

ENERGY FROM BIOMASS

Summaries of the Biomass Projects carried out
as part of the Department of Trade and Industry's
New and Renewable Energy Programme

VOLUME 1: WOOD FUEL SUPPLIES AND SUPPLY CHAINS

ETSU BM/04/00048/REP/1

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INTRODUCTION

These volumes of Summaries provide easy access to the many projects carried out in the Energy from Biomass programme area as part of the Department of Trade and Industry's New and Renewable Energy Programme.

The Summaries in this volume cover contractor reports on the subject published up to December 1997.

This is a summary of work carried out under contract as part of the New and Renewable Energy Programme, managed by ETSU on behalf of the Department of Trade and Industry.

The views and judgements summarised are those of the various contractors and do not necessarily reflect those of ETSU or the Department of Trade and Industry.

REPORTS SUMMARISED IN VOLUME 1¹

Report No	Title	Contractor	Publ. date	Page No
1. SINGLE STEM FORESTRY TRIALS				
<i>ETSU B 1081 A</i>	<i>An experimental study of single stem trees as energy crops - Biomass yields of forest trees</i>	<i>Department of Forestry, University of Aberdeen</i>	1982	5
<i>ETSU B 1081 (b)</i>	<i>An experimental study of short rotation forestry for energy</i>	<i>Department of Forestry, University of Aberdeen</i>	1984	9
ETSU B 1081	Short rotation forestry for energy: single stem plantations	Department of Forestry, University of Aberdeen	1989	12
ETSU B 1265	Trials of single stem energy plantations: biomass production	Wood Supply Research Group, Department of Forestry, University of Aberdeen	1992	16
2. COPPICE TRIALS				
ETSU B 1078	Coppiced trees as energy crops	Forestry Commission Research Division	1990	21
ETSU B 1291	Coppiced trees as energy crops	Forestry Commission Research Division	1993	25
ETSU B 1171	Establishment and monitoring of large-scale trials of short rotation forestry for energy	Forestry Department, Aberdeen University	1989	28
ETSU B 1255	Establishment and monitoring of large-scale trials of short rotation coppice for energy	Wood Supply Research Group, Department of Forestry, University of Aberdeen	1993	31
ETSU B/W2/00126/REP	Establishment and monitoring of large-scale trials of short rotation coppice for energy: Phase III	Wood Supply Research Group, Department of Forestry, University of Aberdeen	1995	34
ETSU B/W2/00402/REP	The continuing study of poplar as an energy crop	Silviculture (S) Branch, Forestry Commission Research Division	1996	38
3. SHORT ROTATION COPPICE CULTIVATION ISSUES				
3.1 Planting, Fertilisation and Root Development				
ETSU B/M4/00487/26/REP	Further evaluation of planting machines for short-rotation coppice	Technical Development Branch, Forestry Commission	1995	41

¹ Items in italics are archived

Report No	Title	Contractor	Publ. date	Page No
ETSU B/W2/00336/REP	Initial spacing of poplars and willows grown as arable coppice	Silviculture and Seeds Research Branch, Forestry Commission Research Agency	1997	44
ETSU B/W5/00215/REP	Fertilisation of short rotation energy coppice using sewage sludge	WRc plc	1995	47
ETSU B/W5/00511/REP	Fertilisation of short rotation energy coppice using sewage sludge	Yorkshire Environmental Limited	1996	50
ETSU B/M4/00487/39/REP	A study of root development in SRC with particular attention to field drainage	Sidney C Banks plc	1996	53
3.2 Weed Control				
ETSU B/W5/00211/REP	Weed control and soil management systems for short-rotation coppice: present knowledge and future requirements	Avon Vegetation Research	1993	55
ETSU B/N2/00132/REP	Evaluation of residual and foliar-acting herbicides on poplar and willow cultivars	Avon Vegetation Research, Long Ashton Research Station	1994	58
ETSU B/W2/00401/REP/1	Report on experiments on weed management in coppice: 1994-1995	Avon Vegetation Research	1996	62
ETSU B/W2/00401/REP/2	Weed management in short rotation coppice: current status and future requirements	Avon Vegetation Research	1996	67
ETSU B/M4/00532/28/REP	Mechanical pre-planting weed control in short rotation coppice using deep forestry ploughing techniques	Border Biofuels Ltd	1997	71
3.3 Pests and Diseases				
ETSU B 1258	Evaluation of the biology and importance of diseases and pests in willow energy plantations	Long Ashton Research Station	1992	74
ETSU B 1328	Interactions of rust diseases with willow biomass clones at different sites	Long Ashton Research Station	1994	77
ETSU B/M3/00388/10/REP	A review of the status and control strategies of known and perceived insect pests on <i>Salix</i> and <i>Populus</i> in Northwest Europe	The Game Conservancy Trust	1994	81
ETSU B/W6/00230/REP	Potential for biocontrol of willow rust with the hyperparasite <i>Sphaerellopsis filum</i>	Long Ashton Research Station	1995	84
ETSU B/W6/00214/REP	Epidemiology, population dynamics and management of rust diseases in willow energy plantations	Department of Agricultural Sciences, University of Bristol Institute of Arable Crops Research	1995	87

