12 April 1977	76
Salix viminalis	Peat	7-10 April 1978	89
Salix daphnoides	do.	do.	87
Salix smithiana	do.	do.	77
Populus TT32	do	do.	91
Alnus glutinosa	do.	do.	82
Salix vittelina	do.	do.	94
Sorbus aucuparia	do.	do.	91
Salix daphnoides	do.	19 April 1979	97
Salix viminalis	Western peat	12-30 March 1979	99
Salix a.gigantea	do.	do.	99

TABLE 8 : Establishment from cuttings

Species	Soil type	Date of planting	Minimum % Establishment
Populus spp. Rap	Mineral	8-9 April 1977	31
Salix viminalis	do	11 March 1977	56
Salix a.gigantea	do	15 March 1977	66
Salix dasyclados	do	14 March 1977	77
Salix a.gigantea	Peat	6-7 April 1978	84
" " "	do	30-31 March 1978	86
Populus TT32	do	6-7 April 1978	99
Salix viminalis	do	30 March 1979	99
Salix a.gigantea	do	27-28 Feb.1980	96
" " "	do	14-15 Jan. 1981	99

Results

It is recognised that some species e.g. Alnus have a high failure rate in planting. Apart from Betula pubescens, the results obtained with rooted plants in these experiments are within the expected range.

It will be noted that the technology of establishment from cuttings has increased from 31% and 56% in 1977, to 99% in 1979. This was due to the availability of better planting material, the refrigeration of cuttings until the optimum time for planting, and the control of weeds at the early stages of growth.

(2) The effect of plant density on the yield of short rotation forestry

The number of plants per hectare has an important effect on the cost of production of any forestry system. Costs increase linearly with the number of plants per hectare, mainly due to the labour cost of planting. On the other hand, with widely spaced plants, cost of weed control will sometimes offset the saving in planting costs. To be realistic one must make provision for small machines to go between the rows and this adds yet another variable to the problem of optimum plant density.

In conventional forestry optimum spacing has been determined by experience, and tables are available giving the optimum spacing for each age of plantation. No such experience exists in regard to short rotation forestry.

With a view to providing some information on the optimum spacing, a series of trials was begun from 1977 to 1979. The results to date are given in this paper.

Materials and Methods

Trial No.1 : This was included in an experiment to compare species which was laid down at Oak Park, Carlow in the spring of 1977. Soil preparation and other treatments, were as described earlier. Cuttings of *Salix viminalis* were planted at two spacings, 0.3 and 0.6 m.
The first harvesting was taken in 1978 and the coppice yields from 1981 onwards (Fig.8).

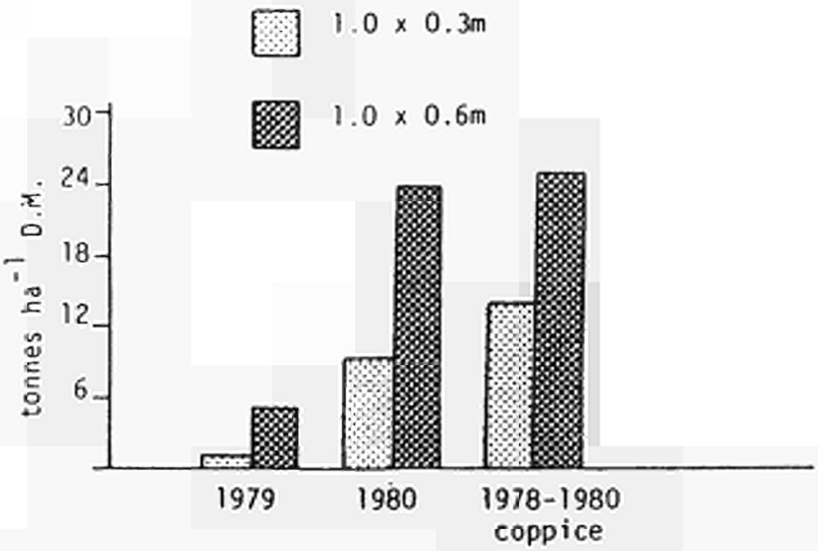


FIGURE 8 : Effect of plant density on the yield of Salix viminalis grown from cuttings, planted in the spring of 1977.

Result

The effect of higher density planting is important during the first 3 years of growth, but differences tend to disappear during the coppicing cycle.

Trial No.2: A Nelder trial covering the range of 0.3 x 1.94 linear metres was laid down at Clonsast in the spring of 1978 with Salix viminalis cuttings. As a precaution against possible soil variation the plantation was made in six segments rather than in a circle. Establishment was about 60%. There was some damage from hares Lepidus temidus. Consequently, plants from two segments were taken out, and used to fill the remaining four replications. All plants were cut back at the beginning of 1980.

In the course of the experiment, it was observed that due to the incidence of weeds, and damage by wind, at the wider spacings (see Plate 10), yields per plant did not increase linearly in proportion to spacing. A two year coppice yield taken in 1982 has been reported (30).

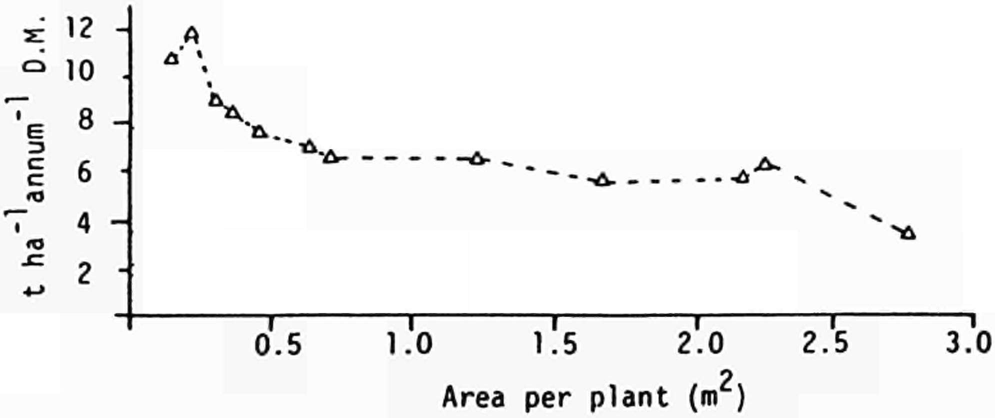


FIG.9 : Effect of plant spacing on the yield of 3 year coppice of <u>Salix viminalis</u> in a Nelder trial on harvested peatland, 1983.

The results for 3 year coppice on one block taken in 1983 showed the yield declined sharply as spacing was increased to 0.45 x 0.45m, but was relatively constant between that spacing and 1.65 x 1.65m (Fig.9). These results may not however be valid for higher yielding species.

PLATE 10 : Nelder trial. Note that at a spacing of approximately 1 m weeds are controlled and leaf litter accumulated.

(3) <u>Spacing trial on blanket peat</u>

This was laid down in the spring of 1979 on improved blanket peat at Glenamoy, Co. Mayo. The soil pH varied from 4.8 to 5.1. Plots were 200m long and 3 or more rows wide. Establishment was 99%. Fertiliser application was 38 kg of nitrogen, 38 kg of phosphorous and

76 kg of potassium, all per ha in 1980. Weeds were a serious problem especially at the wide spacing. Plots were cut back and weeds controlled at the end of 1981. Yields were taken one year later, at the end of the 1982 growing season. The treatments and results are given in Table 9.

TABLE 9

Species	Spacing	Yield t $ha^{-1}annum^{-1}$ D.M.
Salix aquatica gigantea	0.9 x 0.9m	9.3
" " "	0.9 x 1.8m	6.8
Salix viminalis	0.9 x 0.9m	7.7
" "	0.9 x 1.8m	4.0

Results

The results are extremely good for 1 year's regrowth. On the basis of the results from other countries, these yields should increase exponentially over the subsequent 2 years. Until another year's data become available, it will not be possible to evaluate the trade off between yield and the cost of denser planting.

The results also show a substantial advantage in favour of Salix aquatica gigantea over Salix viminalis.

Discussion

The Nelder trial indicated that the optimum spacing is about 1m x 1m. It should be noted however that the species used in this trial, Salix viminalis, is not especially high yielding on peatland.

The trials at Oak Park show that a closer spacing, 0.3 x 1 m, gives a better initial result, but this becomes less significant after coppicing. By the fifth year, there is considerable die back at the closer spacings.

A higher planting density is more costly in terms of material and labour. A wide plant spacing may result in a heavy infestation of weeds, which results in additional costs. There is therefore a trade off in regard to plant density; a wide spacing having low output costs, but requiring relatively expensive weed control measures, and vice versa. It is however difficult to reach firm conclusions on the basis of short term experiments.

(4) Yield of coppice

The extent to which species recover from cutting, and the number of harvestings which one could expect from a single planting, is not well known for most species. Differences between species could be expected to occur. It has been shown in the U.S. (23)(24) that the yield of coppice is 25-50% higher than that of the primary growth. No corresponding information exists in regard to most European species. Some observations have been made on this.

Materials and Methods

Observations were made on the two species trials described above, one on mineral soil and one peat. Weed control was good in both cases, so this was not an interfering factor.

Results

The results for the trial at Oak Park on mineral soil are given in Tables 10 and Fig.7 above.

TABLE 10 : Coppice yield of different species grown at Oak Park, Carlow.

		Coppice yield as % of primary yield			
Experiment	Species	Primary yield			Coppice yield
Species trial	Alnus cordata	79			337
(Oak Park)	Betula pubescens	47			34
	Castanea sativa	114			485
	Fraxinus excelsior	467			952
	Populus F.Pauley	220			77
	Populus Rap	282			386
	Salix viminalis	477			608
	Salix a.gigantea	538			896
	Salix dasyclados	684			755
Spacing trial	Salix a.gigantea	0.91x0.91m	1 yrs.growth		7.7 t ha^{-1}
(Glenamoy)		0.91x1.82m	" "	"	4.2 "
	Salix viminalis	0.91x0.91m	" "	"	4.0 "
		0.91x1.82m	" "	"	0.9 "

In all treatments with the exception of Poplar Fritzi Pauley, coppice yield was substantially better than primary yield. This increase in yield by coppicing is the essential feature of short rotation forestry. In the case of Poplar Fritzi Pauley at Oak Park coppice yield in 1982 was less than the primary yield in 1979. This was due to mortality of the plants because of close spacing (1.0 x 0.3m). The overall results obtained here are in line with those for the U.S. and other countries.

PLATE 11 : Coppice growth of Poplar TT32, two months after harvesting.

FERTILISER EXPERIMENTS ON SHORT ROTATION FORESTRY IN PEATLAND

M. Neenan

The fertilisation of forest trees has been the subject of discussion over a long period. One view is that all inputs into forestry should be kept to a minimum so that a better profit margin can be achieved. The alternative view is that if the growing period is too long, the interest on investment will render the crop uneconomic unless the inputs are kept very low. The same arguments apply to short rotation forestry; a choice has to be made between a high initial investment, and a lower but continuous investment.

Fertilisers are a major cost in short rotation forestry (25)(26). The fertiliser regime must of necessity be matched to the soil type and to an extent, to the species. The results need to be projected to a long term basis. Hitherto little experimental work has ben carried out on short rotation forestry, and such work as exists refers to mineral soil. At the time when this project was begun in 1977, there was no clear indication as to which species would prove best adapted to mined out peatland.

Materials and Methods

Three trials were carried out, all on mined out peatland at Clonsast, and one on blanket peat at Glenamoy.

Trial No.1 - Clonsast, Co. Offaly: Plots consisted of 20 plants spaced at 1.22m in double rows with a discard row between plots. Rooted plants were planted in April 1979, and fertilisation took place in July 1979. Each treatment was replicated 4 times. The species used was *Salix* vittelina. Three rates of nitrogen, phosphorous and potassium were used in a factorial trial of randomised blocks. The plots were harvested after 2 seasons growth. Because of poor growth due to fungus disease (Physalospora myiabeana), yields were low.

Results

The results, which gave only a general indication of the situation, are shown in Fig.10. The response to nitrogen was 70%, as against 35% for phosphorous, and almost no effect, or a negative result from potassium. There were some interactions caused by the unbalance of nutrients.

Trial No.2 - Fertiliser factorial trial on cuttings of Salix aquatica gigantea on peatland

This trial was laid down in an area of newly harvested peatland. Three rates of nitrogen, 0, 100, 200 kg ha^{-1}, phosphorous, 0, 25, 50 kg ha^{-1}, and potassium, 0, 50, 100 kg ha^{-1}, were used in all combinations. Cuttings from refrigeration were planted in the period 22-29 April, 1983. Fertiliser was applied early in May. The new growing shoots were harvested from 7-10 November.

Although large soil variations occurred between blocks, general indication of response can be inferred (see Fig.11). The order of the results was:

$$N_3P_3K_3 > N_3P_3K_1 > N_2P_3K_2 > N_2P_2K_2 > N_3P_2K_3 > N_2P_2K_1$$

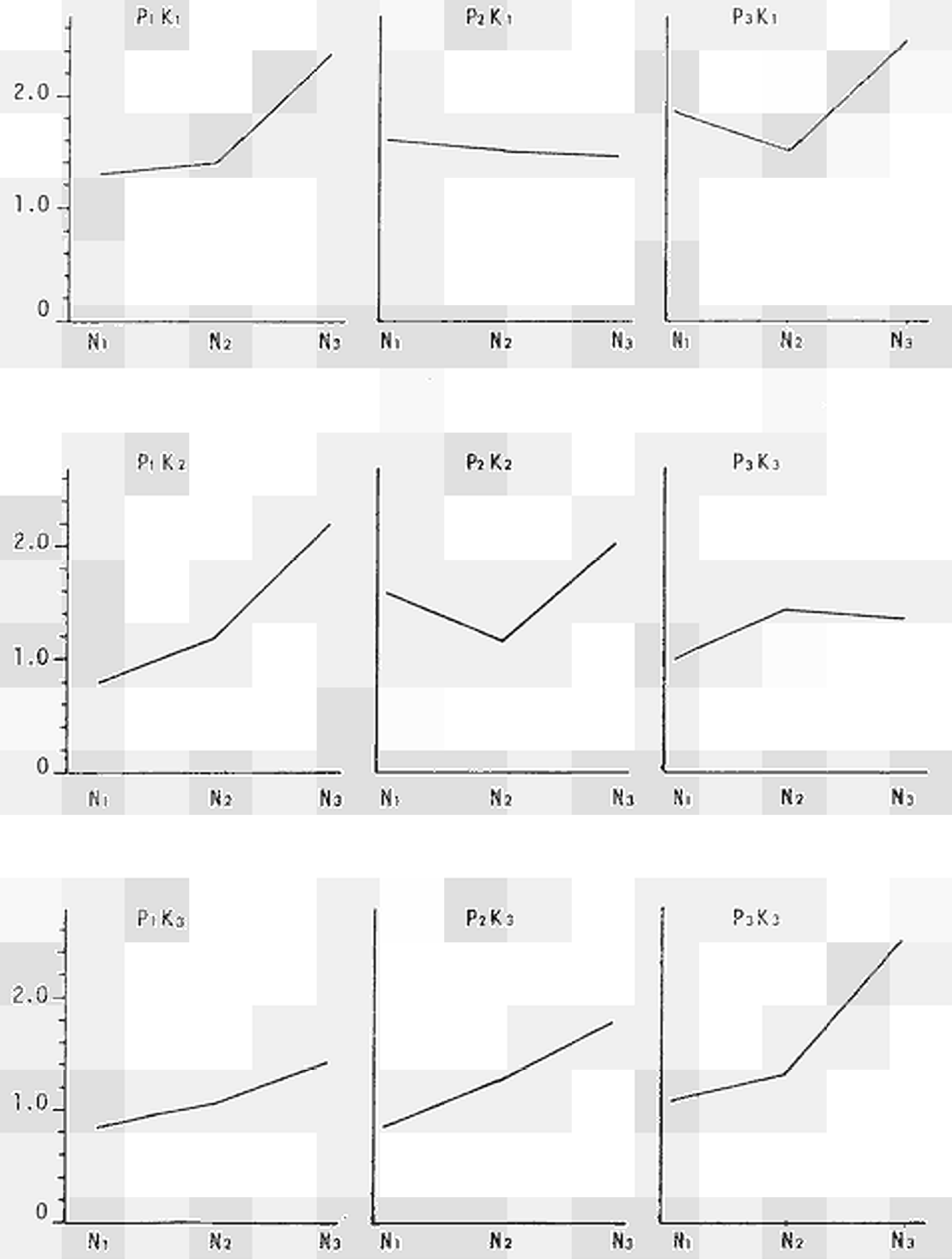


FIG.10 : Results of factorial fertiliser trial on <u>Salix vittelina</u> at Clonsast.

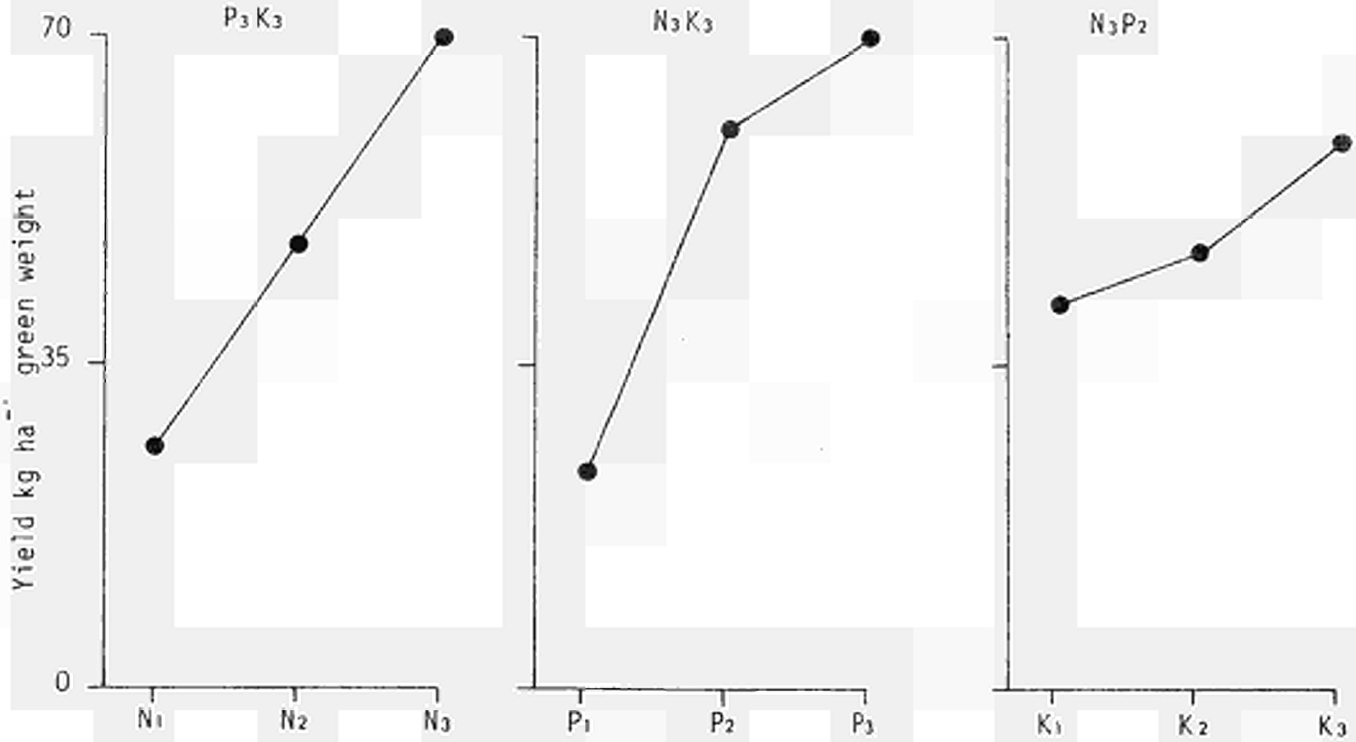


FIG. 11 : Result of fertiliser trial on cuttings of Salix aquatica gigantea planted on mined out peatland.

The most important element was phosphorous but requirements were satisfied at a level of 25 kg/ha. There was a near linear response to nitrogen above the level of 100 kg/ha but nevertheless satisfactory growth could be obtained from 100 kg/ha. The response to potassium was erratic, but as an insurance one might apply a minimal quantity i.e. 50 kg/ha. This gives an initial approximation of the fertilisers required in the first year as

25 kg ha^{-1} of Phosphorous

100+ kg ha^{-1} of Nitrogen

50 kg ha^{-1} of Potassium

Trial No.3: In 1978 a trial was laid down to compare the effect of different rates of nitrogen fertiliser on the yield of *Salix aquatica gigantea* and *Populus* TT32. Planting was by cuttings spaced 0.6m apart each way. Each plot consisted of 20 plants and there were 5 complete and 1 incomplete replications. A basal dressing of 88 kg of P and 176 kg of K per ha was applied at planting time (30 and 31 March 1978). The nitrogen treatments were applied on 28 April 1978. The weedkiller simazine was applied on 1 May 1978. The trees made relatively little overground growth in the first year. The same treatments were reapplied at the beginning of 1979, when all plants were cut back. One replication (Block VI) was harvested in 1980, Block IV was harvested in 1981 and the remaining four blocks were harvested in 1982. All plots were harvested in 1983. The results are given in Table 11.

Results

The results (Table 11) show that the target yield of 12 t ha^{-1} $annum^{-1}$ was attained in 3 years. The response to the nitrogen treatments was inconsistent in that the control treatment was not the worst. This was due to soil variation, later diagnosed as being caused by the presence of fossil wood in the deeper layers.

TABLE 11 : Yields of Salix aquatica gigantea coppice for 1, 2, and 3 years regrowth in the nitrogen fertiliser trial at Clonsast.

Period of growth	% D.M.	Yield
1 year	45.4	12.3
2 years	45.7	34.7
3 years	45.5	47.2

Trial No. 4 - Soil acidity studies on peatland

A pot experiment was conducted on acidity tolerance of *Salix aquatica gigantea*. Acid soil (Sphagnum) from Clonsast was taken to Oak Park where it was allowed to dry out and then broken down to a fine condition. The soil was potted and afterwards the contents of each pot poured on a large sheet of paper. Increments of calcium oxide were added and thoroughly mixed in before repotting. After two weeks, during which the soil was kept moist using distilled water, samples were taken for pH. This ranged from 3.6 to 6.1 (in water). Cuttings were planted in the pots which were maintained in a heated greenhouse. Harvesting took place after 3 months growth. As the results were inconsistent, the experiment was repeated twice more. The final result is still not conclusive (Plate 12), but indications are that from approximately pH 5.3 upwards, acidity is not a major limiting factor with Salix aquatica gigantea. This is further borne out by the good results obtained at Glenamoy where the pH varies from 4.8 to 5.2.

The most surprising result in this carefully controlled experiment, is the large variations which occur in apparently uniform soil.

5.3	5.3	5.1	4.6	4.7	4.2	4.0	3.6	pH
5.6	5.8	5.4	4.4	4.6	4.1	3.8	3.4	values
5.4	5.7	5.2	5.2	4.8	4.1	3.8	3.6	

PLATE 12 : Effect of different increments of calcium carbonate on the growth of Salix aquatica gigantea.