Report No	Title	Contractor	Publ. date	Page No
ETSU B/M4/00487/14/REP	Phenology and population dynamics of willow beetles (Coleoptera: Chrysomelidae) in short rotation coppiced willows at Long Ashton	Long Ashton Research Station	1996	90
ETSU B/M4/00532/27/REP	An applied study of clonal resistance to willow beetle attack in SRC willows	Institute of Arable Crops Research - Long Ashton Research Station	1997	93
4. RELEVANT CASE STUDIES				
ETSU B/W2/00527/REP	Monitoring the progress of NFFO-3 projects: Short rotation willow coppice - agronomy and economics	Sidney C Banks plc	1997	96
ETSU B/W2/00197/REP	The Farm Wood Fuel and Energy Project	R H and R W Clutton	1997	99
ETSU B/W2/00199/REP	Farm Wood Fuel and Energy Project - Crop performance monitoring	ADAS	1997	103

1. SINGLE STEM FORESTRY TRIALS

Report No: ETSU B 1081 A

Publication date: 1982

AN EXPERIMENTAL STUDY OF SINGLE STEM TREES AS ENERGY CROPS - BIOMASS YIELDS OF FOREST TREES

Department of Forestry, University of Aberdeen

Background

A 1979 assessment of the potential of forest biomass as a source of energy in Britain identified two fuel sources:

- trees grown in energy plantations on 10-20 year rotations
- whole trees harvested in early thinnings.

However, because trees are not normally harvested in Britain when they are less than 20 years old, there are serious gaps in knowledge relating to their growth.

Project Objectives

The overall aim of this project was to provide estimates of dry matter production by the whole tree and by its component parts for ten different species with an age range of 12-28 years.

Specific objectives can be summarised as follows:

- To tabulate, for each site, total above-ground biomass per tree and the division between stem, branches and foliage.
- To derive a single-tree model from the mathematical relationship between total biomass and its components and some other easily measured parameter.
- To derive a stand model from the mathematical relationship between the production of dry matter in a stand and some other measurable stand parameter.

Methodology

Ten tree species - alder, birch, *Nothofagus*, sycamore, Corsican pine, Douglas fir, hybrid larch, Scots pine, Sitka spruce and western hemlock - were selected for their biomass production potential. They were examined at several ages up to 28 years and for several growth rates. Account was also taken of each site's production potential.

Circular plots, each 0.05ha in area, were located at random in each sample stand, and the diameter at breast height (dbh) was measured using calipers for about 100 trees with a dbh of more than 5cm. The data were used to determine basal area per ha, number of stems per ha,

and the basal area corresponding to mean dbh. The frequency distribution of tree diameter in the stand was used to weight subsequent sampling for dry weight.

Twelve sample trees were then selected in each stand and felled at 10cm above ground level. Measurements included:

- weight of live and dead branches
- total tree height (including stump)
- stem length from the cut stump to the point where the top diameter measured 7cm (conifers)
- stem length from the cut stump to the point where the top diameter measured 5cm (hardwoods and conifers)
- stem weight.

To work out the stem volume, each stem (up to the point where the top diameter measured 5cm) was cut into five equal sections, and the mid-diameter of each section was measured. Subsequent calculations used Huber's formula.

Half the samples were also assessed for moisture content. The procedure involved:

- extracting, weighing, cutting into 15cm lengths and bagging up one live branch from each third of the crown, and three dead branches, if present, from the tree
- cutting a 5cm disc of stem from the mid-point of each of the five sections used for volume estimation, weighing each disc individually and placing the discs in bags
- drying the five stem sub-samples to a constant weight at 100°C in an oven and determining their moisture content
- determining the dry weight of the live branches and foliage, and calculating the ratio of branch wood to foliage
- splitting the stem discs into wood and bark fractions and establishing the ratio between them
- calculating the mean moisture content of the tree from the moisture content of the discs
- using the mean moisture contents and derived ratios to calculate the dry weights of all the sample trees.

The next step was to derive single-tree models for each site using regression analysis. Biomass yields were predicted for each site by substituting the mean basal area of the 100

trees measured in each sample stand in the appropriate single tree models, and multiplying by the stocking rate.

Stand models were derived from the single tree models for four populations: Corsican and Scots pine to top diameters of 5cm and 7cm, and other conifers to top diameters of 5cm and 7cm.

Findings

Predicted biomass yields for each site sampled are shown in the following table.

Predicted biomass yields for each site and species

Site No	Species	Age (years)	Yield class (m ³ /ha/year)	Standing dry weight (dry tonnes/ha)
015	Alder	12	6	26.4
035	Alder	18	10	73.6
045	Alder	22	14	210.2
075	Birch	25	6	100.0
085	Birch	20	9	99.2
105	<i>Nothofagus</i>	13	17	74.6
115	<i>Nothofagus</i>	24	11	144.5
125	<i>Nothofagus</i>	17	14	102.1
155	Sycamore	28	4	97.4
165	Sycamore	22	10	113.9
195	Corsican pine	19	12	85.9
197	Corsican pine	19	12	85.6
205	Corsican pine	20	16	136.0
207	Corsican pine	20	16	136.0
225	Douglas fir	14	20	86.2
227	Douglas fir	14	20	77.4
235	Douglas fir	18	12	68.2
237	Douglas fir	18	12	67.0
245	Douglas fir	21	16	126.3
247	Douglas fir	21	16	126.3
265	Hybrid larch	13	10	35.9
267	Hybrid larch	13	10	33.9
275	Hybrid larch	20	10	111.4
277	Hybrid larch	20	10	107.2
285	Hybrid larch	20	15	156.2
287	Hybrid larch	20	15	155.9
305	Scots pine	14	14	43.0
307	Scots pine	14	14	36.8
315	Scots pine	18	8	59.9
317	Scots pine	18	8	56.3
325	Scots pine	19	14	108.5
327	Scots pine	19	14	106.9
345	Sitka spruce	14	26	109.2
347	Sitka spruce	14	26	101.9
355	Sitka spruce	22	14	105.4
357	Sitka spruce	22	14	104.7
365	Sitka spruce	20	26	209.2
367	Sitka spruce	20	26	204.9
385	Western hemlock	15	28	174.2
387	Western hemlock	15	28	172.6
395	Western hemlock	17	16	58.1
397	Western hemlock	17	16	58.1
405	Western hemlock	18	20	108.9
407	Western hemlock	18	20	108.3

AN EXPERIMENTAL STUDY OF SHORT ROTATION FORESTRY FOR ENERGY

Department of Forestry, University of Aberdeen

Background

One type of short rotation forestry energy plantation suitable for the uplands and for less fertile areas of lowland Britain involves using single-stemmed trees. Although the rotation period will vary with tree species and site, and will depend on the size of tree required by the end user, periods of 10-20 years should cover most eventualities. It is envisaged that most plantations will be established on fairly small areas of land and will be expensive to operate.

Project Objective

- To overcome the lack of knowledge of this type of forestry by examining the problems and costs of plantation establishment, and the types of system and equipment available for harvesting.

Methodology

Trial plantations were established on three types of site in four geographical regions of the British Isles, as summarised in the table below.

Site details of trial plantations

	Site location	Region	Site type	Area (ha)	Planting year
1	Craibstone	North-east Scotland	Marginal agriculture	0.2	1981
2	Banchory	North-east Scotland	Scrub woodland	0.6	1981
3	Aldroughty	North-east Scotland	Young woodland	1.0	1981
4	Marlefield	Scottish Borders	Marginal agriculture	2.0	1982
5	Kilham	Scottish Borders	Scrub woodland	2.0	1982
6	Witney	Southern England	Marginal agriculture	1.0	1982/1983
7	Tar Wood	Southern England	Scrub woodland	1.0	1982/1983
8	Longridge	Southern England	Young woodland	1.0	1982
9	Crowcombe	South-west England	Marginal agriculture	1.0	1982
10	Queenhill	South-west England	Scrub woodland	1.0	1982
11	Holmington	South-west England	Young woodland	1.0	1983

Two plots of each of ten species were planted on each site at spacings of 1 x 1 metre (10,000 stems/ha). The species used were alder, birch, *Nothofagus*, sycamore, Corsican pine, Scots

pine, Douglas fir, hybrid larch, Sitka spruce and western hemlock. Forestry contracting companies were employed to carry out the work.