Discussion

In trial No.1, the species used was not a high yielding one on peatland. Although the yield results are low, they provide an indication of the nutritional requirements. The greatest response is to nitrogen, and the least to potassium. This result has been confirmed in Trial No.2.

In Trial No.3, the results were a reflection of nitrogen levels, but the optimum yield was obtained with Treatment 5 which is 207 kg of nitrogen per ha. The result is approximately the same after 4 years growth but with the possibility that the optimum might have been reached with treatment 3 (103.5 kg ha^{-1}) or treatment 4 (155 kg ha^{-1} N).

Taking treatment 207 kg ha^{-1} as the optimum, this gives a yield of approximately 30 t ha^{-1} more than the control over 4 years, which is equivalent to 7,500 kg per annum. This is equal to 36 kg of dry matter per kg of nitrogen applied. This may be compared with cereals where the normal range is 5-15 kg of grain per kg of nitrogen. Allowing for straw, the return of total biomass cannot be more than 22 kg per kg of fertiliser nitrogen in the case of cereals. The response to nitrogen by short rotation forestry is therefore of the same order of efficiency, as for other agricultural crops. Nevertheless, efforts must be made to reduce the cost of nitrogen which is one of the most expensive inputs.

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THE RECOVERY OF POPULUS AFTER MECHANICAL HARVESTING

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An area of approximately 1 ha of P.trichocarpa x P.tacamahaca clone 32, which is commonly referred to as TT32, was harvested in the course of testing the prototype short rotation harvester [Contract No.ES-E-R-019-EIR (N)]. Damage to the stumps was apparently severe, many being split all the way to ground level. An experiment was undertaken in order to ascertain whether this damage was significant and if so how it could be overcome by chemical and other treatments. Except where indicated, stumps were not re-cut prior to painting.

Materials and Methods

The following treatments were applied in April 1982:-

1. No paint (control)
2. Bitumastic paint only
3. White paint only
4. White paint containing*Benzyladenine (BA) (5 mg/l)
5. White paint containing BA (50 mg/l)
6. White paint containing BA (50 mg/l) applied to freshly cut stumps
7. White paint containing BA (500 mg/l)
8. White paint containing BA (50 mg/l) + Naphthaleneacetic acid (5 mg/l)

* Benzyladenine is a growth regulator with a known capacity for inducing adventitious buds.

Each of the eight treatments was replicated four times. Each treatment consisted of twenty plants.

PLATE 13 : General view of Poplar TT32 taken after mechanical harvesting and subjected to various treatments as described in the text.

Results

The coppicing capacity was evaluated one year later. Results showed that all trees coppiced; there was no significant difference between treatments. An average of 23 coppice shoots were produced per stump but only one or two shoots become dominant. Dominant shoots were over two metres in height after one growing season.(See Plate 11)

These results show that the natural coppicing ability of *Populus* hybrid TT32 is sufficiently high to ensure successive regeneration. Furthermore, this natural system appears to be self thinning since only one or two shoots became dominant.

WEED CONTROL

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Weed control is a major consideration in the development of short rotation forestry plantations. Since the crop is new, relatively little is known of the selectivity of standard herbicides for broad leaved species. Some information is available from nursery practice, and this indicates that differences occur even between clones (1).

There are two main problems to be resolved, firstly which herbicide is effective in controlling the range of weeds which occurs, and secondly which herbicide will give a sufficiently good result, at a reasonable cost. It will be noted that costs incurred at the beginning can add greatly to the final cost of the biomass; hence relatively inexpensive materials must be used where possible.

Early experience clearly ruled out the option of no weed control especially on peatland where seedlings germinate very readily. During the period of the contract a series of trials was carried out on the main candidate species, and with the full range of herbicides which is commercially available. The terminology used in this paper is the same as that in the British Weed Control Handbook (2).

Test 1

The objective was to investigate the effect of a range of residual herbicides on rooted and unrooted cuttings of *Salix aquatica gigantea*. The date of application was March 20, 1981. The treatments (as proprietary product per hectare) and results are given in Table 12.

TABLE 12

Treatment	Rates	Relative Cost (at low dose)
Atrazine	3.3, 6.6, 13.2 kg/ha	200
Devrinol	4.2, 8.4, 12.6 kg/ha	900
Kerb	3.3, 6.6, 13.2 kg/ha	600
Ramrod	5.7, 8.5, 17.0 l/ha	100
Ramrod	5.7 l + CIPC 4.2 kg/ha	100 + 300
Ronstar	11.0 and 22.0 l/ha	500
Simazine	3.3, 6.6, 9.9 kg/ha	100
Terbuthylazine	3.0, 6.0, 12.0 l/ha	500

Results

Few weeds developed during the first season. The medium and high doses of Ramrod, Ronstar and Ramrod and CIPC (higher dose) caused slight damage to the *Salix*. Other treatments caused no injury to the crop. At the end of the third season weed control was best at the higher rates. This test therefore confirmed the suitability of a number of materials which can be applied at the planting stage and which will cause no crop damage. The old established materials such as Simazine were as effective as the newer and more expensive materials.

Test 2

The aim of this trial was to investigate the effect of a range of herbicides against an established weed cover of *Juncus* spp. Application date was May 29. The treatments were as follows:

Asulox	1.7, 3.4 kg/ha
Casaron	56, 112 kg/ha
Diquat	4.2 l/ha
Gramoxone	4.2 l/ha
Roundup	2.1, 4.2, 8.4 l/ha
Ronstar	10, 20 l/ha
2,4-D	4.4 kg/ha

Results

The weed most difficult to control and that which caused suppression of the crop in unsprayed areas, was Juncus effusus (soft rush). At time of spraying, the rush stood about 20 cm high amongst coltsfoot (Tussilago farfara) and a variety of grasses.

A directed spray of Gramoxone at 4.2 l/ha was the most effective. Roundup at 1.5 l/ha and 3.0 l/ha gave only transitory control, and weed regrowth occurred even at the rate of 6.0 l/ha. The material 2,4-D resulted in excellent overall weed control. Most of the treatments were moderately or highly effective but Asulox failed to control rush. Regrowth of trees was poor in control plots due to heavy overgrowth of weed vegetation (especially that of Juncus). The least expensive materials, 2,4-D and Gramoxone, were equal to the best.

Test 3

The object of this test was to ascertain if herbicide on the newly cut surfaces of the biomass species would damage Salix aquatica gigantea after harvesting. Treatment was Gramoxone at 4.2 l/ha as an overall spray.

Results

Although droplets of Gramoxone lodged in the concave surfaces of the recently cut stems, no damage to the newly developing shoots was evident and the plant was unaffected by the treatment whilst weed control was excellent. It is concluded therefore that this spray can be safely used in the stage between harvesting and regrowth.

Test 4

The objective of this trial was to test Gramoxone with Atrazine against *Juncus effusus* in *Alnus incana* which had been coppiced. The treatments were Gramoxone at 2.8 l/ha plus Atrazine at 6.7 kg/ha as an overall spray on February 11, and untreated control plots.

Results

The treated plots remained weed free for over one year, thus allowing the Alder the opportunity of sending out new shoots which reached 1.3 metres in height. There was slight but transitory yellowing on *Alnus*, which did not appreciably affect the growth. Control plots were overgrown by *Juncus* spp. and other weeds. Their effect on regrowth reduced the height of first year shoots to 0.7m. The tolerance of *Alnus incana* to this herbicide combination has been established.

Test 5

The objective was to compare three rates of Gramoxone (applied in early spring) for the control of mature *Juncus effusus*. The treatments were Gramoxone at rates of 0.7, 1.4 and 2.8 l/ha, applied as overall sprays to 1m high *Juncus* in the pathways in a *Populus* plantation.

Results

The high rate of Gramoxone gave good control of rush, but as the weed was so dense, the bases of the clumps were protected from the spray and some regrowth occurred. All small rush was killed outright by the high and medium dose. The low rate of Gramoxone gave a reasonable amount of kill, but most rush clumps regenerated within a short time.

It is concluded that very mature *Juncus effusus* cannot be killed even by high rates of application. This emphasises the need for herbicide treatments such as described in Test 1.

Test 6

The aim was to see if the control of large clumps of *Juncus effusus* could be achieved by a granular application of Casoran at their bases. Treatments were Casoran G at rates of 111, 222, and 444 kg/ha.

Results

The low rate had no effect on the *Juncus* clumps. The medium rate showed slight yellowing but new growth was strong and healthy, and the high rate although affecting some kill of the top portion of the weed, did not affect its regrowth. The rate which is effective is somewhat too costly.

Test 7

The purpose of this trial was to compare early spring application of Gramoxone (with and without a surfactant) with Roundup for the control of Juncus effusus in Alnus incana. Treatments were Gramoxone at rates of 1.4, 2.8, 5.6 and 4.2 l/ha (with and without Agral) and Roundup at 4.2 l/ha.

Results

There was good control of rush at the high and medium rates of Gramoxone. The effect was not enhanced by the surfactant. The low rate of Gramoxone gave transitory control but regrowth of the weed occurred. The rush was well checked by Roundup but by the end of the season the bases of clumps were regrowing. There was therefore no possibility of reducing the cost through a lower rate of herbicide combined with a surfactant.

Test 8

The objective was to test the effect of Casoran G on the control of an extensive range of weeds in a Poplar plantation on mineralised peatland. The treatments were Casaron G at rates of 100 and 200 kg/ha (applied March 21).

Results

The low growing weeds were controlled by the heavier dose of Casaron G but the lower dose was less effective. At the end of the second season, plants of Populus (the biomass species) in control plots were 8-10% taller than plants in the treated plots. The effective treatment was rather expensive.

Test 9

The aim was to investigate the effect of Gramoxone against a carpet of perennial grass in a young plantation of Salix aquatica gigantea. Application was in early February. Treatments were Gramoxone at rates of 1.4, 2.8 and 4.2 l/ha.

Results

Grass control was most satisfactory at the highest rate, but at the low and medium rates the effect was transitory and regrowth occurred. Re-colonisation was well advanced in all plots by the end of July. There was a clear advantage (15%) in growth vigour to the plants in the sprayed plots.

Test 10

The objective was to test the effect of three herbicides on a heavy perennial grass infestation in a crop of recently planted cuttings of Salix aquatica gigantea. The treatments all of which were applied in mid May, were TCA at 33 and 66 kg/ha, Dalapon 5.6 and 11.2 kg/ha and Clout at 2.8 and 5.6 kg/ha.

Results

Severe damage was caused to the crop by TCA and Dalapon, at both rates. Clout at the lower rate gave fair weed control and caused no damage to the crop. At the higher rate of Clout, control of grass was excellent and crop growth good. Control plots showed less vigorous growth by 20% in comparison with both Clout application levels.

Test 11

The objective was to test a mixture of a contact herbicide (Gramoxone) and residual material (Kerb) as a means of controlling grass (perennial) in a young plantation of Salix aquatica gigantea. Application was in both November and December since the lower dose of Gramoxone is known to be effective for weed control during periods of the year when light intensity is low. Treatments were:

Kerb	3.3 kg/ha
Kerb	6.6 kg/ha
Kerb	6.6 kg/ha + Gramoxone 1.4 l/ha
Kerb	6.6 kg/ha + Gramoxone 4.2 l/ha
Kerb	3.3 kg/ha + Gramoxone 1.4 l/ha
Kerb	3.3 kg/ha + Gramoxone 4.2 l/ha

Results

The slow acting Kerb was not very effective in keeping weed vegetation controlled during the early shoot production of the young plants, but at the higher rate was effective in the longer term control of grass. Kerb at both rates mixed with Paraquat at both rates gave excellent and season-long control of grass, and allowed the unimpeded development of side shoots in the crop. The mixtures containing the higher dose of Kerb were effective for one and a half growing seasons after which grass has begun to re-colonise. There was not noticeable or recorded differences between applications in November and December.

Summary

The effective and economic control of weeds in biomass plantations is essential. Good progress has been made in achieving this whereby a timely application of a contact herbicide (gramoxone) and residual materials (Simazine, Kerb or Atrazine) will maintain weed-free conditions during the crucial stage of crop establishment. Propagation of biomass species is mostly carried out by means of direct stuck cuttings in levelled and fertilised peatland and early germinating and fast growing competitive weeds are detrimental to side shoot development after rooting. As long as the weed population in general and some fast-growing grass species and others (willow herb, rush) in particular, go unchecked, the crop will only make limited progress in the first season.

During the succeeding seasons the weed problem will alter as a result of the selective aspects of weed control regimes. In plantations dominated by the crop e.g. *Salix aquatica gigantea* and *Populus* hybrid, a serious weed problem with *Rubus* (blackberry) can be anticipated. In addition stoloniferous grasses are creating thick mattings of vegetation on the plantation floor and if both of these problems go unchecked they may cause interference to harvesting.

Thus further work on the control of weeds in the changing flora of biomass plantations is necessary.

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Circumstance	Herbicide and rate	Application frequency	Cost per hectare	Comments
1. Recently planted, cuttings of biomass species, in dormant season.	Simazine @ 3.3 l/ha as overall spray	After initial planting on	£8.50	Early weed control is essential so crop can get head start on competing weed problem
2. One year old established plantation which has a weed problem before the season starts. (To be repeated on two and three year old stock where weeds persist and cover of ground by crop is incomplete)	Gramoxone @ 4.2 l/ha a) Simazine @ 3.3 kg/ha or b) Atrazine @ 3.3 kg/ha (against grass) or c) Kerb @ 3.3 kg/ha (against grass)	Annually before bud burst	£34.00 + a) £ 8.50 b) £50.00 c) £80.00	Applied in Feb/March. The object is to kill green weed vegetation in order to allow crop unimpeded progress in early part of season
3. <u>Special Problems</u>:				
a) <u>Juncus effusus (Soft rush)</u>	Gramoxone @ 4.2 /ha as directed treatment in summer or Gramoxone @ 2.1 l/ha as directed spray in Spring/Summer on dense weeds	Annually	£34.50	Controls an extensive range of weeds
b) <u>Epilobium (Willow herb)</u> and	Roundup @ 4.2 l/ha	As required	£17.00	Applied when weed is in full growth, as spot or directed spray
c) <u>Tussilago farfara (Coltsfoot)</u>	Casoron G @ 112 kg/ha	March annually	£260.00	Used only as spot treatment

PROPAGATION OF HARDWOOD CLONES BY MEANS OF TISSUE CULTURE

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Some species and clones are difficult to propagate by conventional methods. Each genus presents different problems in propagation. Hybrids of Populus and Alnus tend to be sterile, and hence vegetative propagation is necessary. Populus species such as P.tremula, P.tremuloides and their hybrids (aspens) cannot be easily propagated by cuttings. Alnus seeds are genetically heterogenous because Alnus is an outbreeder. Vegetative propagation of all Alnus species is difficult. For Alnus and Salix species, considerable gains are anticipated from selection and vegetative propagation of superior individuals.

Vegetative propagation by tissue culture can be used to overcome a number of these problems; in addition it facilitates rapid propagation of superior individuals selected in the field, and the multiplication of promising clones from a small amount of starting material.

1. Propagation of Populus species and hybrids

Hybrid seeds of P.tremula x P.tremuloides obtained from Prof H. Muhs (Germany) germinated poorly in soil. Percentage germination was improved from 57% to 70% by germination of seed on agar. Some plants were transferred to soil, others were propagated by tissue culture. From a single plantlet 3-4 plants could be obtained every four weeks by development of axillary buds. Development of axillary buds was stimulated by benzyladenine (0.25 mg/l). Clonal variation in shoot forming capacity was observed.

Systems of tissue culture propagation were investigated for P.deltoides, P.trichocarpa, P.wilsonii and Populus hybrid TT32 i.e. (P.trichocarpa x P.tacamahaca). With all four species, sterile buds were established in culture. Multiple shoot formation was induced in the presence of benzyladenine (1.0 mg/l) for Populus hybrid TT32. Stem internodes of all four species produced adventitious shoots in the absence of growth regulators. Adventitious shoots appeared to arise from cambial tissue. A mean of 5 shoots were obtained per cultured internode. The yield of plantlets was determined by internode size and position of internodes on plants. Sucrose was essential for shoot formation, 3% was optimal. Plants were rooted and transferred to soil. Plants appeared true-to-type. Adventitious shoot formation in internodes permits the use of all parts of a cutting for propagation.

Mass propagation by cell culture was studied using Populus hybrid TT32. Callus initiated from stem internodes proliferated in liquid medium containing 0.5 mg/l 2,4-D. Cell-colonies grew rapidly in liquid medium and required subculture every week. Cell-colonies retained their capacity to undergo shoot differentiation. When cultured without 2,4-D and in the presence of benzyladenine (1.0 mg/l) plus indolebutyric acid (1.0 mg/l) up to 80% of cell colonies formed shoots yielding up to 11 shoots per colony (1). Shoots were subsequently rooted and transferred to soil. Plants were true-to-type indicating the potential of this system for mass propagation. Further studies have shown that callus induction is also possible for P.deltoides, P.trichocarpa, P.nigra and P.wilsonii.

Plant regeneration from cultured cells and cambial tissue suggest that shoot formation occurs from single cells or small groups of cells. This affords a possibility of altering the genetic constitution of cells prior to regeneration. Protoplasts fusion for hybridization (1) and cell irradiation may facilitate production of useful new clones.

2. Propagation of Alnus and Salix

Buds were collected from 15 year old trees of A.rubra and A.incana and from coppiced trees of A.rubra. Buds were difficult to decontaminate for tissue culture. Actively growing shoots were easily killed by treatments designed to eliminate contaminating micro-organisms. Buds collected in the dormant season were enclosed by scales and were less sensitive to surface sterilization procedures. Sterile cultures were obtained from 10% to 30% of dormant buds.

Four different formulations of macro elements were tested. A medium relatively low in potassium and nitrogen (2) was best for establishment of alder buds in culture. Gibberellic acid (10.0 mg/l) stimulated growth in dormant buds; benzyladenine (1.0 mg/l) was also stimulatory. After several subcultures, a mass of shoot-forming tissue was produced from Alnus buds cultured with 0.25 mg/l benzyladenine. Average shoot yields of 20 (A.rubra) and 40 (A.incana) were obtained per culture every six to eight weeks. Excised shoots of both species gave 100% rooting when cultured in vitro with 5.0 mg/l indolebutyric acid. Rooted plants were readily transferred to soil.

Experiments on culturing buds of Salix aquatica gigantea were successful. Buds were established on Anderson's (2) medium and conditions for multiple shoot formation are under study.

Experiment No. 1: Nitrogen fixation rates and dry matter yields in alder species:

Field plots were established from one year old plants of *Alnus incana*, *A. glutinosa*, *A. cordata*, and seedling plants of *A. rubra*, at Johnstown Castle. Dry matter yields of plant component parts (leaf, shoot, root, and nodule mass) were determined at intervals throughout the growing season, and nitrogen fixation rates measured by the acetylene - ethylene reduction technique (1).

Preliminary cutting experiments showed a loss in nitrogen fixing activity associated with shoot removal. Following cutting, rates of fixation decreased slowly for 2 hours, and after 4 hours began to decline rapidly. About 10% of the original activity remained after 24 hours. In order to avoid any such losses when measuring nitrogen fixing activity, complete plant systems were used, in specially constructed assay chambers, large enough to accommodate the intact plant.

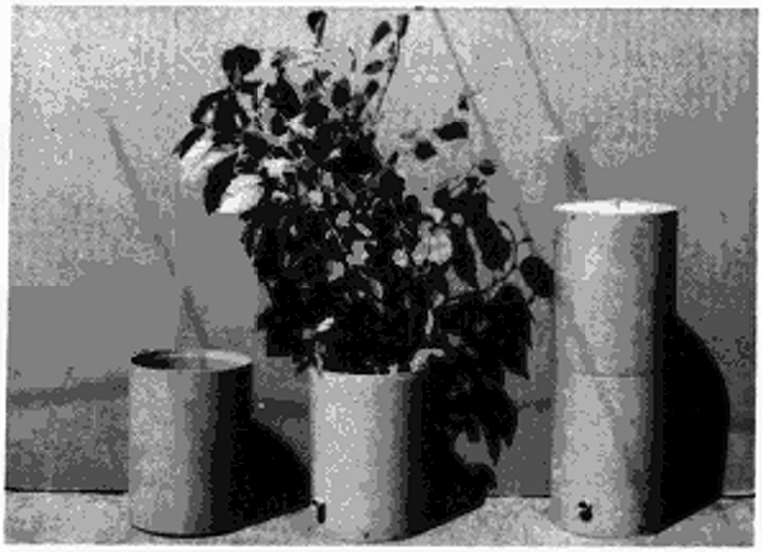


PLATE 17 : Assay chambers used to measure nitrogen fixation rates of intact alder plants.

The chambers were constructed from wavin piping (8" diameter) worked on a lathe to produce two sections fitting with a tongue and groove coupling joint. The internal volume of the chambers was 20L. A circular hole (1.5 cm diam.) was drilled in each section of the chamber to allow both delivery of acetylene gas into the assay system, and the removal of gas samples for ethylene estimations upon completion of the assay. Plants were incubated for 90 mins in the chambers, with both gas inlets sealed to prevent leakage.

Results

Nitrogen fixation commenced late in March in all species, coinciding with leaf emergence. Activity rose to a peak in mid summer, declined rapidly in late September with the onset of leaf senescence, and finally ceased late in November/December when leaf fall was complete. It should be noted that *Alnus* sheds its leaves somewhat later than most other species.

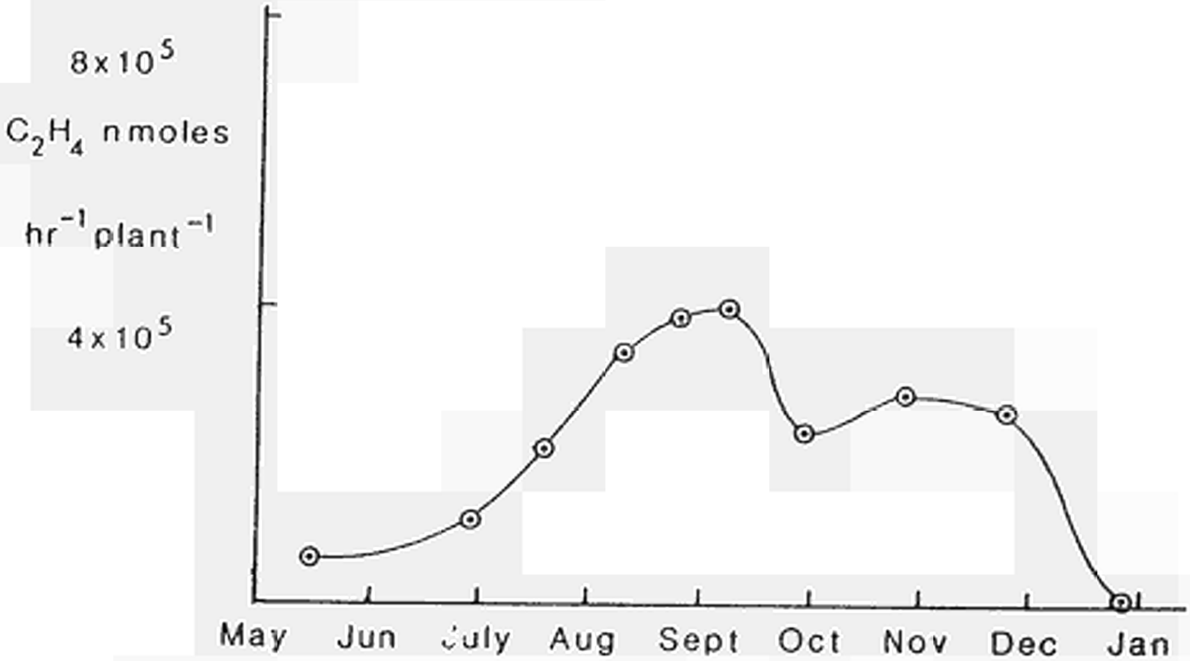


FIGURE 12: Seasonal pattern of nitrogen fixing activity in *Alnus rubra*

A similar seasonal pattern of dry matter production was observed, growth rates rising in Spring, peaking in mid-Summer, at the time when nitrogen fixing activity was highest, then declining during Autumn. Nitrogen concentration in the leaves was highest in Spring, falling somewhat over the growing season, suggesting that nitrogen is exported from the leaves for other parts of the plant (Table 16). High concentrations of nitrogen were still present in the leaves immediately prior to leaf fall. Silvester (2), reports that the litter of Alnus species contribute considerable amounts of nitrogen to the ecosystem.