Findings

Establishment

The trials confirmed that it was possible for relatively small land areas to be established with trees, although the establishment costs are substantially higher than those for extensive areas of conventional forestry in the uplands. Costs were high for three reasons:

- the small areas of land involved
- the relatively high stocking rates
- the experimental nature of the trials.

Economies of scale were found to operate even for the establishment of these small trial areas. The average cost of establishing one hectare was £4223 but ranged from just over £6000/ha for the smallest trial (0.2ha) to £2317 for the largest trial (2ha). Fencing in particular is affected by area, and the average fencing cost was approximately 20% of total establishment cost.

Stocking rates were more than twice those of conventional forestry (perhaps 4000/ha) and involved ten species instead of the single species that would normally be planted in conventional plantations. Furthermore, because the trials were experimental, planting was more closely supervised to ensure the correct spacing.

Weed control proved particularly difficult on woodland sites where hardwoods “seeded in” and shrubs grew prolifically. Close planting necessitated hand weed control using sickles, with a subsequent application of herbicide using a “weed wipe” applicator. Polythene mulches were applied at two sites: this controlled weeds quite effectively but was prone to damage and costly to apply.

Calculations estimated that financial viability could be achieved if plantations achieved a productivity of 10 dry tonnes/ha/year and supplied local domestic fuel wood markets.

Harvesting

Although stumps and roots can be harvested, current opinion is that their recovery for fuel is uneconomic. The main fuel potential lies in the tops and branches that are left behind during conventional harvesting. While concentrated residues can be recovered in a second pass operation, integrated harvesting systems may offer a more satisfactory alternative, with machines selected according to tree size, terrain and accessibility.

The whole tree harvesting and chipping of small trees, which is used in both North America and Scandinavia, may be a UK option in the future now that smaller and less costly equipment is becoming available. Scrub and over-mature woodland could be harvested using conventional techniques.

Most of the small-scale machines currently available for coppice harvesting are tractor-mounted, cut 1-2 year old coppice using twin circular saws, and produce bundles of cut coppice sprouts. The Loughry machine uses a single circular saw, and the cut stems are passed through a series of packers before being tied into bundles weighing 40kg. The machine has undergone limited trials in willow plantations, and some further design work is necessary to resolve problems associated with knotting.

Areas Requiring Further Work

- The management of existing woodland for energy.
- Information on costs and yield from short rotation forestry.
- The role and use of herbicides in energy plantations.
- Further development and testing of the Loughry harvester, and the testing of integrated harvesting systems across a range of forest crops.
- The integration of farming and forestry.

SHORT ROTATION FORESTRY FOR ENERGY: SINGLE STEM PLANTATIONS

Department of Forestry, University of Aberdeen

Background

One possible type of forest energy plantation involves using single-stemmed trees rather than coppice. This type of planting is suitable for the uplands and for less fertile areas of lowland Britain and would complement rather than compete with coppice energy plantations.

Although rotation periods will vary with species, site and the required final dimensions of the tree, periods of 10-20 years should cover most eventualities.

Project Objectives

The aim of this project is to examine the logistics and costs of establishing single-stem forest energy plantations. Specific objectives can be summarised as follows:

- To record all establishment operations and costs.
- To measure growth in height and diameter.
- To determine dry matter production.

This report builds on the findings of the 1984 interim report, Report No: ETSU B/1081 (b). It covers Phase I of the study (1980-1989).

Methodology

Trial plantations were established on three types of site in four geographical regions of the British Isles (see above, Report No: ETSU B/1081 (b)).

Two plots of each of ten species were planted on most sites at spacings of 1 x 1 metre (10,000 stems/ha). The species used were alder, birch, *Nothofagus*, sycamore, Corsican pine, Scots pine, Douglas fir, hybrid larch, Sitka spruce and western hemlock. Longridge wood has only one plot per species. Where plots failed, the replacement species used were lodgepole pine, silver fir, red alder and ash.

All sites were visited in 1985/86 and the position and health of every tree noted. Twenty percent of the surviving trees were selected at random and measured for total height and diameter at ground level. The same measurements have been recorded for subsequent years.

Findings

Establishment operations

Establishment operations varied from site to site, as summarised in Table 1.

Table 1 Site establishment operations

Site	Preparation	Planting	Weed control	Assessment
1	Maintenance of stock/rabbit fencing	20-40cm open rooted stock direct planted late March 1981	1981: Plastic bags Feb. 1982: Chemical 1983/1984: Hand	Losses replaced March 1982 Trees growing well
2	Clearance Forestry ploughing Rabbit fencing	20-40cm open rooted cold-stored stock direct planted early May 1981	1981/1982: None 1983 onwards: Hand	Losses replaced March 1982
3	Clearance Deer/rabbit fencing	20-40cm open rooted stock from cold storage direct planted late April 1981	1981: Hand Feb 1982: Chemical 1983: Hand and chemical 1984/1985: Hand 1986: Chemical	Losses replaced March 1982
4	Agricultural ploughing Drainage ditch Stock/rabbit fencing	20-40cm open rooted stock direct notch planted on furrows late April 1982	1982: Hand 1983: Hand 1984-1986: Chemical	Good survival No beating up Five plots replanted in spring 1986.
5	Clearance Agricultural ploughing Stock/rabbit fencing	20-40cm (+ some 40-60cm) stock direct notch planted February 1982	1982: Chemical 1983: Hand 1984: Chemical	Poor survival Trials discontinued
6	No record	20-40cm open rooted stock direct planted through black polythene mulch 1982	1982: Polythene mulch 1983-1985: No records 1986: Chemical	Poor survival Site discontinued 1988/89
7	Clearance Rabbit fencing	20-40cm open rooted stock direct planted spring 1982	1983: Hand and chemical 1984: Hand	Poor survival Site discontinued 1985
8	Clearance Rabbit fencing	20-40cm open rooted stock planted April 1982	1982: Hand 1983: Hand and chemical 1984 onwards: Hand	Some beating up 1983
9	Unsuccessful bracken clearance Rabbit fencing	20-40cm open rooted stock direct planted January 1982 Anti-mammal smear	1982: Hand x 2 1983-1986: Hand	No beating up 1983 Some replacement 1986
10	Clearance Rabbit fencing	20-40cm open rooted stock direct planted March 1982 Anti-mammal smear	Annual	Some replacement spring 1986
11	Clearance Rabbit fencing	20-40cm open-rooted stock direct planted May 1983 Anti-mammal smear	1984 onwards: Hand	Some replacement 1985/6

Establishment costs

Reliable establishment cost data exist for eight of the trial sites, and these are summarised in Table 2. By far the most important cost elements on all sites were plants and planting, and weeding. The number of man-days required for both operations varied from site to site, reflecting both the size of the trial plot and individual site conditions.

Table 2 Establishment cost data (£) for eight sites

	Site							
	1	2	3	4	8	9	10	11
Site preparation	-	270	472	115	1075	455	621	305
Fencing	-	426	1204	851	782	1254	1319	1063
Plants/planting	259	915	1335	2689	2168	2304	2390	2611
Beating up	80	229	359	-	488	-	-	-
Weeding	910	498	2957	2693	2142	3560	3431	2362
Protection	-	-	-	-	-	183	-	-
Maintenance	-	-	-	-	316	-	46	46
TOTAL	1249	2338	6327	6348	6971	7756	7807	6387

Growth measurements

The growth in height and diameter of randomly selected trees was recorded for each site up to and including the 1987 growing season. The findings are summarised in Table 3.

Table 3 Growth in height (h) and diameter (d) to 1987/88 (cm rounded up)

Species	Site 1		Site 2		Site 3		Site 4		Site 6		Site 8		Site 9		Site 10		Site 11	
	h	d	h	d	h	d	h	d	h	d	h	d	h	d	h	d	h	d
Scots pine	204	6	207	5	241	5	163	4	175	5	-	-	183	5	218	5	177	4
Corsican pine	151	5	-	-	-	-	110	3	-	-	-	-	130	6	-	6	-	4
Douglas fir	270	6	294	5	264	5	91	2	-	-	-	-	248	6	359	6	214	4
Western hemlock	152	4	247	4	296	5	-	-	-	-	-	-	270	4	343	5	227	3
Sitka spruce	303	6	263	5	253	5	214	4	101	2	167	3	191	4	275	5	195	4
Hybrid larch	166	6	349	6	289	5	275	5	-	-	250	4	286	4	382	6	336	5
<i>Nothofagus</i>	187	4	-	-	237	4	-	-	-	-	258	4	281	5	508	7	310	5
Sycamore	422	7	249	4	150	3	159	3	264	4	328	5	-	-	299	4	-	-
Birch	247	5	-	-	231	4	315	5	-	-	350	5	339	5	482	6	-	-
Alder	381	7	351	6	279	4	578	8	-	-	605	7	176	3	354	5	-	-
Ash	-	-	-	-	-	-	-	-	-	-	205	3	-	-	-	-	-	-
Silver fir	-	-	-	-	-	-	-	-	-	-	163	3	-	-	-	-	-	-