TABLE 16: Variation in the nitrogen content in the leaves of four alder species, over the growing season.

SPECIES	% N content in leaves		
	Early April	Mid August	Early October
A. rubra	4.6	3.4	3.2
A. glutinosa	4.3	3.7	3.6
A. cordata	4.0	3.5	3.2
A. incana	4.7	4.0	3.4

More than 70 per cent of the nitrogen fixing activity occurred between mid-June and mid-September. The quantities of nitrogen fixed per hectare from March to November based on a high planting density, are given in Table 17.

TABLE 17: Nitrogen fixed kg ha^{-1} $annum^{-1}$, by four alder species, where the planting density was 10,000 plants ha^{-1}.

SPECIES	Kg nitrogen fixed $ha^{-1}annum^{-1}$
A. incana	212
A. glutinosa	140
A. cordata	115
A. rubra	105

A. rubra, which was still in the seedling stage when planted out, fixed the least nitrogen. However this species had the highest specific activity (Nitrogen fixed/g dry nodule wt.) and also had the greatest growth rate.

Field plots of seedling plants of the newly introduced species A. firma, A.japonica, and A.nitida (which had performed well in glasshouse conditions), showed a similar seasonal pattern of nitrogen fixation. However, absolute rates of fixation were poor, as were growth rates.

Experiment No.2: Effect of soil on alder nitrogen fixation:

A.rubra seedlings were planted singly in 5" pots containing a mineral soil (Johnstown Castle) and peat soils obtained from Clonsast, Glenamoy, and Swanlinbar areas, in May, 1982.

Preparation of soils: Lime was added to raise the pH of the soils for values suitable for nodulation to occur (pH 5.6 - 5.8). The amounts required were determined by experiment. (Table 18).

TABLE 18: Levels of lime added to 4 soils, to raise the pH to values suitable for nodulation of alders.

Soil	Lime (g) $457g^{-1}$soil	Original pH	pH after addition of lime
Swanlinbar	1.00	5.2	5.8
Clonsast	2.22	4.0	5.6
Glenamoy	2.22	4.3	5.7
Johnstown	0	5.7	5.7

(pH values are those occurring 8 weeks after addition of lime)

Osmocote, (a controlled release fertilizer containing 18%N, 4.8%P, 8.3%K and 3.4%S) and fritted trace elements were mixed into the soils, at the recommended levels of 457g Osmocote/171g fritted trace elements/51.184 kg peat. Plants were maintained with water, in glasshouse conditions. Plants were assayed at intervals for nitrogen fixing activity, and after one year dry matter yields were determined.

TABLE 19: Percentage plants fixing nitrogen and rates of nitrogen fixation by A.rubra, in 4 soils, 3 months and 1 year following planting

	After 3 months		After 1 year	
Soil	% Plants fixing N_2	Mean Activity C_2H_4 n moles pl/hr	% Plants fixing N_2	Mean Activity C_2H_4n moles pl/hr
Johnstown Mineral soil	50	12,705	100	374,900
Clonsast mined out peat	42	4,200	100	102,090
Glenamoy western Blanket peat	25	7,880	100	23,340
Swanlinbar Gley soil	16	566	100	97,280

The highest rates of nitrogen fixation and total dry matter yield occurred in the mineral soil. Although effective nodulation was slow in the Swanlinbar soil, after one year rates of nitrogen fixation and dry matter yields were similar to those obtained in the Clonsast peat. The poorest rates of fixation were found in the Glenamoy peat after one year, surprisingly, as after three months, plants in this soil were the second highest fixers of nitrogen.

These results suggest that the highest concentration of the alder endophyte was present in the mineral soil and that the distribution of the endophyte in the other soils is limiting for optimum nodulation and nitrogen fixation.

Experiment No.3 :

Aseptically grown seedlings of *A.nitida* and *A.firma* were planted singly in 4" pots, containing 4 different soils, treated with lime, on 9 February 1983. Plants were maintained with Crones (nitrogen free) nutrient solution, pH 5.8. After six months plants were assayed for nitrogen fixing activity.

TABLE 20: Nitrogen fixation by A. nitida and A. firma in 4 different soils, 6 months after planting.

	Mean Activity C_2H_4 n moles pl^{-1} hr^{-1}	
Soil	A. firma	A. nitida
Johnstown, mineral soil	42452	36786
Swanlinbar, gley soil	35935	28102
Glenamoy, blanket peat	30849	18595
Clonsast, mined out peat	26632	10094

A. firma had a higher fixation rate than A. nitida in all four soils. The highest rates of fixation occurred in the mineral soil, while the lowest activities occurred in the Clonsast peat. Referring back to Table 13, the lowest activities in A. rubra occurred in the Glenamoy peat, while the Clonsast peat showed rates of fixation similar to those of the Swanlinbar soil. This suggests that different alder species are selective for different strains of the endophyte present in the soils.

Experiment No. 4: Effect of inoculation:

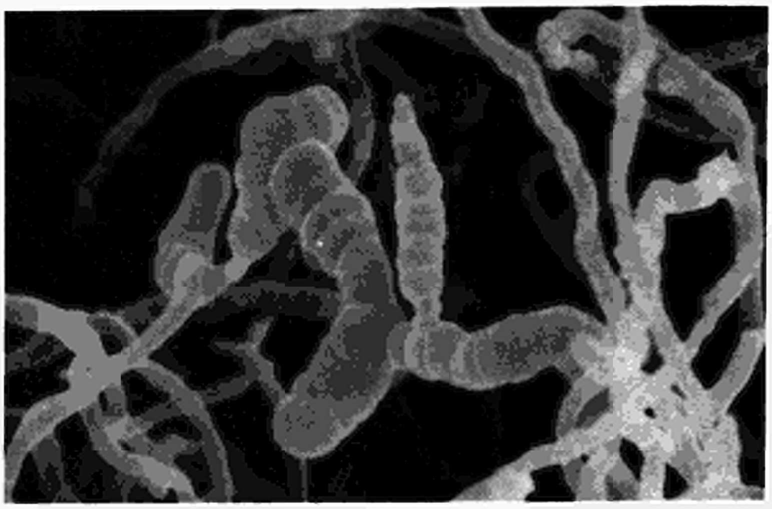
Aseptically grown alder seedlings were planted in Clonsast peat, and inoculated with a crushed nodule suspension containing the nitrogen fixing endophyte. There was a marked response to inoculation in A. nitida, A.incana, and A.firma in terms of both increased nitrogen fixation and dry matter production. A.rubra, A.cordata, and A. glutinosa, showed no such response.

It is reasonable that a more infective, less effective strain of endophyte, present in the Clonsast peat, successfully competed with the applied inoculum where no response was observed.

Experiment No. 5: Isolation in pure culture of the nitrogen fixing endophyte:

The endophyte of A.rubra and A.incana have been isolated using a combination of techniques described in the literature. Surface sterilization of nodules with osmium tetroxide, coupled with pre-incubation on nutrient agar to detect remaining surface contaminants proved most effective. Aseptically sliced nodule sections were incubated at 25°C submerged in liquid nutrient medium. Filamentous outgrowth from the nodule sections was evident after 4 weeks, and the organisms grew successfully on sub culturing. Microscopic examination of both isolates revealed an actinomycete with branched hyphae, containing sporangia.

PLATE 18 : Scanning Electron micrograph of A.rubra endophyte in pure culture SEM x 5100



Hyphae

Sporangia

Both isolates nodulated and fixed nitrogen in aseptically grown alder seedlings, at rates varying from (0.5 - 1.5) x 10^3 n moles C_2H_4 $hr^{-1}g^{-1}$ fresh nodule wt.

Discussion

Field evaluations of a number of alder species revealed that species of *A.rubra*, *A.cordata*, *A.glutinosa* and *A.incana* have rapid growth rates, and fix large quantities of nitrogen, comparable to fixation rates in legume species.

The species *A.rubra* is particularly promising. This makes the proposition of short rotation forestry feasible in two respects:

(a) indepedence from fertilizer nitrogen requirements.

(b) rapid biomass production.

Selection for trees genetically disposed to fix high levels of nitrogen is a consideration, which could be of practical importance in optimising the potential for biomass production from short rotation forestry.

The *Alnus* endophyte appears to be widely distributed. Nodules were found on all alder trees on areas visited. Experiments determined that levels of endophyte vary in different soils, and that different alder species may select for certain strains of the endophyte.

For optimum nodulation and nitrogen fixation, inoculation with effective, efficient strains of the endophyte is desirable. Inoculation responses were obtained in some species using crushed nodule suspensions, but such crude inocula are unreliable.

Infectivity tests with the isolated strains of *A. rubra* and *A. incana* proved positive, but inoculation studies have not yet been evaluated.

Screening for highly efficient strains of the nitrogen fixing endophyte may be a means of significantly increasing nitrogen inputs into short rotation forestry systems using large scale inoculation

Conclusions

(a) Alnus species can contribute up to 200 kg N/ha/annum to a short rotation forestry system.

(b) Maximum rates of nitrogen fixation are obtained on mineral soils and use of marginal land areas for production e.g. peatlands may require inoculation with appropriate bacteria to achieve maximum benefit from nitrogen fixation.

(c) Procedures are now becoming available for obtaining pure cultures of the nitrogen fixing endophyte which will greatly facilitate inoculation.

References

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PROPAGATION OF POTENTIALLY USEFUL ALNUS SPECIES

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Many of the genera being tested for growth performance in the biomass tests are commonly propagated by seed, eg. Alnus, Betula and Sorbus. When a selection or hybrid shows a desirable growth performance, then propagation must be carried out by vegetative means. Hardwood cuttings of most (but not all) forms of Salix and Populus root easily. Alnus is noted for being difficult to root from either hardwood or softwood cuttings.

Although all species can be rooted by tissue culture, this is a relatively costly procedure. As indicated above, the more difficult species of Alnus can be propagated in this way. It was necessary however to ascertain if a less expensive method could be developed for some species of this genus. Several tests were carried out with both softwood or hardwood cuttings.

The hardwood cuttings were inserted in boxes in a damp compost of two parts of moss peat to one part of washed sand of granitic origin. All cuttings were propagated in an unheated house in early January and were recorded for rooting in the following May. The results are shown in Table 14.

The softwood cuttings were taken at the end of May. A small knob of the previous years wood was left at the base of each cutting. Although rooting was not of a high order except of A.incana, it is nevertheless felt that this type of propagation is more controllable. Softwood cuttings of a number of species were tested for rooting during summer of 1983. The results are shown in Table 15.

TABLE 14: Percentage rooting of hardwood cuttings of <u>Alnus</u> species

	Species			
Treatment	A.cordata	A.glutinosa	A.incana	A.rubra
Hardwood				
No wound, no hormone	0	5	2	0
No wound, 0.8% IBA*	7	0	5	5
Wound, no hormone	2	0	5	5
Wound, 0.8% IBA	25	30	65	45
Softwood				
No wound, 0.8% IBA	30	30	90	20

* indole-butyric acid

TABLE 15: Percentage rooting of softwood cuttings of Alnus spp.

Date of Propagation	Species	% Rooting	Date of Propagation	Species	% Rooting
April 1983	A.glutinosa	75	May 1983	A.rugosa	90
"	A.hirsuta	0	"	A.serrulata	10
"	A.orientalis	25	"	A.subcordata	98
"	A.rhombifolia	66	"	A.tenuifolium	7
"	A.rugosa	70	June 1983	A.incisa	78
"	A.spaethii	0	"	A.nitida	62
"	A.tenuifolium	100	"	A.serrulata	14
May 1983	A.rhombifolia	0		A.cordinca 'Sipkes'	60-70

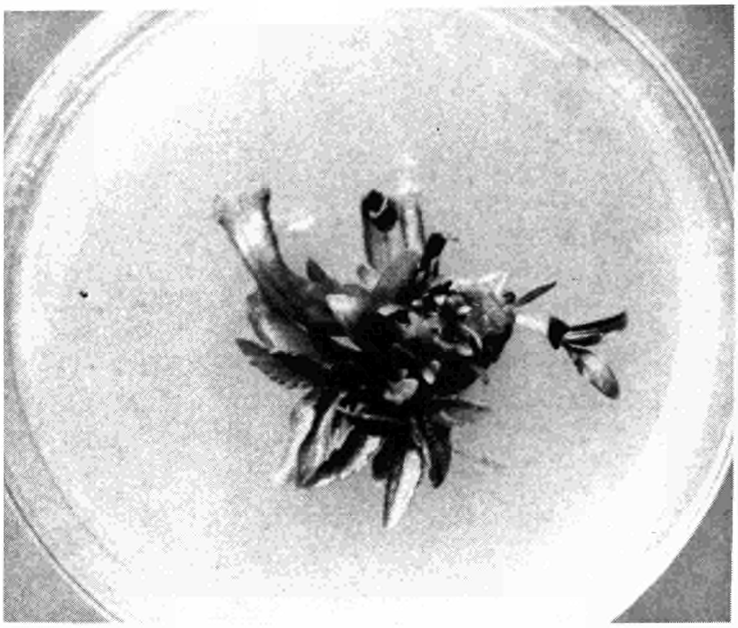

PLATE 14: Poplar plantlet developed by cell suspension culture.

PLATE 15: Rooted plant of Alnus rubra from tissue culture

PLATE 16: Plants from cell cultures, bottom three plants from stem internode tissue cultures.

NITROGEN FIXATION IN ALDER SPECIES

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Summary

Seasonal effects on nitrogen fixation and growth rates in *Alnus* species were determined. The effect of soil types and of inoculation on nodulation and nitrogen fixation rates were studied. As crushed nodule inoculum contains inhibitory substances affecting nodulation, strains of the alder endophyte (*Frankia* spp) were isolated in pure culture for inoculation studies. The endophyte appears to be widely distributed. Nodules were found on all alder trees in areas visited. It was determined that levels of endophyte vary in different soils, and use of marginal land areas for production e.g. peatlands may require inoculation with appropriate species to achieve maximum benefit from nitrogen fixation.

Introduction

In the production of short rotation forestry, nitrogen can be a limiting factor. The application of nitrogen fertilizer is costly as well as being sometimes mechanically difficult. It is known that trees of the species *Alnus* have the capacity to fix nitrogen from the atmosphere. The amount of nitrogen fixed and the geographical distribution of the microbe have not been studied hitherto. In this series of experiments an attempt was made to quantify the amount of nitrogen fixed and the extent to which this varied with season of growth and soil type.

Conclusions

These experiments show that tissue culture may be successfully used to propagate Populus, Alnus and Salix. Rapid multiplication of promising clones for field testing was facilitated. A supply of planting material of poplar has been developed more rapidly than would have been possible through using conventional methods.

Propagation is possible using material from individual trees which show superior characteristics (1). With Alnus spp., capacity to coppice is erratic (see above). This capacity seems to be genetically determined. It is hoped to develop coppicing clones of A.incana and A.rubra by propagation from individual trees which had survived coppicing.

References

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(2) Anderson W.C. 1975. Propagation of Rhododendrons by tissue culture. Part 1. Development of a culture medium for multiplication of shoots. Proc.Int.Plant.Prop.Soc. 25 129-135.

PESTS AND DISEASES IN SHORT ROTATION FORESTRY

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It is to be expected, that with intensive culture, some pests and diseases which occur in natural populations of the tree species, will increase. In the case of insect pests, predator species will also increase and a balance will be achieved once more.

Fungal and bacterial diseases

Salix dasyclados suffered from a fungal attack which was probably Melanpsora capreum (1). Salix vittelina on the peatland was almost destroyed by a fungus. This was probably Physalospora myiabeana (2). No fungus or bacterial disease was observed on Populus, Alnus, Salix viminalis or Salix aquatica gigantea.

Insect pests

A serious attack of flea beetle (Phyllodecta vulgatissima) occurred in Salix viminalis and Salix dasyclados. This was successfully controlled by spraying with of the insecticide Decis (deltamethrin). Salix aquatica gigantea was only slightly attacked by this pest. Some flea beetle was also observed on Alnus, but the damage was negligible.

Alnus suffered from a severe attack of sawfly larvae (Croesus septentrionalis). An Ichumonid parasitic wasp which closely resembled the known predator of this pest was recorded at Clonsast towards the end of 1982 (1).

Other pests

The most important problem was weeds, the control of which has been mentioned above. During snowy weather some problems have occurred from grazing by hares (*Lepidus timidus*) at Clonsast. These can be controlled by fencing.

References

(1) Dunne, R. (1982). Personal communication, September 1982.

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PLATE 19 : Effect of spraying with insecticide on the control of beetles in *Salix viminalis*.

GENERAL CONCLUSIONS REGARDING GROWING

The project had many limitations. Most experiments were conducted only once which left them susceptible to weather conditions in the year of establishment. A major disadvantage was that even the species was not known. Cultural trials were carried out on different species and the results have to be extrapolated to what are now known to be the best species or clones. Until 1981 it was not possible to begin an experiment with the best combination of species, spacing and fertilisers.

In the majority of cases the plot size was too small and the replications too few to give statistically significant results. At the same time it must be mentioned that the state of the art of this crop in 1977 did not justify more than a preliminary study on this project.

The results though somewhat fragmented, indicate clearly that woody plants grown on a rotation of 4-10 years (depending on soil type) will provide fuel at a cost effective price.

On the mountain soil, in exposed areas and in Sphagnum peat, only conifers will survive. On abandoned farmland a wide range of species including Alnus, Populus and Salix, will survive. On second class mineral soil Populus trichocarpa, its hybrids, and Salix dasyclados were best. The coppice yield was substantially better than the primary yield.

The best species so far tested on peat is Salix aquatica gigantea, but some species including Poplar may have possibilities if roots can get into the mineral layers underneath the peat. This requires high initial application of nitrogenous fertiliser.

It has become apparent that the peatland soil at Clonsast is highly variable. This is most apparent in the greenhouse experiment on pH levels, but it also shows up in the field experiments (Table). Some soil survey work on this during 1982 and 1983 showed that there is a layer of very acid Sphagnum peat of variable thickness, buried underneath wood peat. This occurred on Fertiliser trial No.4 above. The problem is a man made one and could therefore be avoided in future peat harvesting operations. Some species of plants e.g. Pinus contorta are very acid tolerant, and will survive on the undisturbed peat where there is a layer of more than 0.5m of Sphagnum, as for example in the Forestry & Wildlife Service trial at Derrycoffey, but higher yields on a shorter term basis can be expected where acidity is corrected to allow coppicing species to grow. The success of species which will succeed on the harvested peatland is therefore influenced by the amount of Sphagnum which is underneath.

The pot experiment also proved that even in the controlled environment of the greenhouse, Salix aquatica gigantea would not root from cuttings at a very low pH level. This explains some of the earlier field results.

With a moderate application of lime to the surface (as in the Clonsast centre) and an initial heavy application of fertiliser, the rooting system could be expected to penetrate and go through the Sphagnum layer. This would account for the good results in the nitrogen fertiliser trial with Salix aquatica gigantea, which was laid down in 1978.

It has been found that Alnus survives well, and fixes nitrogen in many soil types. The coppicing capacity of this genus is variable but it should be possible to overcome this by tissue culture, followed by conventinal vegetative propagation.

The optimum spacing trial has not been finalised but indications are that a population of 10,000 plants or less per ha is sufficient if appropriate herbicides are used.

In the iteration trial at Clonsast, where the best combination of species and silvicultural treatments as previously established, were applied, the target yield of 12 t $ha^{-1}amnum^{-1}$ was exceeded. With further research there is every reason to expect that in this area, the yield can be consistently increased to about 18 t $ha^{-1}annum^{-1}$.

SECTION II

FUEL ANALYSIS AND STORAGE

FUEL PROPERTIES OF SHORT-ROTATION COPPICE

Gerard J. Lyons & Noel McNamara

Utilisation of s.r.f. biomass will depend on its physical and chemical properties which determine the quality and value of the coppice as a primary fuel. Yet, only a limited number of studies have been performed to characterise the biomass fuel qualities of coppicing hardwoods (1)(2)(3)(4). This study examines the biomass characteristics of coppice growth for six of the candidate species being investigated in some of the silvicultural trials reported earlier.

An extensive fuel analysis programme was conducted to determine the following characteristics for components and/or harvested fuel chips of the six chosen species : 1. Moisture content (on harvest), 2. Specific gravity, 3. Calorific value, 4. Ash content, 5. Percentage volatiles, 6. Fixed carbon, 7. Particle size distribution (for harvested chips), and 8. Bulk density (of harvested chips). In all, 1800 individual tests were completed.

The species selected were 1. *Fraxinus excelsior*, 2. *Populus* Fritzi Pauley, 3. *Populus* Rap, 4, *Salix aquatica gigantea*, 5. *Salix dasyclados*, and 6. *Salix viminalis*.

Methods

Coppice sprouts from each of five randomly chosen trees for the six species were collected during the harvesting of a 3-year coppice experimental plot (described earlier pp.16-22) at the Agricultural Institute farm in Oak Park, Carlow. Once felled, sub-samples of stemwood, bark and twig components were isolated for individual trees; trees were then chipped to produce whole-tree chips, the primary fuel product of coppice biomass and a material composite of stem, bark and twig components. Whole tree chips for each tree were also sub-sampled for experimental replication. The whole-tree chip samples for bulk density and particle size determinations were taken from a bulk harvesting of trees for each species, where tree-to-tree differences are meaningless. All chipping was by a Fulghum disc chipper.

Moisture content, calorific value, ash content and percentage volatile tests were conducted in accordance with British Standard 1016 (Parts 3, 4 and 5)(5)[1]. Fixed carbon percentage was evaluated on the basis of measured ash and volatile contents. Specific gravity tests, by immersion of the sample, were carried out on wet volume and oven-dry weight.

Particle size tests were carried out on a 5-screen classifier made from American Standard perforated plate, with round holes of sizes 31.5 mm, 25 mm, 19 mm, 13.2 mm and 6 mm. This corresponds to the William chip classifier design (6). To standardise bulk density measurement, an experimental fixed volume device, similar to the Bushelling machine used in grain bulk density testing, was constructed. A volume of chips was allowed to fall vertically through an average height of 0.5m, to fill a cylindrical chamber of 0.15 m radius and 0.01 m^3 volume. Bulk density tests were conducted on both freshly harvested and oven-dry wood chips.