TRIALS OF SINGLE STEM ENERGY PLANTATIONS: BIOMASS PRODUCTION

Wood Supply Research Group, Department of Forestry, University of Aberdeen

Background

This report summarises Phase II (1989-1992) of the single stem energy plantation study that was begun in 1981. It focuses on tree growth and the determination of biomass production on eight of the 11 original sites. It also assesses the economic viability of such plantations on farms.

Project Objectives

The aim of Phase II of this project is to examine the economic viability of short rotation single stemmed trees for energy. Specific objectives can be summarised as follows:

- To measure the growth in height and diameter.
- To determine dry matter production.
- To develop a single stem plantation growth model.
- To determine the costs of production.

Methodology

Following a review of the state of each plantation in 1989, monitoring was discontinued at Kilham in the Scottish Borders (Site 5) and at Witney (Site 6) and Tar Wood (Site 7) in Southern England.

Biomass production at the remaining sites was determined by harvesting a proportion of the trees. The close spacing of the crop precluded the felling and removal of randomly selected trees, so a one-in-three line-thinning approach was adopted, with sample trees being selected from the thinned lines.

Each site was visited in September 1989 and the diameter at breast height (dbh) of each tree was measured using calipers. The sampling strategy adopted during subsequent thinning was based on the frequency distribution of dbh for each species on each site.

The sample trees selected from the thinned lines were felled at 10cm above ground level, and measurements were made of whole tree weight and height, dbh and, after delimiting, stem weight.

Half the sample trees were sub-sampled to determine their moisture content. The procedure adopted is described in Report No: ETSU B 1081 A, summarised above.

The average dry biomass of the sample trees was calculated using the equation:

$$\text{WT dwt} = (100 - \text{WT MC\%}/100) \times \text{WT gwt}$$

where WT dwt = whole tree dry weight
WT gwt = whole tree green weight
WT MC% = whole tree percentage moisture content

The calculation was carried out for each of the ten sample trees of each species on each site, and the average single tree dry weight determined.

The equivalent biomass productivity in dry tonnes/ha/year was determined by multiplying the dry biomass values by stocking rates and dividing by the age of the trees.

A new set of trees was selected for height and diameter measurement. The growth of these trees was monitored during 1990/1991.

Findings

Growth measurements

Growth measurements to 1989/90 are summarised in Table 1 below. Growth in height varied with site and species, the best performance being recorded for alder, which achieved 7.8m after nine years. Most species attained average heights in excess of three metres.

Biomass production varied widely across species and sites as a result of species/site suitability.

Moisture content ranged from 32% for common ash at Longridge (Site 8) to 66% for Scots pine at Crowcombe (Site 9). For most sites and species, the measured moisture content was usually more than 50%.

Average single tree dry weight varied from less than 1kg for common alder growing on a dry site to 9.8kg for western hemlock growing on a good site. Biomass productivity for each site and species, assuming a 100% survival rate, ranged from less than 1 dry tonne/ha/year for common alder to 12.2 dry tonnes/ha/year for western hemlock. For species where published yield class graphs exist, these values exceeded those predicted, except in the case of Sitka spruce.

Actual survival rates were often significantly less than 100%, ranging from as low as 20% to 100%, depending on species and site. As a result, the predicted yield of the trial plots (Table 2 below) ranged from less than 0.5 dry tonnes/ha/year to 7.3 dry tonnes/ha/year.

Table 1 Growth in height (cm) and diameter (cm rounded up) to 1989/90

Species	Site 1		Site 2		Site 3		Site 4		Site 6		Site 8		Site 9		Site 10		Site 11	
	h	d	h	d	h	d	h	d	h	d	h	d	h	d	h	d	h	d
Scots pine	320	7	333	8	367	7	280	7	263	6	137	2	273	7	338	7	287	6
Corsican pine	210	8	-	-	-	-	-	5	215	-	-	-	-	6	242	-	-	-
Douglas fir	413	9	438	8	404	7	130	3	-	-	-	-	376	8	530	8	359	7
Western hemlock	269	5	377	7	426	8	-	-	-	-	-	-	409	6	532	8	364	5
Sitka spruce	431	9	410	8	398	7	349	7	153	3	274	5	241	5	440	8	306	6
Hybrid larch	463	9	495	8	455	7	426	8	-	-	367	6	382	6	572	8	538	8
S Beech (Nothofagus)	310	7	-	-	372	6	-	-	-	-	414	7	428	8	714	10	519	7
Sycamore	549	10	337	6	237	4	273	6	364	6	522	8	-	-	494	7	-	-
Silver birch	318	7	-	-	330	6	517	8	-	-	463	7	458	7	616	8	-	-
Common alder	507	9	526	9	372	5	739	11	-	-	781	10	231	4	493	7	-	-
Common ash	-	-	-	-	-	-	-	-	-	-	336	5	-	-	-	-	-	-
Silver fir	-	-	-	-	-	-	-	-	-	-	307	6	-	-	-	-	-	-
Lodgepole pine	-	-	-	-	-	-	104	2	-	-	-	-	110	3	81	2	119	3
W poplar	-	-	-	-	-	-	230	4	-	-	-	-	-	-	-	-	-	-
Red alder	-	-	-	-	-	-	215	3	-	-	-	-	-	-	-	-	-	-

Table 2 Predicted yield (dry tonnes/ha/year) at survival rate achieved

Species	Site							
	1	2	3	4	8	9	10	11
Scots pine	5.1	3.4	3.4	1.5	-	3.1	3.2	3.5
Corsican pine	1.6	-	-	1.0	-	0.9	-	-
Douglas fir	4.3	5.7	3.7	0.8	-	2.2	6.1	2.3
Western hemlock	1.2	3.8	1.5	-	-	2.6	4.2	1.4
Sitka spruce	7.3	6.8	3.8	4.5	2.4	3.4	4.6	2.6
Hybrid larch	4.7	4.8	3.6	3.1	1.3	2.9	4.2	2.2
S Beech (<i>Nothofagus</i>)	1.4	-	0.5	-	1.6	1.5	4.8	2.9
Sycamore	4.5	1.3	0.7	1.5	4.0	-	2.2	-
Silver birch	0.7	-	1.9	2.8	1.8	3.5	4.7	-
Common alder	3.5	2.9	0.8	6.5	4.3	0.4	1.7	-
Common ash	na	na	na	na	3.5	na	na	na
Silver fir	na	na	na	na	2.4	na	na	na

Apart from Corsican pine, the conifers have performed better overall than the broadleaved trees. However, biomass assessments were completed before many of the trees had reached their maximum increment, and higher productivity levels may be likely in the longer term, particularly with more intensive management in the earlier years and the associated higher survival rate.

The variations that occur reflect, in some instances, the natural variations in site, region and initial land use. Common alder, for instance, showed exceptional growth on the two wet sites of Marlefield (Site 4) and Longridge (Site 8), while the growth of Sitka spruce varied significantly with both site and region, doing particularly well in North-east Scotland and the Scottish Borders.

Single-tree models

To allow the use of easily measured tree parameters to estimate whole tree biomass quantities without recourse to destructive sampling, single-tree models were developed using the regression equation:

$$Y = a + bX$$

where Y = total dry tree biomass;

X = $dbh^2 \times$ height

Models were developed for each of the main species and were summarised as follows:

Conifers: $Y = 2.235 + 0.032X$

Pines: $Y = 1.501 + 0.057X$
Broadleaves: $Y = 1.123 + 0.022X$

Economic analysis

An economic analysis of producing biomass from single stem plantations was also carried out. This was based on the following assumptions:

- a farmer-operated system, costed on the materials used, and employing contractors for the specialist operations of harvesting, chipping and transport
- a 20-year rotation
- productivities of 6-12 dry tonnes/ha/year for conifers and 6-10 dry tonnes/ha/year for broadleaves (ie 100% survival rates)
- costs discounted at the Government test discount rate of 5%
- the take-up of Farm Woodland Premium Scheme grants.

Discounted costs were found to range from £0.95/GJ to £2.40/GJ, depending on productivity level and plantation size.