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[1]This standard was originally developed for the fuel analysis of coal and coke.

Statistical analysis of the results was used to determine the true variation between the six species, and between components tested. The analysis of variance was conducted using the GENSTAT (7) package, and produced Variance Ratio (F-test) and Standard Error of Difference (SED) values for both species-to-species and component-to-component differences. The tables of results presented here show: 1. the mean values for components and species, 2. the F-test significance level at which differences were significant, and 3. SED values.

Results and Discussion

Moisture Content, Specific Gravity and Calorific Value: Results of these tests are presented in Tables 1, 2 and 3, respectively. The main feature of the moisture content results is the dramatically lower value for *Fraxinus* coppice - on average 15 per cent lower than other species. Moisture differences between components were small for all species except *Fraxinus*, where bark and twigs were significantly higher in moisture than stemwood. Specific gravity of *Fraxinus* bark was also considerably lower than for stemwood or whole stem (i.e. stem with bark attached) samples (Table 2).

The calorific values shown in Table 3 are the gross anhydrous (i.e. oven dry samples used) heats of combustion. These figures for 3-year coppice sprouts are lower than the range of estimates normally quoted in the literature (18.8-20.0 MJ/kg) (2)(4) for older sprouts and mature timber; but they are comparable with values measured by Sastry and Anderson (1) for certain Populus hybrids (2-year sprouts), and to figures quoted by Arola (8). As wood fuel is often sold on a volume

TABLE 1: Moisture content of 6 short-rotation coppice species, harvested in mid winter.
(Wet weight basis)

SPECIES	COMPONENT-UNITS (%)				MEAN	S E D	SIG. LEVEL [P <]
	1. Bark	2. Twigs	3. Stem	4. W.T. Chips			
Fraxinus excelsior	42.00	41.22	30.14	32.22	36.40	1.651	0.001
Populus Fritzi Pauley	55.28	51.52	54.36	53.94	53.78	1.505	N.S.
Populus Rap	50.22	45.42	51.00	50.20	49.20	6.050	N.S.
Salix aquatica gigantea	50.74	53.86	51.42	53.00	52.56	1.516	N.S.
Salix dasyclados	51.08	55.90	51.20	53.56	52.90	3.170	N.S.
Salix viminalis	49.48	53.74	48.56	47.52	49.83	1.817	0.05
MEAN :	49.80	50.28	47.80	48.41			
S E D :	1.887	3.415	3.640	3.115			
Sig.Level [P <]	0.001	0.001	0.001	0.001			

Overall Mean: 49.06

TABLE 2 : Specific gravity of stem, bark and whole stem (i.e. stem with bark) components of six short-rotation coppice species. (Wet volume and oven-dry weight basis).

SPECIES	COMPONENT			MEAN	S E D	SIG. LEVEL [P <]
	1.Stem with bark	2.Stem	3. Bark			
Fraxinus excelsior	0.5311	0.5484	0.4001	0.4932	0.01467	0.001
Populus Fritzi Pauley	0.3678	0.3607	0.3458	0.3581	0.01564	N.S.
Populus Rap	0.3055	0.3146	0.3551	0.3250	0.02251	N.S.
Salix aquatica gigantea	0.3880	0.3769	0.3733	0.3794	0.01303	N.S.
Salix dasyclados	0.4125	03811	0.4168	0.4034	0.01407	N.S.
Salix viminalis	0.4605	0.4510	0.4372	0.4495	0.01465	N.S.
MEAN :	0.4109	0.4054	0.3880			
S E D :	0.01868	0.02310	0.02362			
Sig.Level [P <]	0.001	0.001	0.01			

Overall Mean: 0.4014

TABLE 3 : Calorific values (gross anhydrous) of six short-rotation coppice species.

SPECIES	COMPONENT-UNITS (MJ/kg)				MEAN	S E D	SIG. LEVEL [P <]
	1. Bark	2. Twigs	3. Stem	4. W.T.Chips			
Fraxinus excelsior	17.407	17.961	18.193	18.015	17.894	0.1856	0.01
Populus Fritzi Pauley	17.912	17.943	17.689	17.692	17.809	0.0641	0.01
Populus Rap	17.837	18.226	17.995	18.100	18.039	0.1593	N.S.
Salix aquatica gigantea	17.991	18.431	17.917	18.037	18.094	0.0928	0.001
Salix dasyclados	17.430	18.157	17.662	17.770	17.754	0.1522	0.01
Salix viminalis	18.330	18.865	18.387	18.155	18.434	0.0923	0.001
MEAN :	17.817	18.264	17.973	17.961			
S E D :	0.1468	0.1583	0.1328	0.1025			
Sig.Level [P <]	0.001	0.001	0.001	0.001			

Overall Mean: 18.004

basis, Tables 2 and 3 have been used to derive volumetric calorific values. These are shown in Table 4. A table of net calorific values (Table 5) at measured moisture contents is based on Tables 1 and 3. The net calorific value is a more realistic measure of the potential heating capacity of a given weight of harvested wood biomass.

The ash content, percentage volatiles and fixed carbon content (computed) are presented in Tables 6, 7 and 8 respectively. Differences between components were significant for all species, with a greater percentage of ash occurring in bark and consistently higher volatile contents in stemwood. The very high volatile percentage in stemwood, at 89.36% (averaged over species) is likely related to stem age, as literature values quoted for hardwoods (at 77-80% approx.) (9) (10) normally refer to mature fuelwood, including bark and twigs.

Particle size and bulk density of chipped s.r.f. coppice provide important information for the design of handling, storage and conversion systems. However, these parameters are not fixed 'state properties' of s.r.f. wood, but depend greatly on age of the coppice, on chipper design (disc or drum), blade configuration and sharpness, and chipper speed. Thus, literature values are almost non-existant. Table 9 shows the results of a screen analysis for the six candidate species and indicates a high percentage of chips (50%) occurring in the 13.2mm-25mm category. Tables 10 and 11 present the bulk densities for the four principal chip sizes and whole-tree (un-screened) samples, for both freshly harvested and oven dried chips. The benefits of reducing fuel moisture content (by field storage) before transporting the biomass are obvious from the large drop in bulk density due to drying.

The potential for natural drying during field storage of wood chips, and the effects of such storage on fuel properties are discussed in the following section.

TABLE 4 : Calorific values (gross anhydrous) per unit volume of six short-rotation coppice species.

SPECIES	COMPONENT-UNITS (GJ/m^3)			MEAN
	1. Bark	2. Stem	3. W.T.Chips	
Fraxinus excelsior	6.964	9.977	9.568	8.836
Populus Fritzi Pauley	6.193	6.380	6.507	6.360
Populus Rap	6.334	5.661	5.529	5.841
Salix aquatica gigantea	6.716	6.753	6.998	6.822
Salix dasyclados	7.265	6.730	7.330	7.108
Salix viminalis	8.014	8.292	8.360	8.222
MEAN :	6.913	7.286	7.380	

Overall Mean: 7.198

TABLE 5 : Net calorific value at measured moisture content (see Table 1) of six short-rotation coppice species.

SPECIES	COMPONENT-UNITS (MJ/kg)				MEAN
	1. Bark	2. Twigs	3. Stem	4. W.T. Chips	
Fraxinus excelsior	8.299	8.769	11.046	10.523	9.646
Populus Fritzi Pauley	6.063	6.794	6.137	6.218	6.302
Populus Rap	6.990	8.112	6.919	7.125	7.285
Salix aquatica gigantea	6.967	6.574	6.801	6.556	6.667
Salix dasyclados	6.627	6.054	6.719	6.325	6.442
Salix viminalis	7.379	6.798	7.587	7.668	7.363
MEAN :	7.067	7.191	7.520	7.404	

Overall Mean: 7.295

TABLE 6 : Ash content of six short-rotation coppice species.

SPECIES	COMPONENT-UNITS (%)				MEAN	S E D	SIG. LEVEL [P <]
	1. Bark	2. Twigs	3. Stem	4. W.T.Chips			
Fraxinus excelsior	2.55	1.99	1.10	1.15	1.70	0.269	0.001
Populus Fritzi Pauley	4.34	3.33	1.10	1.45	2.56	0.488	0.001
Populus Rap	3.07	2.23	0.81	1.38	1.87	0.522	0.01
Salix aquatica gigantea	2.66	2.42	1.01	1.09	1.80	0.225	0.001
Salix dasyclados	3.59	2.23	1.67	1.30	2.20	0.309	0.001
Salix viminalis	2.75	2.15	1.00	1.43	1.83	0.268	0.001
MEAN :	3.16	2.39	0.96	1.30			
S E D :	0.490	0.353	0.165	0.320			
Sig.Level [P <]	0.01	0.05	0.001	N.S.			

Overall Mean: 1.99

TABLE 7 : Percentage volatiles in six short-rotation coppice species.

SPECIES	COMPONENT-UNITS (%)				MEAN	S E D	SIG. LEVEL [P <]
	1. Bark	2. Twigs	3. Stem	4. W.T.Chips			
Fraxinus excelsior	81.09	81.43	87.43	85.57	83.88	0.566	0.001
Populus Fritzi Pauley	81.93	81.73	91.09	86.86	85.40	0.978	0.001
Populus Rap	82.29	83.00	89.89	88.00	85.79	1.269	0.001
Salix aquatica gigantea	78.09	79.35	88.76	85.83	83.01	0.843	0.001
Salix dasyclados	77.49	79.40	89.66	85.44	82.99	0.941	0.001
Salix viminalis	81.54	80.93	89.35	86.27	84.52	1.959	0.01
MEAN :	80.41	80.97	89.36	86.33			
S E D :	2.012	0.985	0.389	0.916			
Sig.Level [P <]	N.S.	0.01	N.S.	N.S.			

Overall Mean: 84.27

TABLE 8 : Fixed carbon content of six short-rotation coppice species.

SPECIES	COMPONENT-UNITS (%)				
	1.Bark	2. Twigs	3. Stem	4. W.T.Chips	MEAN
Fraxinus excelsior	16.16	16.58	11.47	13.28	14.42
Populus Fritzi Pauley	13.73	14.94	7.81	11.69	12.04
Populus Rap	14.64	14.77	9.30	10.62	12.44
Salix aquatica gigantea	19.25	18.33	10.33	13.08	13.19
Salix dasyclados	18.92	18.37	8.77	13.26	14.81
Salix viminalis	15.71	16.92	9.65	12.30	13.65
MEAN :	16.43	16.64	9.63	12.37	

Overall Mean: 13.74

TABLE 9 : Particle size distribution of whole-tree chips from six short-rotation coppice species.

SPECIES	COMPONENT-UNITS (% Retained)						
Sieve sizes:	6.3 mm	13.2 mm	19 mm	25 mm	31.5 mm	Fines	Twigs
Fraxinus excelsior	19.00	24.95	23.99	14.80	3.25	2.32	11.67
Populus Fritzi Pauley	18.90	20.74	24.69	17.08	8.25	3.35	6.95
Populus Rap	17.56	18.47	23.09	20.61	10.92	3.66	5.16
Salix aquatica gigantea	17.79	22.56	20.70	20.21	4.13	3.39	11.17
Salix dasyclados	19.49	27.30	26.09	15.43	1.14	2.68	7.82
Salix viminalis	23.00	27.09	27.63	7.69	0.99	3.66	9.91
MEAN :	19.29	23.52	24.36	15.97	4.78	3.17	8.78
S E D :	2.750	1.755	2.697	3.184	1.306	0.433	1.741
Sig.Level [P <]	N.S.	0.001	N.S.	0.01	0.001	0.05	0.01

TABLE 10 : Bulk density (fresh weight) of whole-tree chips from six short-rotation coppice species.

SPECIES	COMPONENT UNITS (kg/m³)					MEAN	S E D	SIG. LEVEL [P <]
Sieve size:	6.3 mm	13.2 mm	19 mm	25 mm	W.T. Chips (unscreened)			
Fraxinus excelsior	188.80	215.42	223.93	234.61	224.11	217.37	3.102	0.001
Populus Fritzi Pauley	254.99	228.55	229.47	216.59	238.46	233.61	1.833	0.001
Populus Rap	228.32	205.37	202.32	198.14	219.18	217.00	2.334	0.001
Salix aquatica gigantea	222.66	244.05	225.90	217.91	202.17	222.54	1.589	0.001
Salix dasyclados	212.27	226.24	220.89	209.22	231.11	219.94	1.968	0.001
Salix viminalis	213.67	226.47	210.46	209.89	214.62	215.02	1.796	0.001
MEAN :	220.12	224.35	218.83	214.39	221.61			
S E D :	1.953	1.847	2.736	2.047	2.164			
Sig.Level [P <]	0.001	0.001	0.001	0.001	0.001			

Overall Mean: 220.91

TABLE 11 : Bulk density (dry weight) of whole-tree chips from six short-rotation coppice species.

SPECIES	COMPONENT UNITS (kg/m^3)					MEAN	S E D	SIG. LEVEL
Sieve size:	6.3 mm	13.2 mm	19 mm	25 mm	W.T. Chips (Unscreened)			[P <]
Fraxinus excelsior	138.98	170.10	168.20	180.60	168.00	165.17	3.340	0.001
Populus Fritzi Pauley	126.96	127.03	131.06	126.35	134.90	129.26	1.524	0.001
Populus Rap	124.29	124.22	121.89	129.27	132.30	126.39	1.370	0.001
Salix aquatica gigantea	118.56	127.67	126.28	119.05	117.63	121.84	1.241	0.001
Salix dasyclados	118.04	135.45	137.58	135.99	126.75	130.76	1.515	0.001
Salix viminalis	111.95	122.91	121.48	117.25	117.88	118.29	1.196	0.001
MEAN :	123.13	134.56	134.41	134.75	132.91			
S E D :	1.232	2.922	1.638	1.434	1.552			
Sig.Level [P <]	0.001	0.001	0.001	0.001	0.001			

Overall Mean: 131.95

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STORAGE OF WOOD FUEL CHIPS

Gerard J. Lyons & Noel McNamara

In order to ensure high biomass yield levels, harvesting of short-rotation plantations must be confined to the dormant season (November to March). Thus, if a continuous supply of fuel to the conversion plant is to be maintained, some degree of storage will be essential. Furthermore, it is desirable to reduce the moisture content of freshly harvested wood before conversion by direct combustion. The increase in biomass fuel value due to drying (either by natural or artificial means) is illustrated in figure 1.

While it is acknowledged (1) that wood chips may not be the most suitable form of wood fuel from a conversion or storage viewpoint, they are likely to remain the primary fuel product from conventional and short-rotation forests for some time. Whole-tree portable chippers are now in widespread use both in the U.S. and Scandinavia (1)(2) and wood chip delivery and handling systems have been commercially used by the pulp and paper industry for many years (3). However, development of alternative harvesting equipment is underway and Arola (4) reports on the design and testing of a wood chunking machine.

Several studies (5)(6)(7) have investigated the bulk storage of pulp chips and bark residues, and commented on the dangers of spontaneous ignition in large storage piles. However, in examining wood chips as a primary fuel we are more concerned with the effects of short-term (i.e. 1 to 6 months) field storage on the fuel properties (especially moisture content) of wood chips.

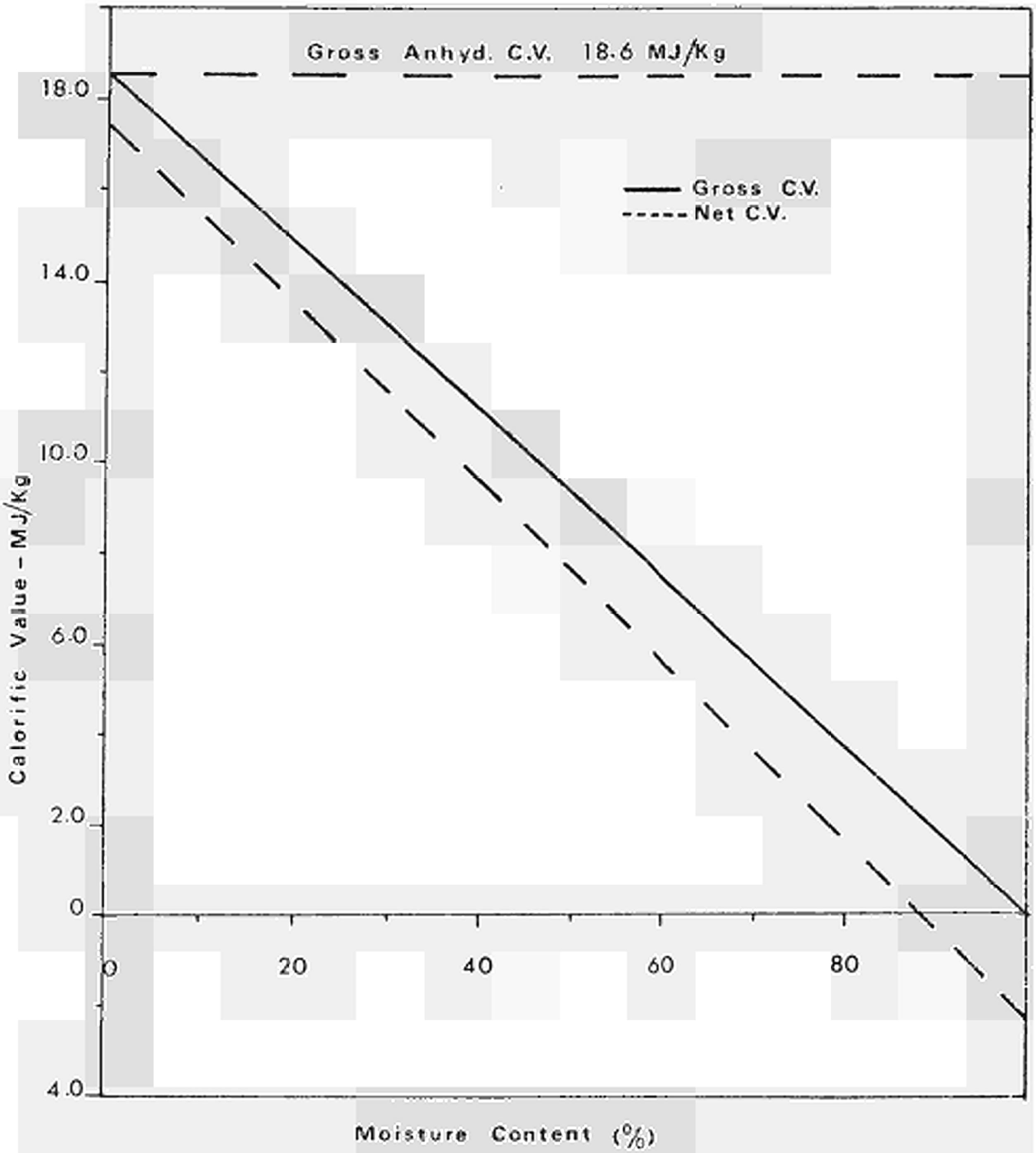


FIGURE 1 : Variation of gross and net fuel value of wood with moisture content.

The objectives of the work presented here were to:

a. investigate the potential for natural drying of wood fuel chips stored in small piles (or windrows) on the energy plantation, and

b. to determine the effects of such storage on the fuel properties and value of wood fuel chips.

Methods

A series of small scale field storage experiments and a complimentary laboratory investigation were carried out on whole-tree chips harvested (using a Fulghum disc chipper) from young coppice sprouts of *Fraxinus excelsior*. As sufficient quantities of biomass were not available from the principal candidate species (*Alnus*, *Populus* and *Salix*) in the experimental plots, a natural coppice stand (8-10 years old) of *Fraxinus* was harvested for these experiments. Analysis of the fuel properties of chip samples was according to the procedures outlined in the previous ('Fuel Properties') section.

Field storage experiments: Three 90-day storage periods were investigated: 1. Winter, 2. Spring-Summer, and 3. Summer-Autumn. For each storage experiment, a group of 6 conical chip piles (1.5 m high and 2.5 m in diameter), each containing approximately 2.3 m^3 of chips, were manually constructed using freshly harvested chips. Wire mesh sample bags of chips (7 per pile) and copper-constantan thermocouples were placed in the piles during construction. Moisture content samples were taken at harvest and during pile formation. Chip pile temperatures were measured three times daily using a digital electronic thermometer connected to the thermocouples in the pile.

After 15 days of storage one of the piles was dismantled, moisture content (m.c.) sample bags were recovered and m.c. loss/gain determined. After each subsequent 15-day period a further chip pile was dismantled until, at the end of the storage period, complete m.c. V's time and temperature profiles were plotted. Climatic data, including 1. air temperature, 2. relative humidity, 3. potential evaporation and 4. potential evapotranspiration, were monitored at the Agricultural Institute's Oak Park weather station, situated about 1 km from the storage site.

Laboratory experiments: Six 50-litre sealed cylindrical containers of rigid plastic were filled with fuel chips of various quality - 2 containers for each of 1. Whole tree chips, 2. Screened (bark/foliage-free) chips and 3. Leaves and fines. These vessels were placed inside 250 mm insulation of polystyrene granules, to reduce heat loss to an insignificant level. Such insulation conditions are likely to apply to chips stored in the inner regions of large storage piles. Air was supplied from an air compressor, connected through 5 mm diameter pipes and rotameter flow meters to the base of the cylinders. The rotameters were adjusted to supply air at a flow rate of 6.8×10^{-6} m^3/s. A Beckman Field-lab analyser 1008 was used to measure percentage oxygen in the air exhausted from each storage vessel through a sampling valve. The oxygen analyser was calibrated to read 20.8% for ambient air; the difference between ambient and exhaust air oxygen levels thus allowed depletion rates (and hence respiration) to be calculated.

During the 30 day experimental periods oxygen levels were measured twice daily. Temperatures in each bin, ambient and exhaust temperatures were monitored continuously by a Microdata M1600L data logger, using copper-constantan thermocouples. Dry matter losses were evaluated by weighing the chip bins and sampling for moisture content before and after storage.

A complete analysis of wood chip fuel properties was conducted before and after a 90-day storage period using the insulated vessels described. In this experiment, short-rotation coppice chips harvested from an experimetal plot of _Populus_ Rap were used, in addition to the whole-tree and screened samples of _Fraxinus_ chips.

Equilibrium moisture content was experimentally determined for each of the short-rotation species 1. _Fraxinus excelsior_, 2. _Populus_ Fritzi Pauley, 3. _Populus_ Rap, 4. _Salix aquatica gigantea_, 5. _Salix dasyclados_ and 5. _Salix viminalis_. Replicated weighed samples of leaves, bark, twigs, stem (10-12 cm split lengths), and whole-tree chips, for each species, were stored in a controlled environment chamber set for the desired humidity and temperature conditions. After 2-3 weeks of storage, sample weights stabilised; samples were then re-weighed and final (equilibrium) moisture content determined.

Results and Discussion

Wood, being a hygroscopic material, tends towards achieving an equilibrium with the surrounding environment. Thus, the moisture content (and natural drying potential) of wood fuel chips stored in the open is a function of both the relative humidity and temperature of the surrounding air. The U.S. Forest Products Laboratory [USFPL] (8) have published a table of values relating wood equilibrium moisture content (EMC) to relative humidity and temperature. While based on data for Sitka spruce alone, this table is widely used in estimating EMC, regardless of species, particle size, etc. (9). Figure 2 shows the variation of EMC (drawn from USFPL table) over a year, based on 3-year monthly average relative humidity and temperature data for Oak Park, Carlow. The potential evapotranspiration, which is a useful measure of drying conditions, is also shown, for the 3-year data.

Results of EMC experiments on six short rotation coppice species are shown in figure 3, with theoretical (USFPL table) values for comparison. The trend of measured values roughly parallels the tabulated EMC's but are on average 5 per cent lower. The discrepancies are likely due to the difference in sorption characteristics between the species and particle sizes used in the two sets of data. The measured values shown more accurately represent the EMC for wood fuel chips produced from short rotation coppicing hardwoods.

While the potential for natural drying in small chip piles (or windrows; less than 2m high) is directly related to ambient environmental conditions, the time of harvest dictates these conditions as well as the initial m.c. value of the harvested fuel. Published data (including Irish s.r. coppice results) for the seasonal variation of moisture content in hardwoods is presented in figure 4. Fraxinus excelsior, the species used in the storage experiments, is one of the driest hardwood species (8). The seasonal variation of its m.c., as measured in the natural coppice stand, is shown in figure 5, together with the duration of the field storage experiments conducted.

Most of the published studies on wood chip storage fail to present details of the origin, species, particle size, bulk density and fuel

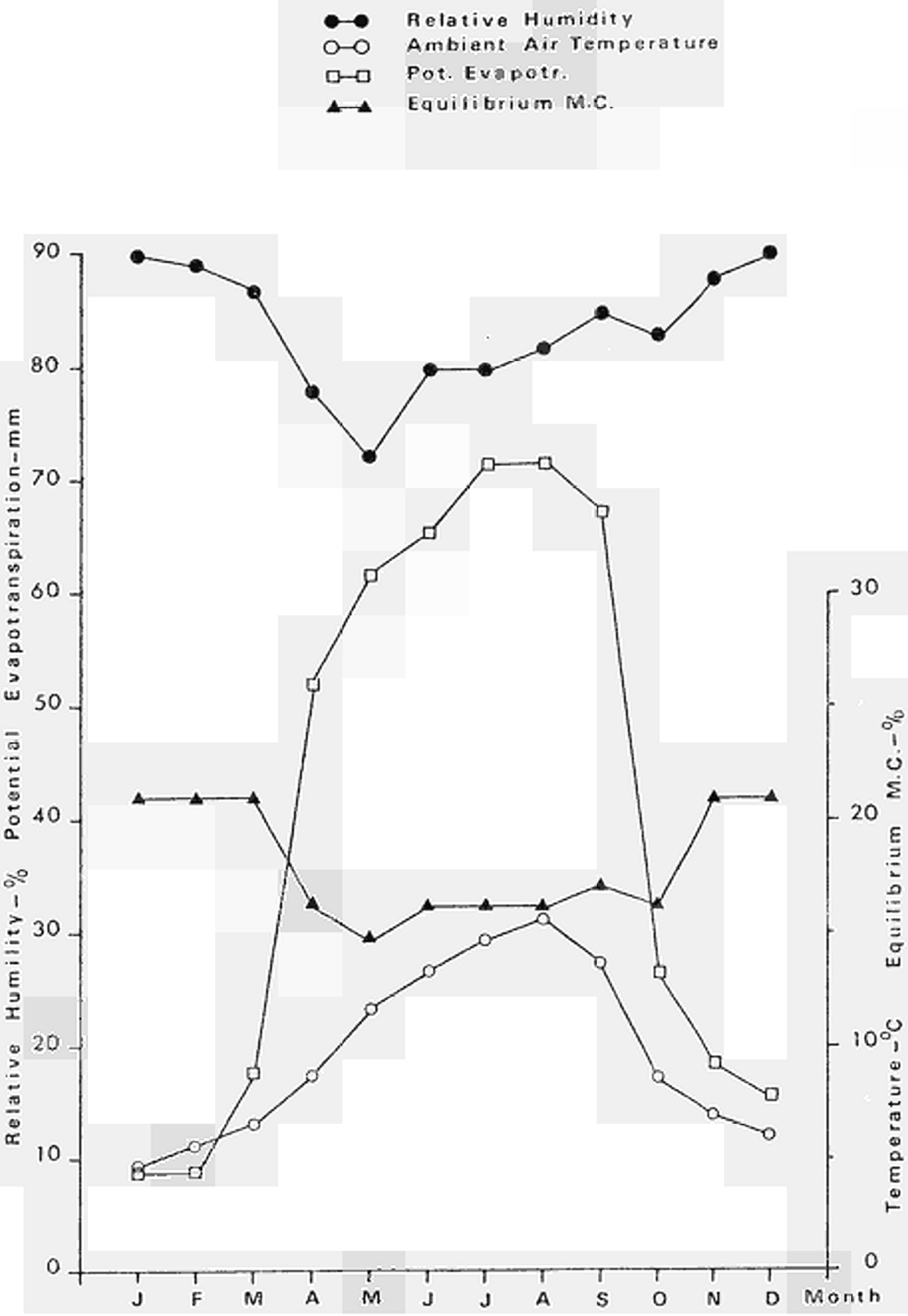
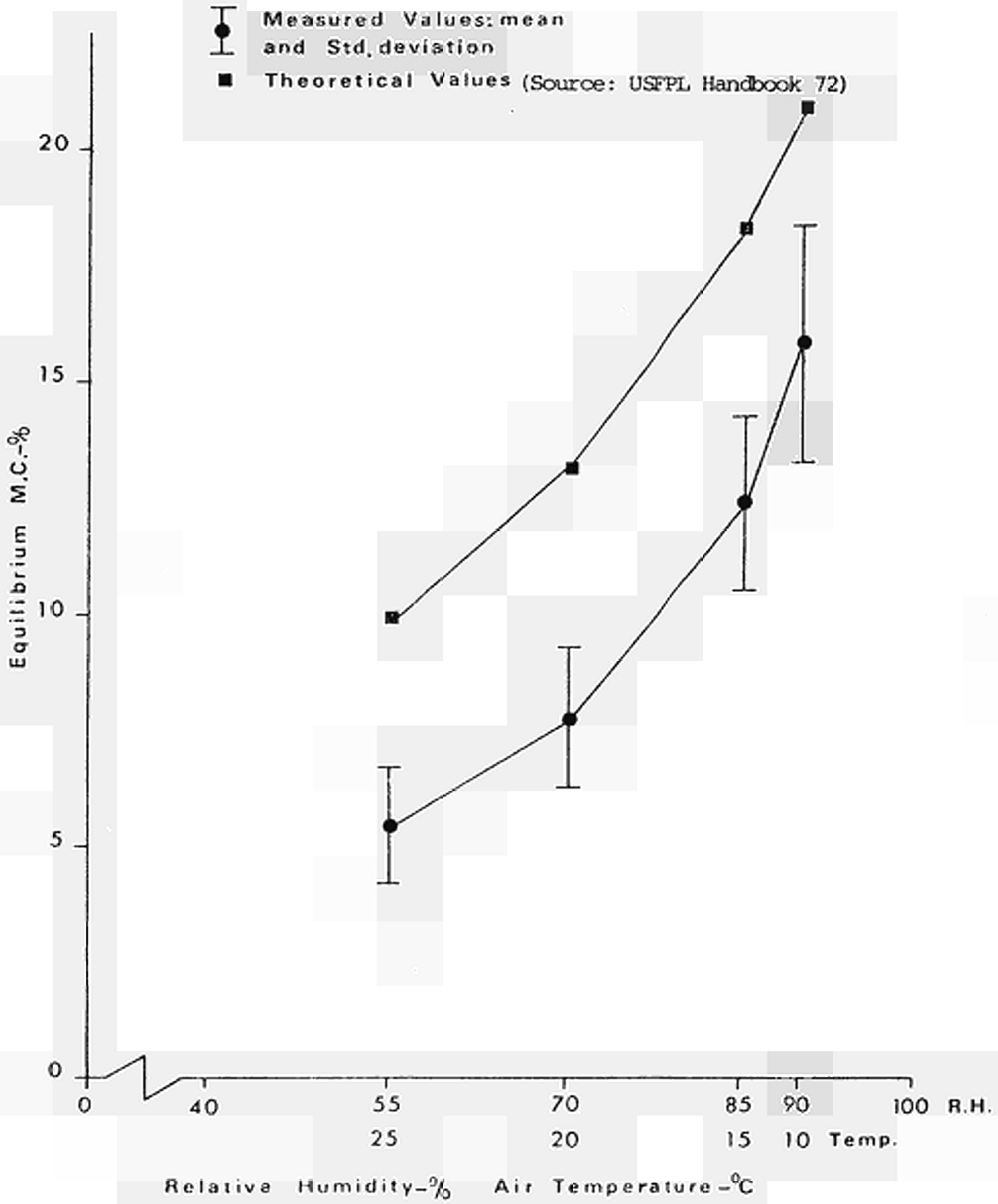


FIGURE 2 : Seasonal variation of equilibrium moisture content (theoretical) with relative humidity, ambient air temperature and potential evapotranspiration. Mean of 3 years values for Oak Park, Carlow.

FIGURE 3 : Mean equilibrium moisture content values for components of six short rotation candidate species. Standard deviations are based on 6 species x 5 components (leaves, bark, twigs, stem and whole-tree chips).



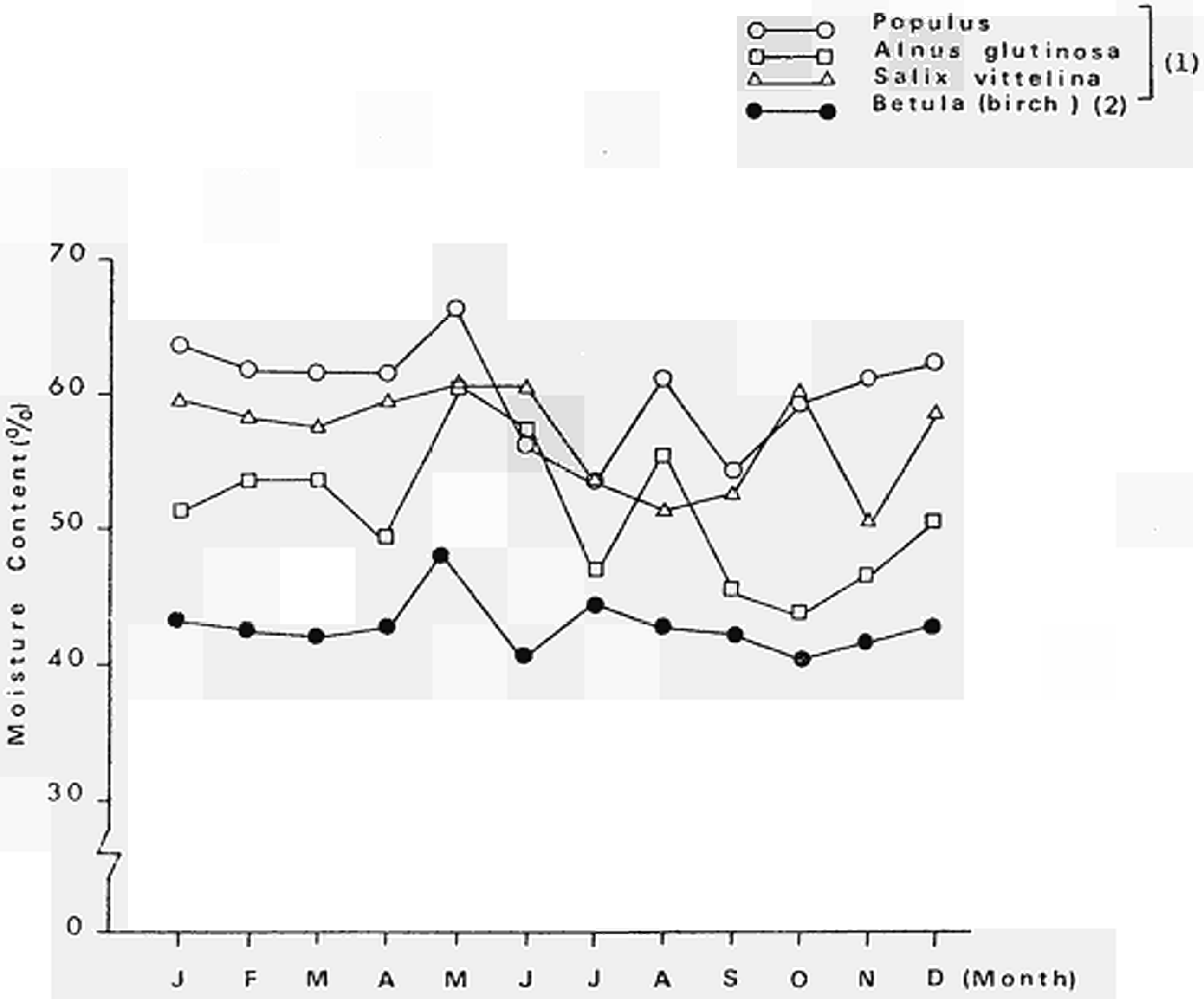


FIGURE 4 : Seasonal variation of moisture content in s.r.f. candidate species, as cited in literature.

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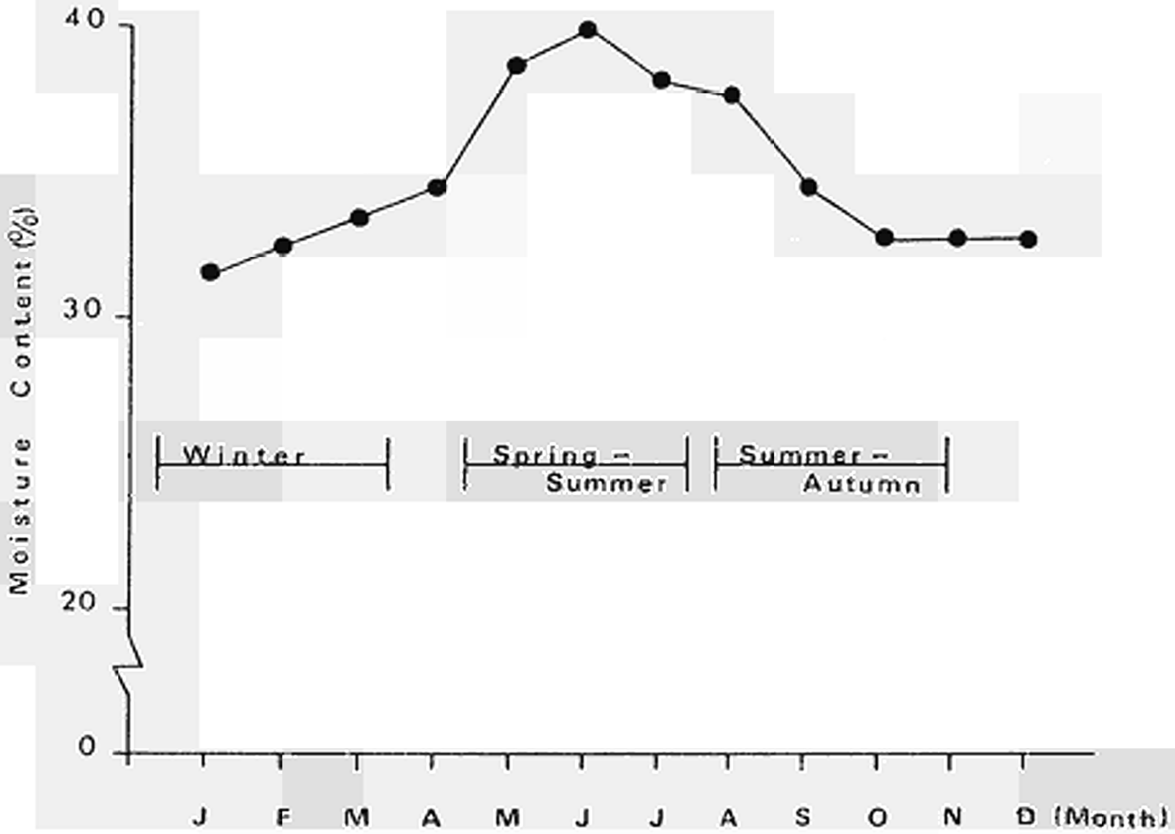


FIGURE 5 : Seasonal variation of moisture content in ash (*Fraxinus excelsior*) coppice, used in storage experiments. Duration of the 3 field storage experiments is also shown.

characteristics of material being used in storage experiments. Table 1 provides an analysis of representative samples of whole-tree chips as used in the field and laboratory experiments in this investigation.

Results from the three field storage experiments - Winter, Spring/Summer and Summer/Autumn, respectively - are shown in figures 6, 7 and 8. While drying down to 25 per cent m.c. is achieved during spring and summer storage (Fig.7), an equilibrium of 27-28 per cent is finally reached. Under field storage conditions drying to the wood's material EMC, as shown in figure 3, is not practical, due to the effects of: packing in the storage pile, continuously varying climatic conditions, and re-wetting by rain. The effect of re-wetting is especially visible in figure 6, towards the end of the storage period. This is further illustrated in figure 9, which shows that re-wetting of chips occurs principally in the outermost chip pile zones.

Moisture content data for a 90-day field storage experiment using chips harvested from experimental plots of 2 short-rotation candidate species are presented in Table 2. Although the initial m.c. is much higher than that shown in figure 6 for winter storage of <u>Fraxinus</u>, the final value is approaching that attained by the <u>Fraxinus</u> chips over a similar period. This suggests that, regardless of initial m.c., fuel chips stored in small piles will dry to an equilibrium level, under prevailing climatic conditions. Pile temperatures for these two species are shown in figure 10. The temperature profile over the summer-autumn storage season (see figure 7) is presented in figure 11. During the first 20 days of storage, chip pile temperatures were 7-10°C higher than ambient, but then stabilised at 3-5°C above ambient.

In large chip piles, where ventilation of inner regions will be greatly reduced, the effects of self-heating and biological degradation

TABLE 1 : Analysis of wood chips (*Fraxinus excelsior* - natural coppice) used in field storage experiments

Property	Mean	Standard Deviation	No.of samples
Calorific Value	17.440 MJ/kg	0.100	5
Ash Content	1.012%	0.266	5
Percentage Volatiles	84.62%	0.279	5
Fixed Carbon	14.37%		Estimated
Specific Gravity	0.4799	0.0599	5
Bulk Density - Fresh (32%m.c.)	280.51 kg/m^3	9.81	3
- Dry	199.19 kg/m^3	3.32	3
Particle Size Distribution:			
Sieve 1	24.03 % retained	3.04	3
Sieve 2	17.57 "	1.21	3
Sieve 3	23.57 "	0.37	3
Sieve 4	19.70 "	1.65	3
Sieve 5	15.10 "	1.90	3

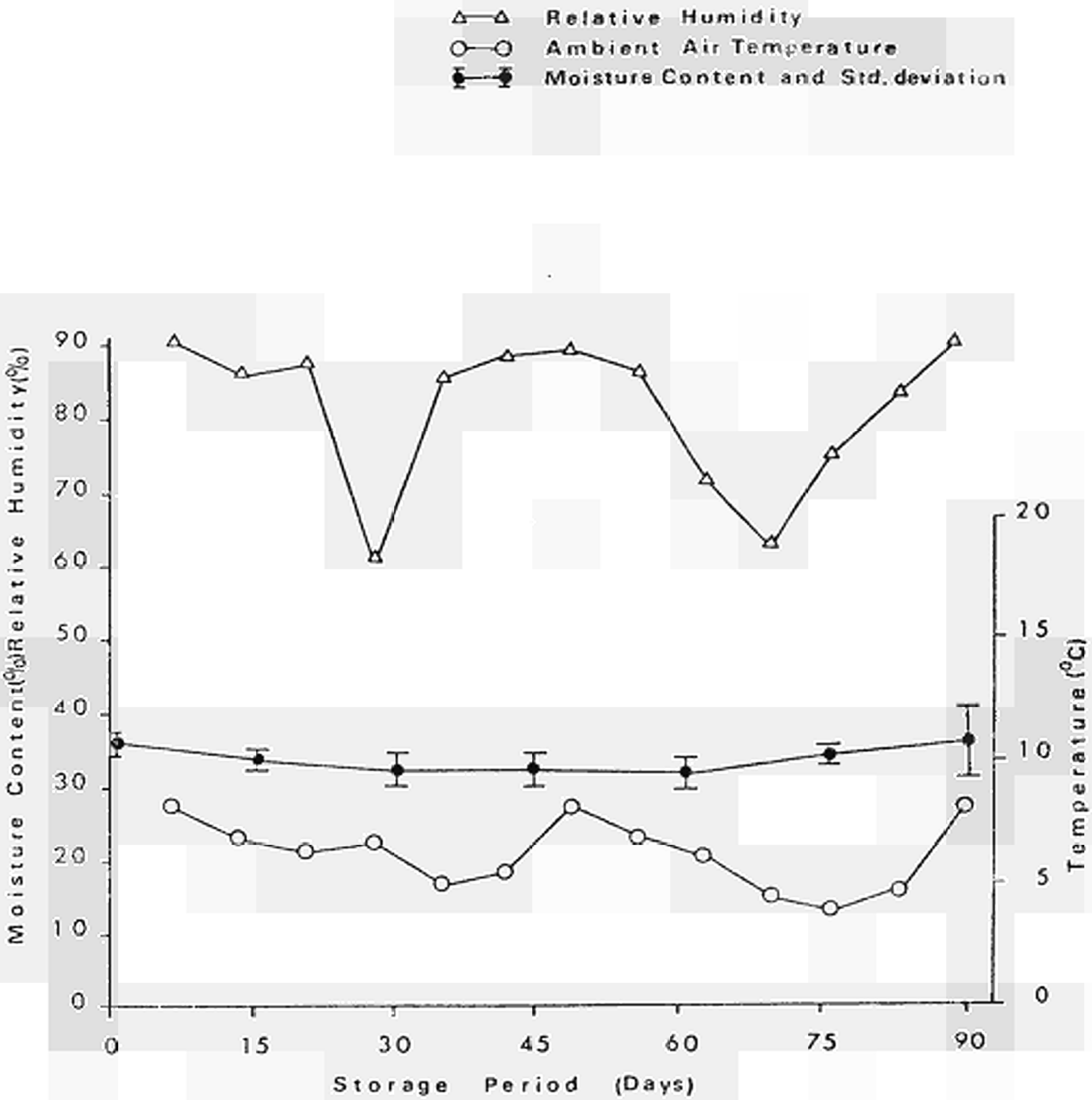


FIGURE 6 : Winter storage : average m.c. of wood chips in experimental piles. Brackets denote standard deviation of seven samples.

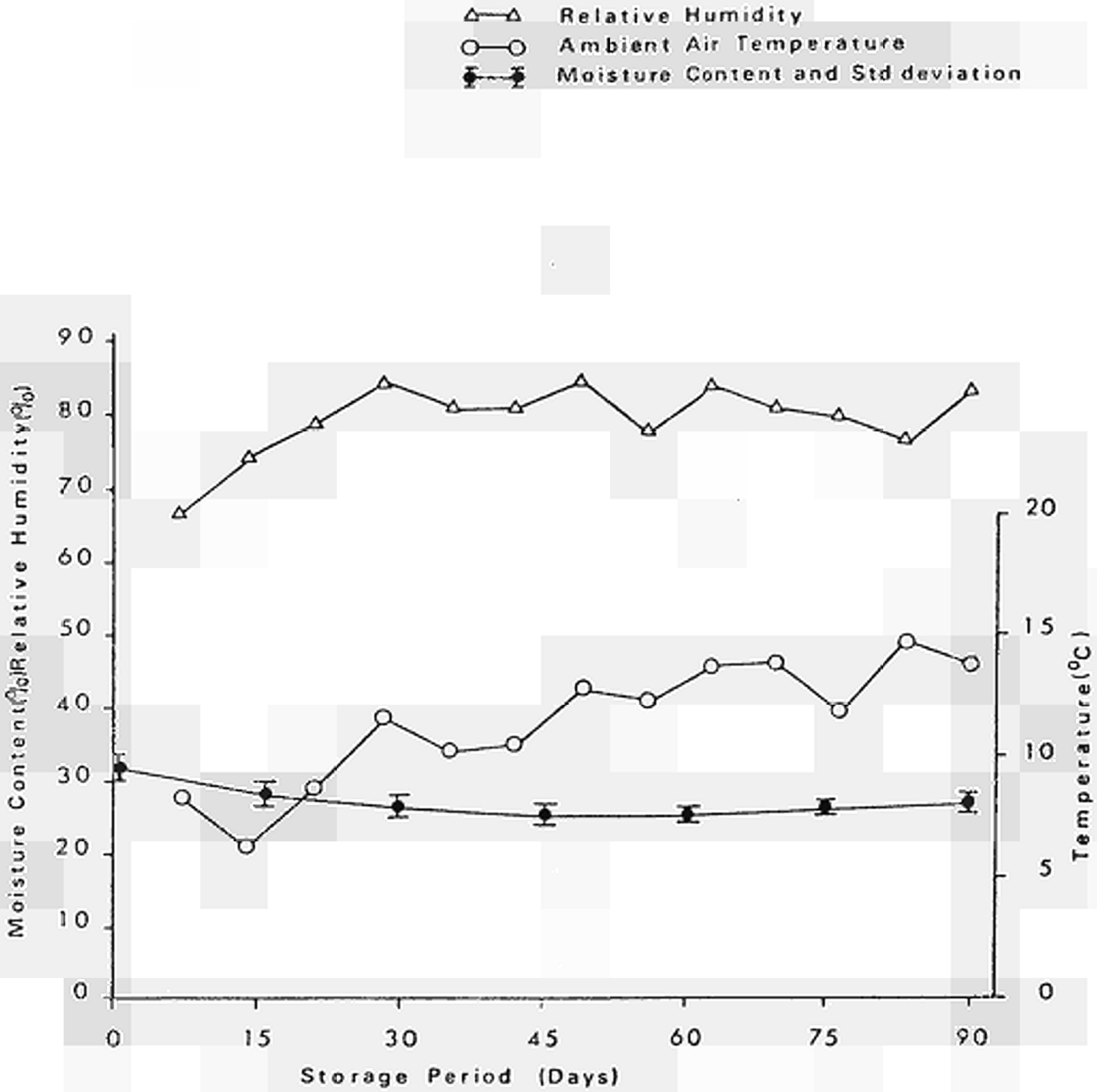


FIGURE 7 : Spring-Summer storage : Average m.c. of wood chips in experimental piles. Brackets denote standard deviation of seven samples.

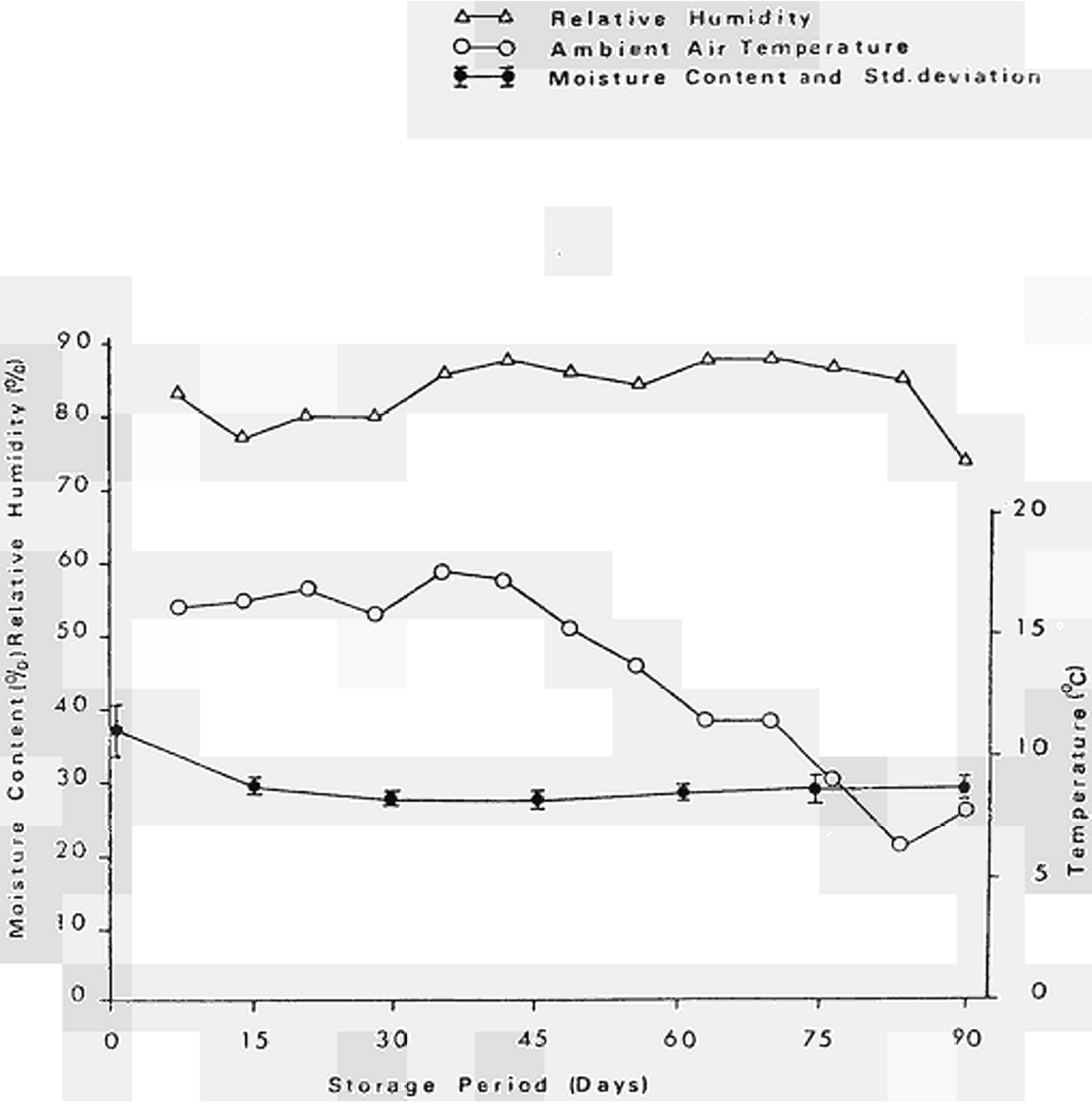


FIGURE 8 : Summer-Autumn storage : Average m.c. of wood chips in experimental piles. Brackets denote standard deviation of seven samples.

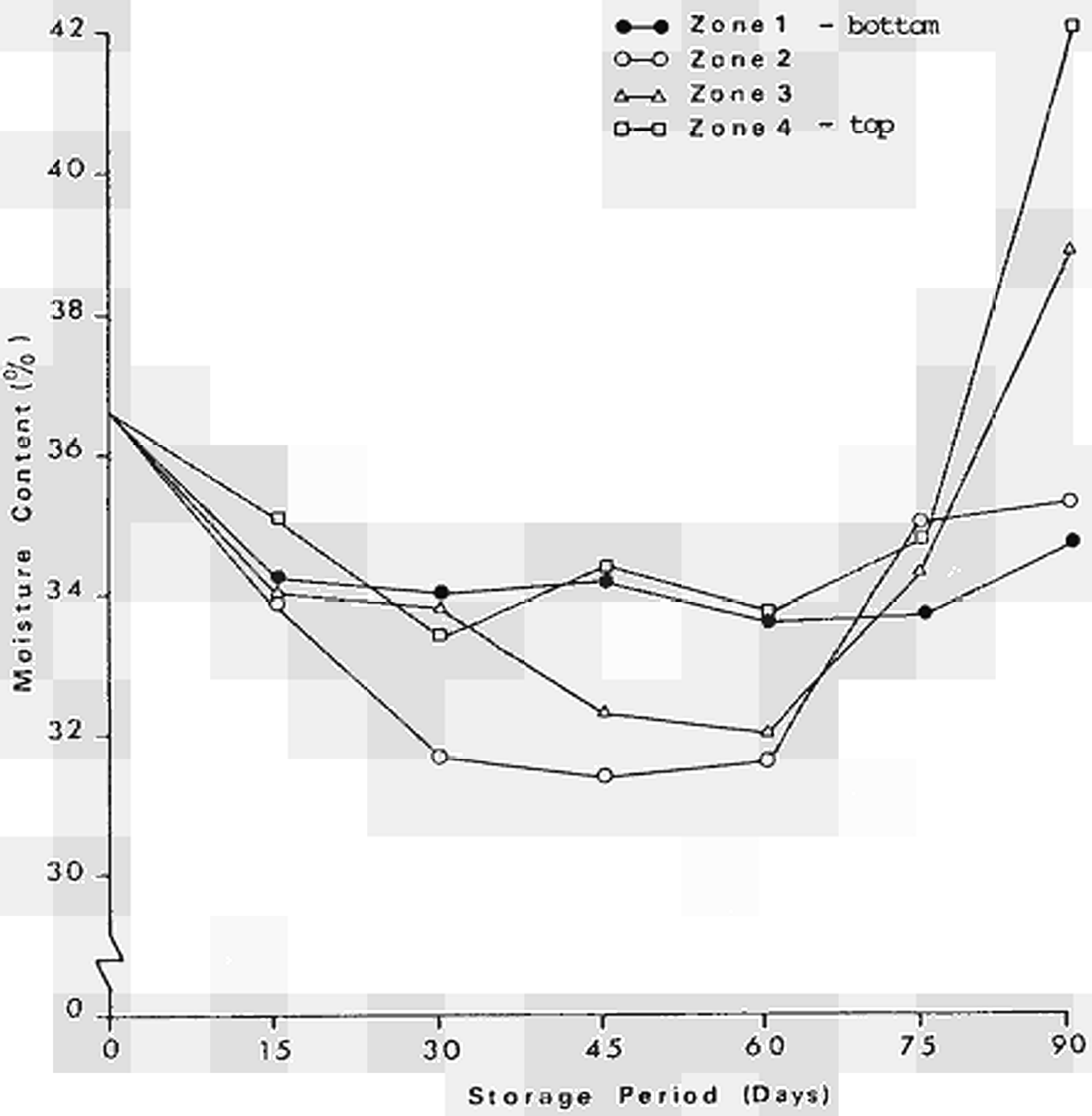


FIGURE 9 : Average zonal m.c. of wood chips in experimental piles. Winter storage.

Table 2 : Moisture content of S.R.F. species before, and after 90 days (11 Nov. to 11 Feb.) winter storage in 2.3 m^3(approx.) piles

Species	M.C. Before (%)			M.C. After (%)		
	Top	Middle	Bottom	Top	Middle	Bottom
Populus spp.	54.40	54.40	54.40	48.55	47.86	45.30
Salix spp.	49.15	49.15	49.15	38.45	38.45	42.40

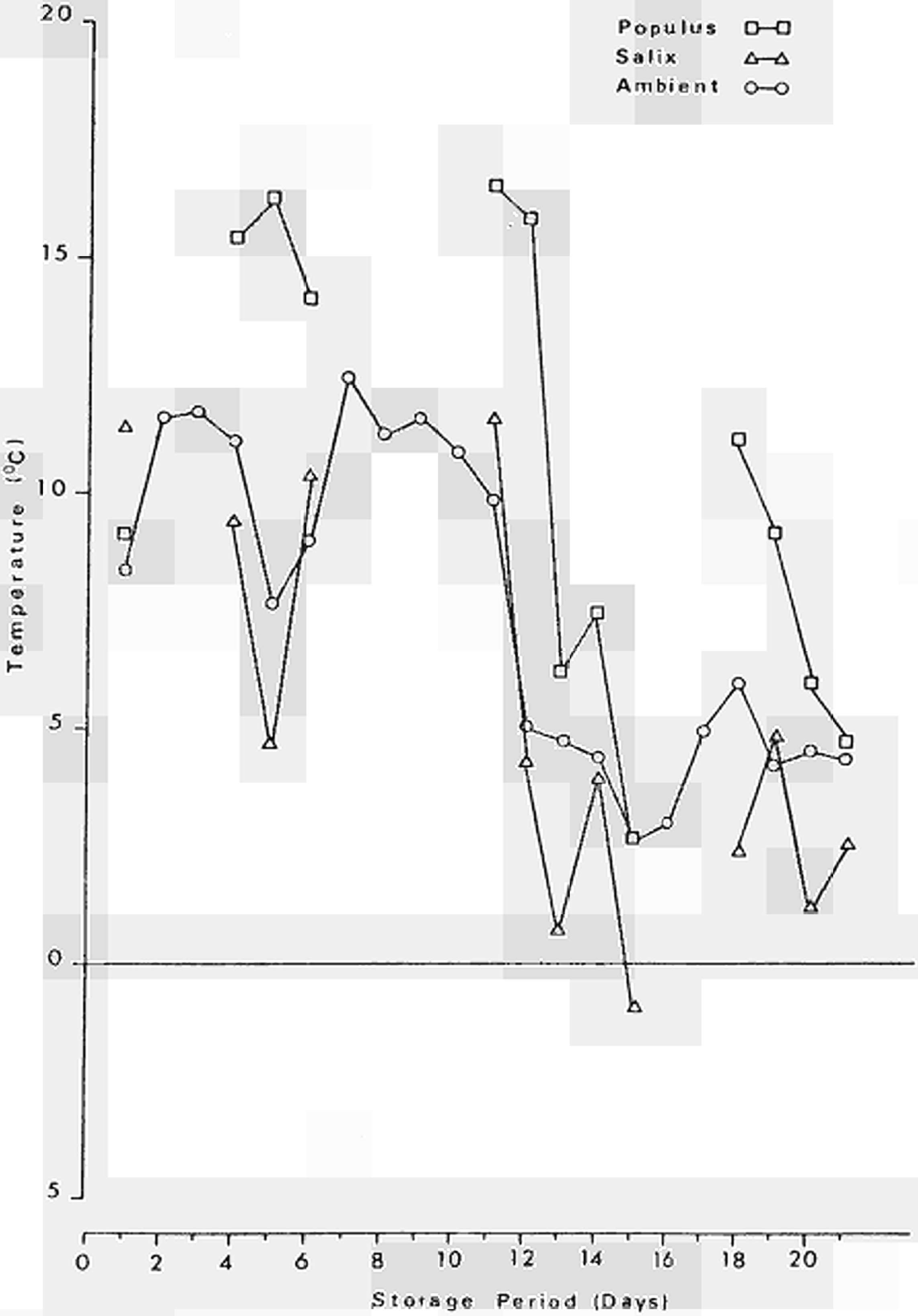
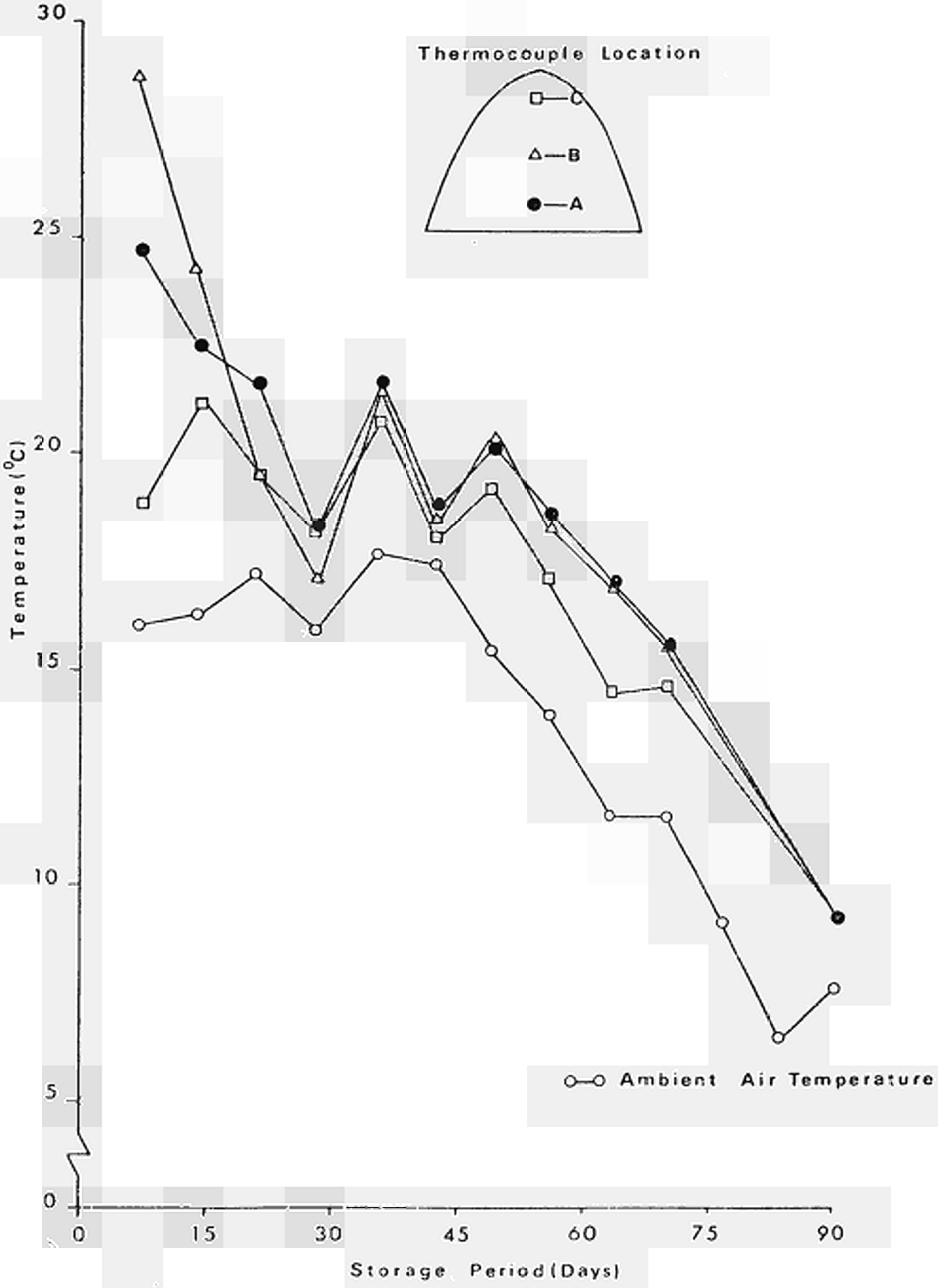


FIGURE 10 : Variation of temperature within experimental field storage piles of two s.r.f. species.

should be more pronounced. These effects were examined as part of our laboratory storage programme. Figure 12 shows a characteristicaly rapid rise in chip temperatures during the first 15 days of storage; this is accompanied by high wood respiration rates, as shown in figure 13. The highest temperature rise and respiration rates were recorded in vessels filled with samples of leaves and fines (see Figs.12 and 13), with proportionately lower values for whole-tree chips and clean (screened) chips, respectively.

Tables 3 and 4 show the effects of storage on fuel properties of fuel chips and the dry matter losses recorded in laboratory and field storage experiments. Together with figures 12 and 13 these tables indicate that greater losses, higher self-heating and respiration rates occur in more biologically active samples of wood, such as leaves. By restricting harvesting to the winter and early spring period, these problems would be reduced, as cleaner foliage-free chips will be produced. On a dry matter basis calorific value and specific gravity of the fuel chips did not change over a 90-day storage period. But a slight increase in fixed carbon percentage was due to a corresponding decline in ash and volatile contents. Dry matter losses were of the order 1.14% per month for short-rotation chips.

FIGURE 11 : Variation of temperature within experimental field storage pile. Summer-Autumn storage.



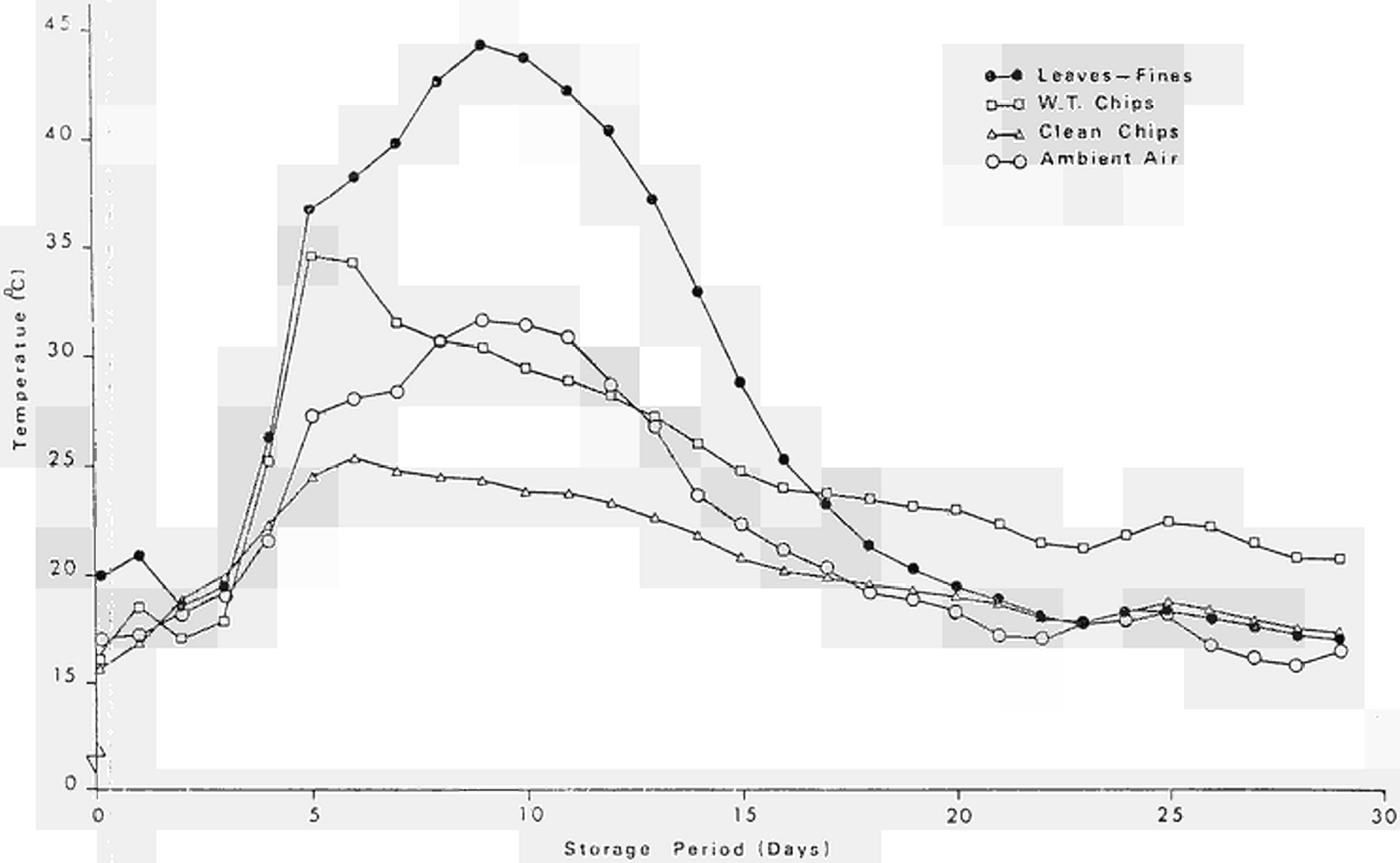


FIGURE 12 : Variation of temperature within experimental storage bins.

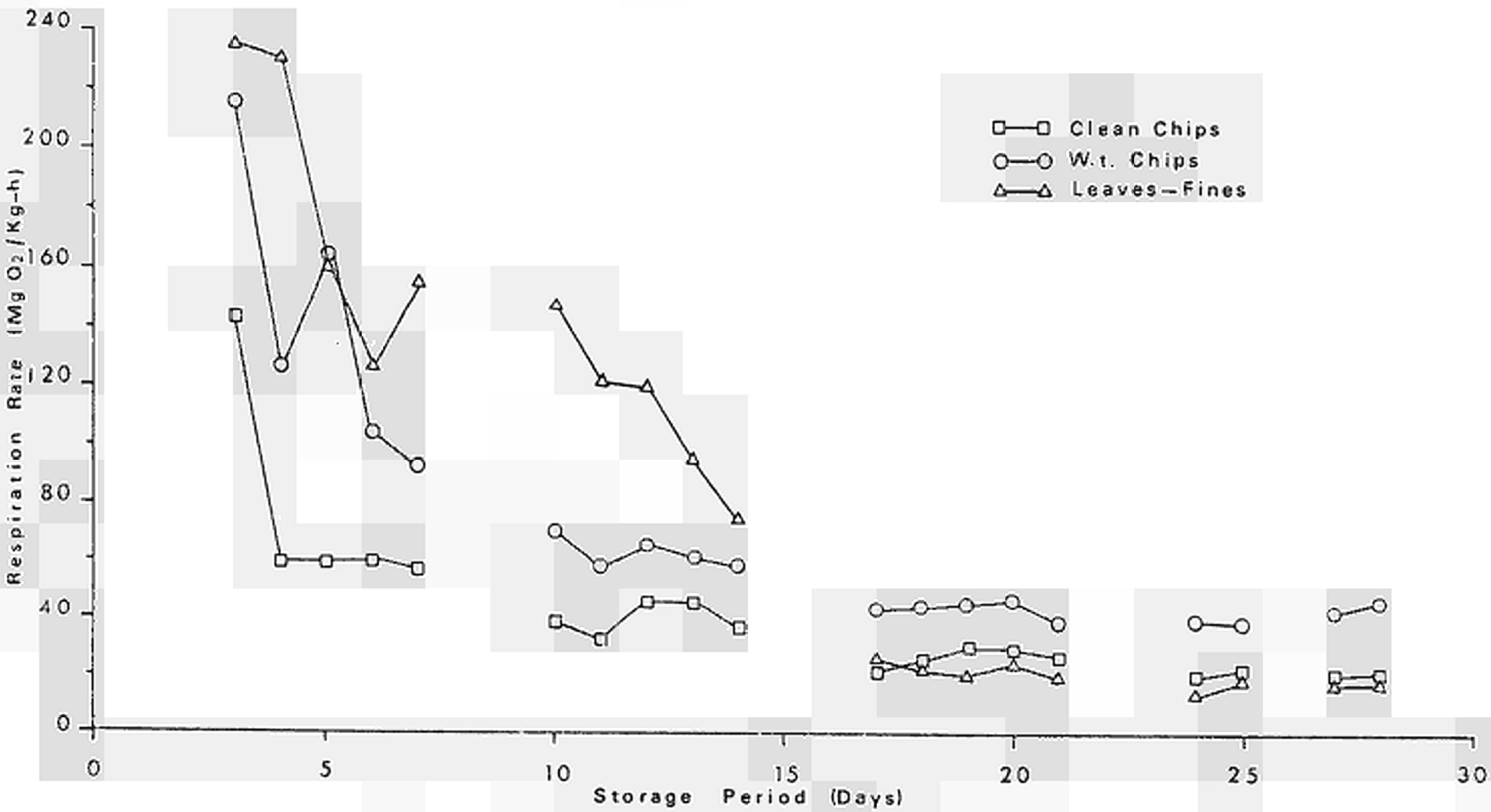


FIGURE 13 : Respiration rate of wood chips in experimental storage bins.

Effect of Storage on Fuel Properties

TABLE 3 : Analysis of wood chips before and after 90 days of sealed bin, insulated storage

Property	Clean Chips				Whole Tree Chips				S.R.F. Chips			
	Before		After		Before		After		Before		After	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Moisture Content (%)	29.98	0.29	29.42	0.72	31.20	0.58	30.65	0.26	53.95	0.87	53.18	2.04
Calorific Value (MJ/kg)	17.80	0.24	17.79	0.38	17.66	0.25	17.87	0.25	17.76	0.13	17.55	0.19
Ash Content (%)	1.24	0.53	0.91	0.53	1.39	0.62	1.02	0.48	1.28	0.55	1.28	0.55
Percentage Volatiles (%)	86.75	1.64	86.95	1.08	85.00	1.22	84.50	1.52	86.41	2.52	85.01	3.68
Fixed Carbon (%)	12.01	est.	12.95	est.	13.61	est.	14.48	est.	12.31	est.	13.71	est.
Specific gravity	0.548	0.04	0.574	0.048	0.546	0.040	0.546	0.047	0.348	0.039	0.349	0.042
Dry Matter (kg)	8.24	2.87	8.19	2.86	8.84	2.97	8.58	2.92	4.91	2.21	4.74	2.17

$\bar{x}$: Mean
s : Std.deviation

TABLE 4 : Dry matter losses during storage

Experiment	Duration	Material	Total D.M. loss (kg) (in samples)	D.M. loss/mo.
Lab. 1982	30 days	1. Clean chips	0.019 kg	0.21%/mo.
		2. W.T. chips	0.125 kg	1.34%/mo.
		3. Leaves-fines	0.515 kg	5.55%/mo.
Lab. 1983	90 days	1. Clean chips	0.047 kg (0.57%)	0.19%/mo.
		2. W.T. chips	0.255 kg (2.88%)	0.96%/mo.
		3. S.R.F. chips	0.167 kg (3.41%)	1.14%/mo.
Field [Summer/Autumn]	90 days	W.T. chips	6.645 kg (1.13%)	0.38%/mo.

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SECTION III

ECONOMIC ASSESSMENT

ECONOMICS OF SHORT ROTATION FORESTRY ENERGY PLANTATIONS

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Consistent with the project's aim of producing a primary fuel from s.r.f. at a competitive cost, we have continuously monitored changes in fuel production costs resulting from establishment, cultivation, processing and yield information provided by the experimental programme. During the 1970's, escalating fossil fuel prices ensured favourable comparative economic returns from indigenous alternative energy sources, such as s.r.f. biomass. Now, declining demand and price stability in the energy marketplace have imposed stricter price limitations on new energy sources.

Economic analysis provides a means of quantifying the effects of alternative production strategies, yield levels, soil and site types, land availability and energy market issues. The main objectives of the work presented here were to:

a. Evaluate s.r.f. energy production costs

b. Establish the economic returns available to s.r.f. producers, in comparison with alternative land uses

c. Examine the effects of plantation management decisions, productivity levels and financial parameters.

Besides providing the results required for these analyses, the financial systems models developed as part of the project represent, in themselves, a major product of the work. While developed for economic assessments of s.r.f. energy plantations, these models (ENCROP and SALIX) may be applied to conventional forestry, and to other biomass energy crops. Both programs are written in ANSI standard FORTRAN IV and have been implemented on a range of DEC, IBM and UNIVAC computers. The models and documentation are available from the author, and are discussed in detail in the following references (1)(2)(3).

ANALYSIS

Discounted Cash Flows

Short rotation forestry plantations generate a complex stream of cash flows (both costs and revenues) associated with the range of management activities, from initial site preparation to recurring harvests and fuel sales. In order to evaluate production costs and annual returns, it is necessary to adjust for the differences in timing of such cash flows; that is, to allow for the time value of money. The Discounted Cash Flow technique (D.C.F.) (4) applied within the ENCROP and SALIX models fulfils this objective, and relies on the principle that all future costs and revenues have a present value determined by the compound rate of interest which would be yielded by the best alternative investment. Thus all expected cash flows are discounted back to the present (that is, to the start of the project) at the prevailing real rate of interest. Similarly, all present value costs and revenues may be re-distributed over the project's economic lifetime, thus yielding equivalent annual values and hence unit production costs.

It is important to distinguish between real and nominal rates of interest, especially during a period of high inflation. The real rate is equivalent to the nominal (or market) rate with the effect of inflation netted out; their relationship is described by the equation (5):

$$1 + I_r = \frac{1 + I_n}{1 + I_g}$$

where:

I_r = Real rate of interest

I_n = Nominal or market rate of interest

I_g = General rate of inflation.

The analysis presented here was conducted in terms of real rates of interest and at the current IR£ currency value (1IR£ = 0.7129 ECU). At present, no reliable long term data is available on real interest rates for Ireland (6). However, in the appraisal of Government projects, real rates of 2-4 per cent are currently used (7). The appropriateness of such rates is supported by a recent analysis of historical market and inflation rates (6). Here, s.r.f. investments are evaluated using real rates of 2, 3, 4, 6 and 8 per cent, thus providing a sense of sensitivity to changes in interest rates. But the discussion is focussed primarily on the lower, currently prevailing, rates.

Management Costs

In the absence of commercial energy plantations, practical experience of s.r.f. production is still limited to experimental plots. The technology of production and harvesting, expected biomass yields, fuel outputs and markets are all likely to change dramatically as s.r.f. approaches commercialisation. Hence, input costs and expected prices can only be tentative at this stage. Nevertheless, available data and field experience to date can provide a reasonable estimate of financial viability, and guide potential investments in s.r.f production.

In the analysis presented, three sets of management input costs were derived to represent a high, medium and low cost scenario (Table 1). These costs reflect the site preparations, cultural practices, levels of fertiliser and herbicide application, etc. which would be required to produce target biomass yields (of the order 10-15 t/ha/yr dry matter) on low-grade sites, including cutover peatland, glacial soils and poorly drained mineral soils. In each case the selected mix of activities and applications were based on experimental data and field experience; they were prepared in consultation with researchers involved in the silvicultural trials described earlier in this report. The cost estimates are based on current commercial rates for the chosen operations and application levels. Where no commercial data existed for specific activities, such as harvesting, expected unit costs were calculated on the basis of capital, interest, maintenance, fuel and labour charges associated with these operations.

All activity costs were assumed to remain constant relative to the general rate of inflation.

TABLE 1 : Cost sets used in the analysis.

Activity	Units	Management Cost Set		
		High	Medium	Low
1. Site preparation	£/ha	108.70	57.00	37.00
2. Drainage	£/ha	70.00	34.80	-
3. Fencing	£/ha	114.00	91.00	-
4. Roading	£/ha	497.00	158.00	-
5. Planting	£/plant	0.195	0.101	0.077
6. Fertilisation a.	£/ha	81.35	68.76	66.04
Fertilisation b.	£/ha/harvest	66.04	38.13	-
7. Weed control a.	£/ha	61.94	47.12	47.12
Weed control b.	£/ha/harvest	32.30	32.30	-
8. Regeneration	£/ha	107.00	107.00	107.00
9. Coppicing('cutting back')	£/ha	40.00	40.00	40.00
10. Harvesting	£/t(f.wt.)	9.50	6.50	4.00
11. Transportation	£/t-km	0.126	0.095	0.080

Yields

Experimental results presented by Neenan earlier in this report (see section on Growing and Land Utilisation) suggest that coppice yields of 10-15 t/ha per year of dry matter are consistently obtainable where species, site preparation and cultivations are matched with site (climatic and edaphic) conditions. In order to account for variations in expected yield, economic analyses were conducted for a range of yield levels from 15 t/ha to 35 t/ha of green biomass (that is, fresh weight, at 50% moisture content approximately).

Yield tables drawn from Dutrow (8)(9) were used to simulate growth in the SALIX model, to examine the effects of planting density and cutting cycle. These data, for American Sycamore (Platanus occidentalis), correspond well with the yields recorded in this programme's experimental plots, and average 18-25 t/ha per year of green biomass on a 4-year cutting cycle with planting densities in the range 4,485-20,000 plants per hectare. These tables are presented in an appendix (Appendix 1).

A yield decline factor of 0.35 per cent per year was applied to all yield estimates within the ENCROP and SALIX models. This decline amounts to between 8 and 9 per cent over a 24-year rotation, and accounts for a reduction in expected yields due to rootstock deterioration and soil damage caused by successive harvestings.

Fuel Prices

Besides management costs and biomass yield levels, fuel sales price is the most important determinant of economic viability. Price governs the periodic income from harvest revenue, and thus the rate of return on invested capital and the annual gross margin (or equivalent annual value) for planted land.

The price paid for s.r.f. wood fuel in the energy marketplace is related, not only to the actual fuel energy content (in terms of calorific value), but also to the perceived value of the fuel to the consumer. In this latter context, a consumer is likely willing to pay a premium price for a fuel such as oil or gas, because of the cleanliness and convenience of using these fuels. For this reason our fuel comparisons presented here are based on coal and peat, which are of more direct relevance in terms of market opportunities, conversion efficiencies and convenience.

Economic analyses were conducted for four individual s.r.f. fuel energy equivalent prices, covering the domestic, industrial and electricity sectors (Table 2). In calculating energy equivalents, allowance was made for the loss in calorific value due to moisture in the fuel (assuming 30% 'as-fired'), as well as the boiler stack losses resulting from fuel moisture and excess air. While these losses are, to some degree, subjective (they vary with fuel moisture [see sections on Fuel Properties and Storage] and boiler design and capacity), the 'useful heating value' of the fuel, thus derived, is an appropriate measure of the true value of a fuel to the consumer.

TABLE 2 : S.r.f. delivered fuel prices and equivalent market price for commercial energy sources

S.r.f. chips Price (£/t-green)	Equivalent Fuel/ End-use sector	Equivalent Fuel Market Price (£/t)
1. 12.50	Steam coal/Electricity	45.00
2. 16.50	Coal-industrial smalls/Industrial	60.00
	Waste wood chips/Electricity	16.50 @ 50% m.c.
3. 22.70	Machine peat/Industrial	34.50
4. 29.00	Bituminous coal/Domestic	104.80
	Machine peat/Domestic	40.00

During the past decade international energy prices have risen at a higher rate than the general rate of inflation. Thus, it became common to apply real rates of inflation (of 3 to 4 per cent) to fuel price in conducting energy related economic studies. Figure 1 illustrates the

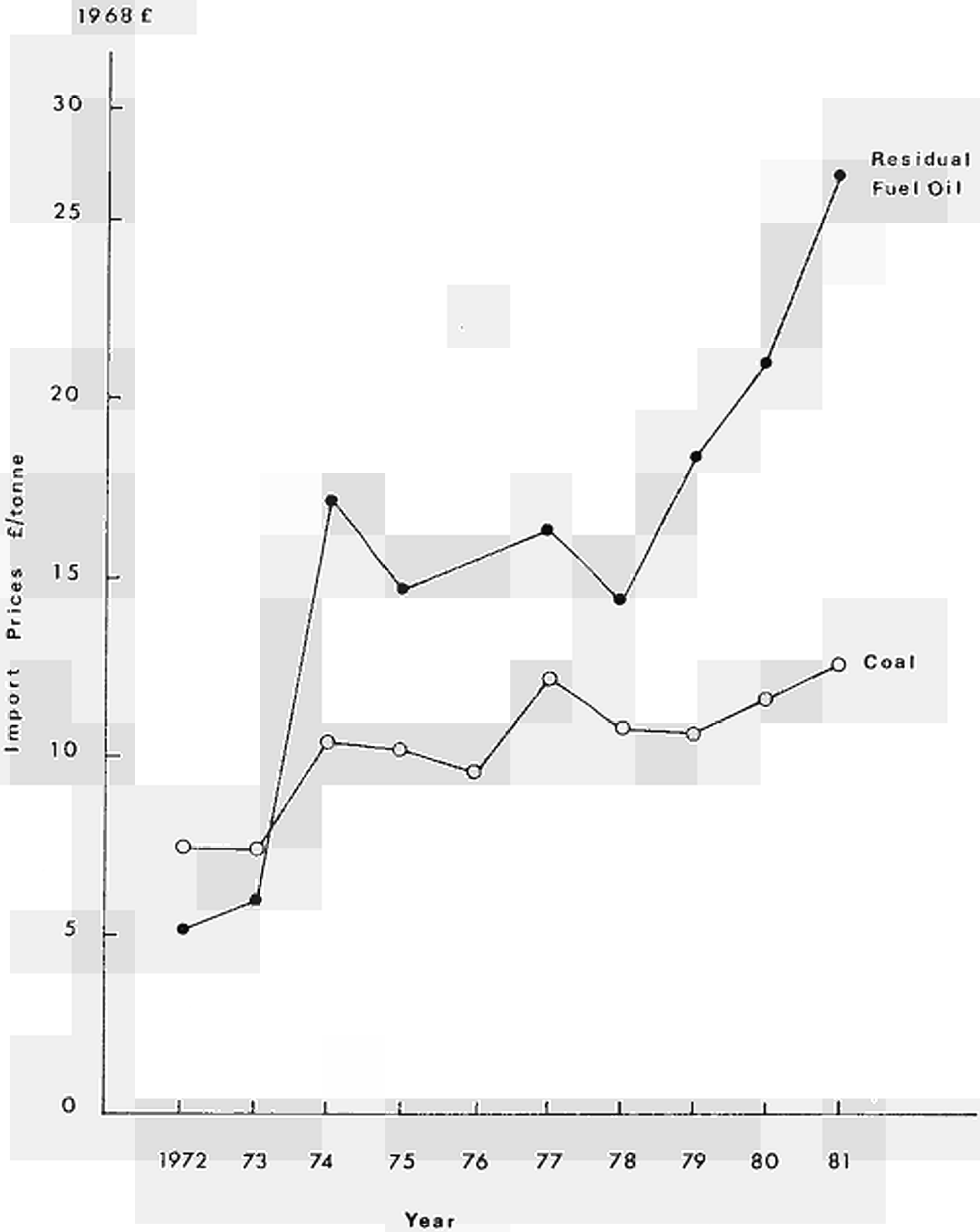


FIGURE 1 : Real import prices for Residual Fuel Oil and Coal, 1972-81. Constant 1968£.

Source: December issues of Trade Statistics of Ireland for years 1972-81.

escalation in the real price for coal and oil imported into Ireland over the period 1972 to 1981. While the present slump in international energy trading has stabilised fuel prices, the effects of real increases in commercial energy prices should not be ignored. These effects are tested here for fuel price inflation rates of 2 and 4 per cent.

RESULTS

Over 1,000 individual production options were evaluated. Each option consisted of a different combination of management cost level, planting density, cutting cycle, length of overall rotation, estimated biomass yield, discount rate and fuel price. Economic indicators produced by the analyses include: present net worth, present value costs and revenues, equivalent annual value, equivalent annual costs and revenues, internal rate of return, benefit/cost ratio, break-even period and production cost per tonne. In the results summarised here, we use production cost per tonne and equivalent annual value as the principal criteria of economic viability.

Table 3 presents a summary of s.r.f. production costs for the three cost sets, at a range of discount rates. This (and later tables) table is drawn from our 'basic management scenario' which comprises a 4-year cutting cycle, 10,000 plants per hectare planting density, 25-year overall rotation (investment period), and a 50 km transport distance; establishment is from cuttings, and all plants are cut-back after the first growing season to initiate coppice growth.

TABLE 3 : S.r.f. production costs (IR£/t - fresh weight)

Discount Rate (%)	Management Cost Level		
	High	Medium	Low
2	23.73	15.44	10.29
3	24.30	15.67	10.41
4	24.93	15.93	10.55
6	26.34	16.52	10.89
8	27.94	17.21	11.29

In order to allow direct price comparison with commercial energy sources, Table 4 shows the production cost in terms of tonnes of oil equivalent (t.o.e.). Fuel energy equivalents are based on the 'useful energy' content (discussed above) of each fuel. Commercial energy figures shown relate to delivered prices, and the range reflects prevailing prices in the industrial and domestic sectors.

TABLE 4 : S.r.f. production costs (IR£/t.o.e.) and current commercial energy prices.

Discount Rate (%)	Management Cost Level		
	High	Medium	Low
2	128.14	83.37	55.57
3	131.22	84.62	56.21
4	134.62	86.02	56.97
6	142.23	89.20	58.80
8	150.88	92.93	60.97

Commercial energy prices:-	IR£/t.o.e.
1. Oil - Industrial (heavy fuel oil)	209
2. Coal - Industrial smalls and domestic	90 - 157
3. Peat - Machine	120 - 140

Under the high management cost scenario s.r.f. production costs are higher than current market prices for coal and peat. However, if input costs could be reduced to the medium or low scenario levels, s.r.f. plantations could compete favourably, even with the lowest priced commercial fuels. All cost scenarios prove economically feasible with respect to a fuel oil energy equivalence datum.

Reduction of input costs may, in some instances, reflect below optimal cultivations, planting densities, etc., and hence lower biomass yields. The extent to which lower (or higher) yield levels affect economic viability was tested by a series of sensitivity analyses. Table 5 and figures 2 and 3 illustrate the net effect of biomass productivity on s.r.f. production costs; these are drawn from the basic management scenario with a 2 per cent real discount rate.

In general, production costs per tonne decrease as expected yields increase; the percentage cost decrease from lowest to highest yield levels is 22 per cent for the medium cost scenario. However, yield level alone does not greatly affect economic viability, especially for low and medium input cost scenarios. A forty percent increase in yield only enables an 8 per cent reduction in fuel production costs for the medium costs scenario (see figure 3); while a decrease of the same magnitude increases production costs by 18 per cent. The effects of management cost level are much more significant, as evident from

TABLE 5 : Variation of s.r.f. production costs with yield level. Discount rate is 2% (IR£/t - fresh wt.)

Yield level (t/ha/yr-fr.wt.)	Management Cost Level		
	High	Medium	Low
15	27.84	17.69	11.54
20	24.68	15.97	10.58
25	22.79	14.93	10.01
30	21.53	14.24	9.62
35	20.63	13.75	9.35

FIGURE 2 : Effect of yield and management cost level on s.r.f. production costs. Shaded area shows the range of yields obtained in experimental plots by An Foras Taluntais.

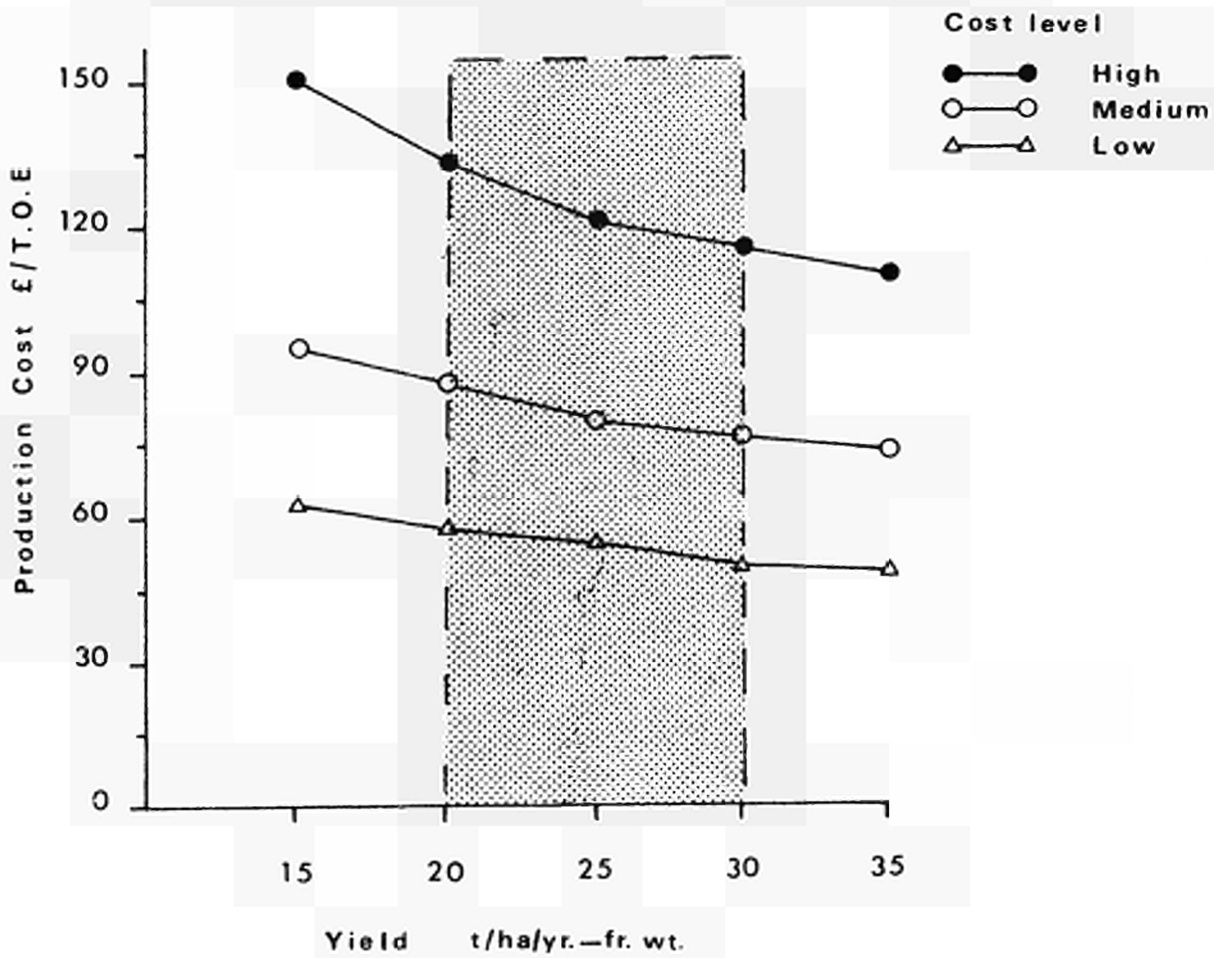


FIGURE 3 : Sensitivity of s.r.f. production costs to productivity and management cost levels.

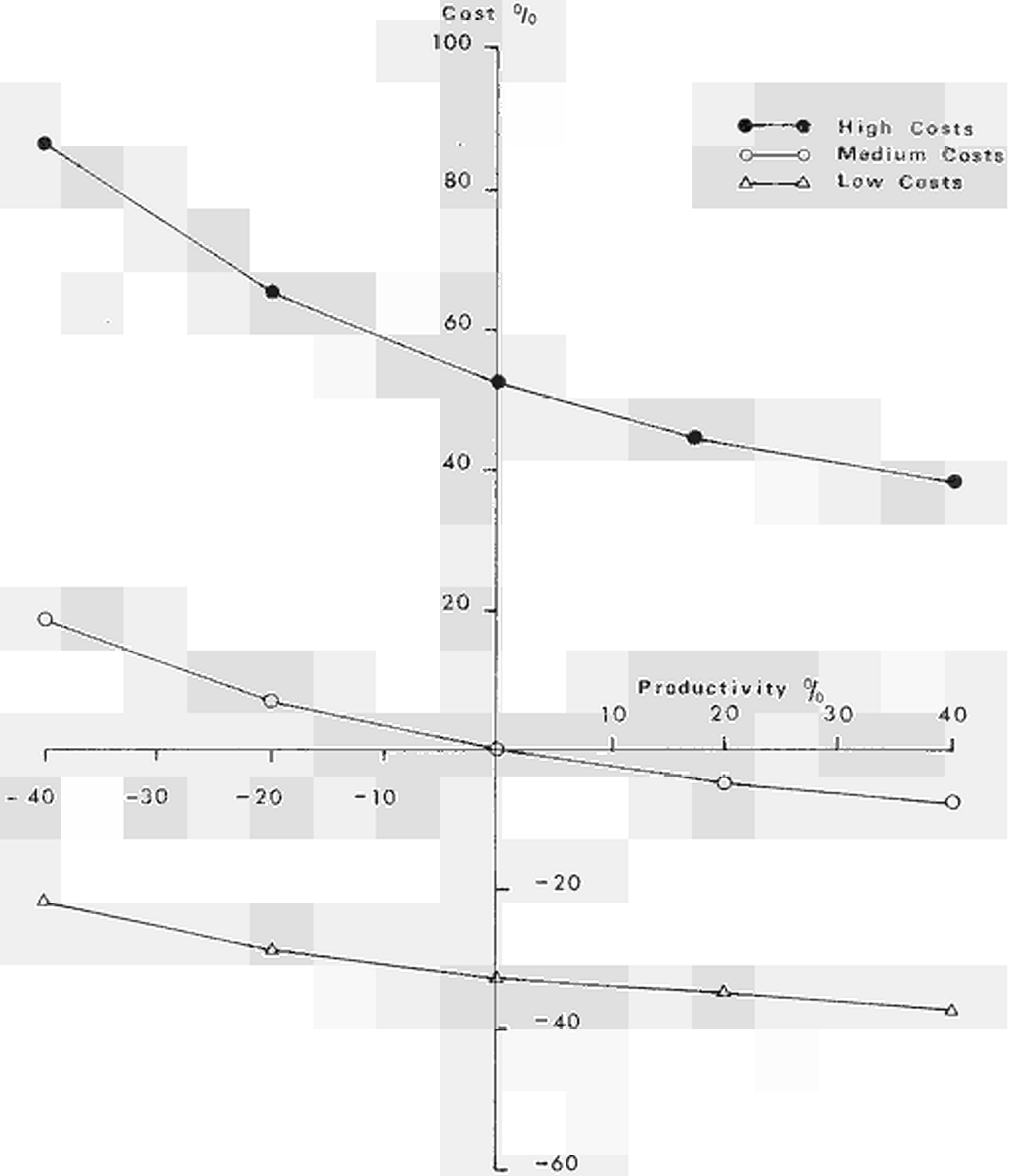


figure 3. These results suggest that, where target yield levels (10-15 t/ha/yr of dry matter) can be sustained, there is greater scope for improving economic returns by input cost reduction rather than through increasing biomass productivity.

Figure 4 shows the dependence of fuel production costs on initial planting density and cutting cycle, for the medium cost scenario and a 2 per cent discount rate. This relationship is also presented in Table 6 for the high, medium and low management cost levels. Production costs are relatively insensitive to the range of planting densities studied, but decrease with longer cutting cycles. For all input cost levels, minmum production costs are produced by a 5-year cutting cycle with the lowest (4,485 plants per hectare) planting density. Under medium management costs, production costs vary less than £1.00 per tonne for densities from 4,485 to 10,000 plants per hectare, for all cutting cycles. On a 2-year cutting cycle, a 13,333 plants/hectare planting density results in the lowest production cost for high and medium input cost scenarios. Medium planting densities (10,000-13,333 plants/hectare) may be preferable to lower levels, regardless of cutting cycle, even though production costs may be marginally greater. These planting densities result in higher average yields (and hence, greater returns) and may also reduce the cost of weed control, as earlier crown closure would eliminate competition from weeds.

The annual returns per unit area yielded by investment in s.r.f. for high, medium and low cost scenarios, a range of production levels, and three discount rates are presented in Table 7. These equivalent annual values are for the 'basic management scenario' with a fuel price of £22.70 per tonne, the energy equivalent price of peat in the industrial sector (see Table 2). For all except the 30 t/ha and 35 t/ha yield levels, the return to land is negative for the high cost

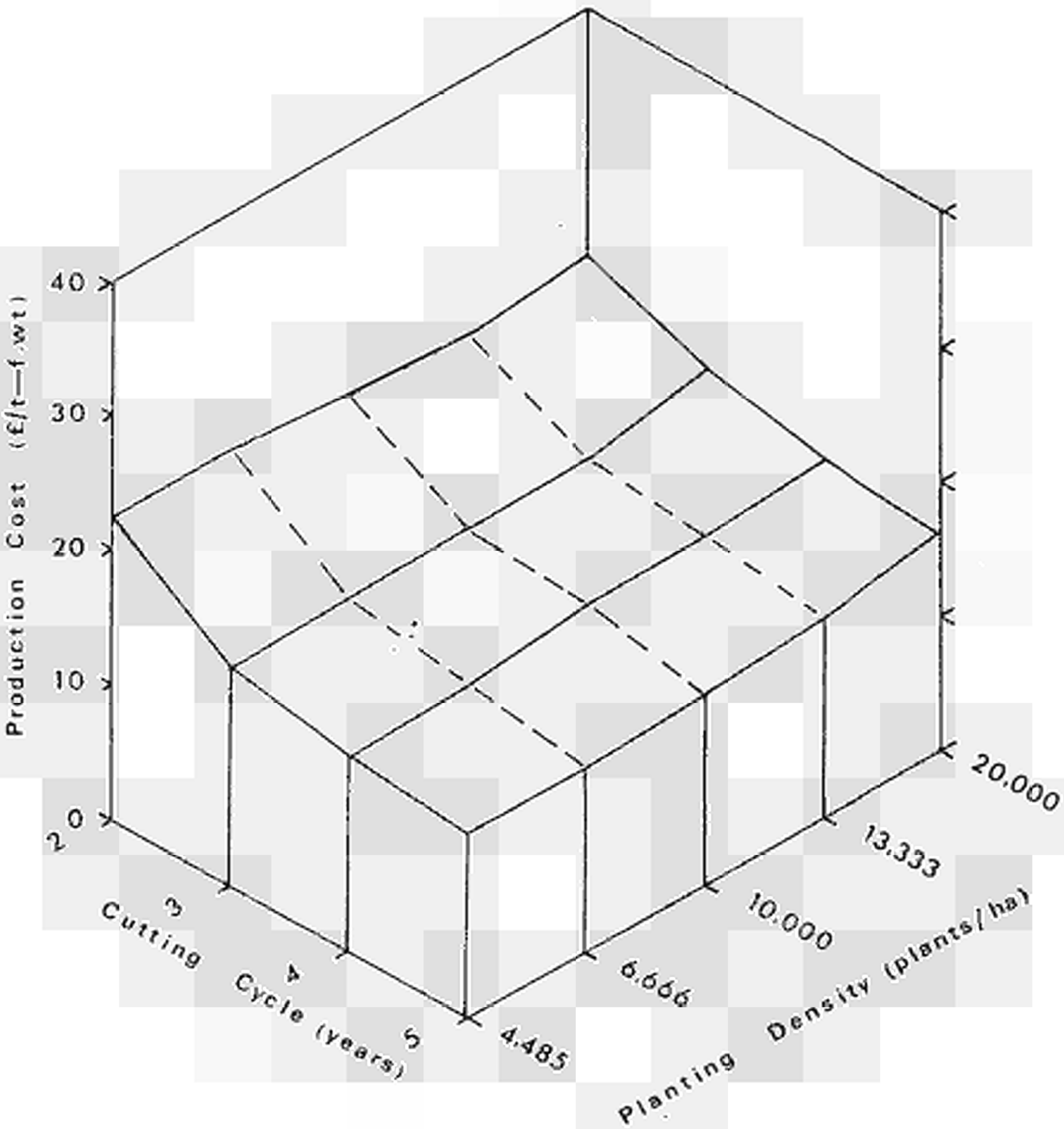


FIGURE 4 : Effect of planting density and cutting cycle on production cost. Discount rate is 2%. Medium management cost scenario.

TABLE 6 : Cost per tonne (£/t - f.wt.) by planting density, cutting cycle and management cost level. Discount rate is 2%.

Planting density (Plants/ha)	Cutting cycle (years)			
	2	3	4	5
		High Cost Level		
4,485	35.15	24.32	22.29	20.45
6,666	35.41	24.96	22.80	21.34
10,000	34.25	25.86	23.73	22.29
13,333	33.51	26.59	24.50	23.10
20,000	35.82	28.98	27.01	25.55
		Medium Cost Level		
4,485	22.53	16.00	14.75	13.67
6,666	22.50	16.29	14.99	14.13
10,000	21.64	16.72	15.44	14.61
13,333	21.08	17.05	15.83	15.01
20,000	22.18	18.26	17.11	16.27
		Low Cost Level		
4,485	12.12	9.97	9.55	9.08
6,666	12.65	10.34	9.84	9.45
10,000	12.86	10.83	10.29	9.88
13,333	13.00	11.22	10.66	10.24
20,000	14.16	12.24	11.68	11.21

TABLE 7 : Equivalent annual returns per hectare (£/ha) by yield level, management cost set and discount rate.

Yield level (t/ha/yr-fr.wt.)	Management Cost Level		
	High	Medium	Low
		Discount rate : 2%	
15	-81.62	57.01	141.15
20	-51.34	107.47	205.65
25	-21.06	157.94	270.16
30	9.21	208.40	334.66
35	39.49	258.86	399.17
		Discount rate : 4%	
15	-121.20	33.14	122.51
20	-92.08	81.68	184.56
25	-62.95	130.23	246.61
30	-33.82	178.77	308.66
35	-4.70	227.31	370.71
		Discount rate : 6%	
15	-164.85	7.19	102.48
20	-136.87	53.83	162.10
25	-108.88	100.47	221.72
30	-80.90	147.11	281.34
35	-52.91	193.75	340.96

scenario. However, with low and medium management costs all yield levels and discount rates give favourable economic returns. Figure 5 illustrates the effect of discount rate on economic returns for the three management cost levels.

Given that s.r.f. would be grown on low grade or marginal land areas, it is worthwhile to consider the comparative returns of s.r.f. and alternative land uses on such soil categories. Table 8 shows the average national Management and Investment and Family Farm Income figures for marginal land areas, from 1979 to 1981; these are drawn from the Agricultural Institute's Farm Management Survey (10). As all labour costs are included in the analysis of s.r.f. returns, the Management and Investment Income figure is a more appropriate measure for direct comparison. It is evident, that even with high management costs, s.r.f. energy plantations would yield greater economic returns than present farm enterprises on these low grade soils.

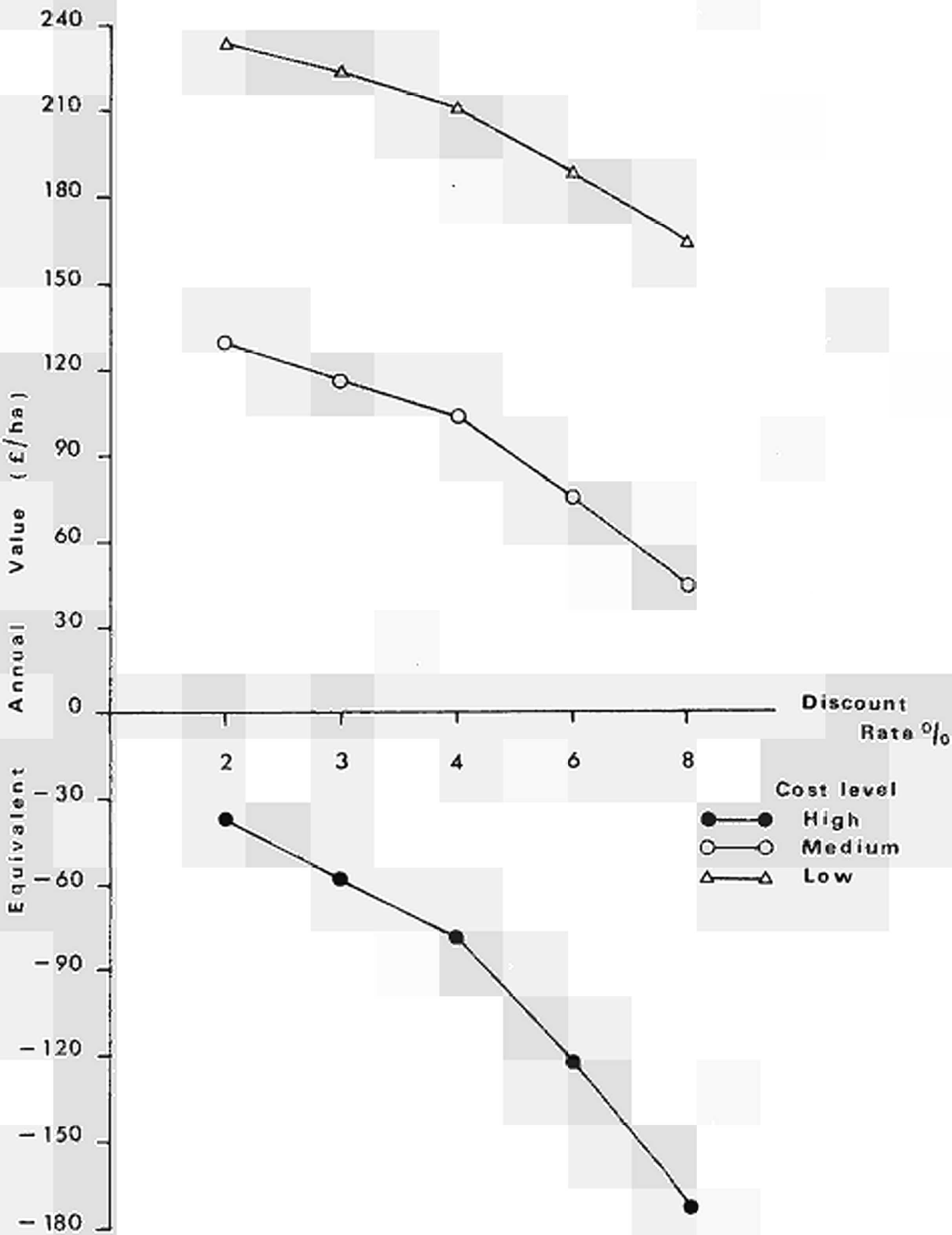
TABLE 8 : Average management and investment income and family farm income per acre and per hectare, 1979 to 1981, in Feb. 1983 IR£

All farms, Table 61, [Ir£ per adjusted acre]						
Soil Group	Management and Invest.Income[b]			Family Farm Income[a]		
	1979	1980	1981	1979	1980	1981
2	-44.5	-66.7	-54.5	104.1	71.0	82.5
3	-64.1	-84.8	-82.0	70.0	54.5	54.2
	Per hectare					
2	-109.9	-164.7	-134.6	257.1	175.4	203.8
3	-158.3	-209.5	-202.5	172.9	134.6	133.9

Notes: [a]Family farm income is defined as the value of gross output less direct non-labour costs and overheads

[b]Management and investment income is family farm income less the value of family labour, costed at the prevailing agricultural worker's wage.

FIGURE 5 : Effect of discount rate and management cost level on equivalent annual returns per hectare.



The final parameters affecting s.r.f. economic viability are 1. the price expected per tonne of fuel sold, and 2. the assumed real inflation rate of the selected fuel price. Table 9 presents the returns per hectare produced by the four fuel prices and three fuel price inflation rates tested. The wide spread of returns shown in this table illustrates the dependence of s.r.f. economics on fuel price. At present there are no established commercial energy markets for s.r.f. biomass. Therefore, it is difficult to ascertain the true 'market clearing' price for s.r.f. wood chips. However from the range of values studied (see Tables 2 and 8) it is clear that s.r.f. fuels could provide more favourable economic returns than present subsistence enterprises, on low-grade land areas, even with a £16.50/t expected fuel price.

In summary, s.r.f. energy plantations in Ireland can produce wood fuel at costs in the range of £55-£120 per tonne of oil equivalent, under low-to-high management costs, and with biomass yields (10-15 t/ha/yr dry matter) at a level consistently being obtained in this programme's experimental plots. With production costs of this order, s.r.f. can compete favourably with commercial energy sources, and yield greater economic returns than those currently available to marginal land owners. As with other alternative energy sources, the market forces and commercial energy price threshold at which s.r.f. will become more attractive to both producer and consumer, remain to be seen.

TABLE 9 : Equivalent annual returns per hectare (£/ha) by fuel price, fuel price inflation rate and management cost set. Discount rate is 2%.

Fuel price (£/t - fr.wt.)	Fuel Price Inflation Rate (%)		
	0.00	2.00	4.00
		High Cost Level	
12.50	-236.89	-156.50	-44.35
16.50	-158.78	-52.67	95.38
22.70	-37.72	108.27	311.95
29.00	85.30	271.80	532.01
		Medium Cost Level	
12.50	-68.99	11.39	123.55
16.50	9.11	115.23	263.27
22.70	130.18	276.16	479.84
29.00	253.20	439.70	699.91
		Low Cost Level	
12.50	-35.51	115.89	228.05
16.50	112.59	219.73	367.77
22.70	234.68	380.67	584.34
29.00	357.70	544.20	804.41

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APPENDIX 1

Yield tables (cumulative for American Sycamore (*Platanus occidentalis*), as used in SALIX model.

Planting Density (Stems/ha)	Stand Age (years) 2	3	4	5
	Seedling Yields (t/ha - fresh weight)			
4,485	8.97	31.41	50.48	67.31
6,666	9.00	34.70	55.90	78.20
10,000	12.30	39.10	61.50	85.40
13,333	15.60	43.60	67.10	92.30
20,000	21.20	47.00	70.00	92.80
	Coppice Yields (t/ha - fresh weight)			
4,485	15.71	46.00	72.92	112.19
6,666	17.90	50.40	80.60	114.80
10,000	22.90	56.50	89.00	124.30
13,333	27.90	62.60	97.30	133.90
20,000	31.90	67.70	101.40	136.60

Source : Based on Dutrow (Ref.8) and Dutrow & Saucier (Ref.9).

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