2. COPPICE TRIALS

Report No: ETSU B 1078

Publication date: 1990

COPPICED TREES AS ENERGY CROPS

Forestry Commission Research Division

Project Objectives

The aim of the project was to investigate the potential for biomass production from a range of broadleaved tree species grown on short rotation, close-spaced coppice systems on a range of typical sites.

Specific objectives can be defined as follows:

- To investigate the growth and yield of selected broadleaved species in relation to crop spacing and length of rotation.
- To collect information on site suitability.
- To produce yield models for assessing the economic viability of biomass production.

Methodology

Six experimental sites were established in the southern part of the UK during 1981/82 and a seventh at Aberfoyle in Central Scotland in 1986. They were chosen to represent the range of site types likely to be available for biomass production. There were two main site categories: agricultural land and felled woodland. Within each category, sites were selected to represent different grades of land and a range of climatic conditions as shown in the following table.

Characteristics of the seven experimental sites selected

Site name	Former land use	Grade of land	Rainfall	Temperature
Alice Holt, Surrey	Agricultural	Low	Moderate	High
Long Ashton, Avon	Agricultural	High	High	Moderate
Mepal, Cambridgeshire	Agricultural	High	Low	Low
Sheffield Park, East Sussex	Woodland	Low	Low	Low
Witney 1, Oxfordshire	Woodland	Low	Low	High
Witney 2, Oxfordshire	Agricultural	Low	Moderate	Moderate
Aberfoyle, near Glasgow	Agricultural	Low	High	Low

The trees for each site were selected from six species chosen for their fast growth rates, their coppicing ability or on the basis of evidence from other biomass programmes. The six species were:

- *Populus trichocarpa x deltoides* RAP (clonal)
- *Salix burjatica* Korso (clonal), formerly known as *S. aquatica* Gigantea
- *Eucalyptus archeri*
- *Alnus cordata*
- *Nothofagus procera*
- *Nothofagus obliqua*

Three other species were introduced as replacements for failed plots:

- *Salix viminalis* Bowles Hybrid (clonal)
- *Alnus glutinosa*
- *Alnus rubra*

Three or four species were grown on each site using 1 x 1 and 2 x 2 metre spacings, and two- and four-year rotations. Planting was to a randomised block design with three replicates. In each square of 64 trees, the outside rows acted as a buffer, leaving 36 trees to be assessed. Two sites also established circular “Nelder” design plots with variable spacings, but using the same species as the main plots.

Biomass yields were determined using a two-stage sampling process:

- a random sample of 12 stools per plot, with every stem measured for basal diameter
- a smaller sample of individual stems across the entire stem diameter range.

The second sample was used to determine the total dry weight of the stem. A regression analysis of stem dry weight against basal diameter was carried out for each spacing and rotation for each species on each site. The regression coefficient was then used to convert the larger sample of stem basal diameters to stem dry weights. Dry weights per hectare were calculated.

Dry chips from each spacing and rotation were analysed for nitrogen, phosphorus, potassium, magnesium and calcium content.

Findings

Establishment

Prolific weed growth and invading natural coppice made the two ex-woodland sites difficult and expensive to manage. Both were closed without yield assessment.

Establishment on the agricultural sites was more successful, although some plots failed and were replanted with other species. Both *Nothofagus* species failed because of damage caused

by winter cold. *Eucalyptus archeri* grew well initially but was subsequently severely damaged by cold and silver leaf disease. *Alnus cordata* experienced patchy survival and growth and was replaced. *Alnus glutinosa* also experienced poor growth.

Weed control was the greatest problem. Winter applications of a residual herbicide achieved adequate control during the early part of the growing season, but herbicides had to be re-applied to many plots using knapsack sprayers later in the year.

All successfully established plots were cut back to about 10cm above the ground at the end of the first growing season to initiate coppicing. Some species proved unsuitable for coppicing, notably *Alnus rubra* and *Salix burjatica* Korso, the latter's poor form hindering harvesting.

The most successful species were *Salix viminalis* Bowles Hybrid and *Populus* RAP, which grew and coppiced well.

Yields

Overall yields ranged from 2.0 to 19.4 dry tonnes/ha/year, with considerable variation between sampling years, sites, species and planting/rotation patterns. Yields in 1987/88 were generally higher than in 1985/86 because the stools were better established. Variations between sites, however, were difficult to determine because establishment patterns and attacks by pests and diseases varied widely from site to site.

The highest recorded yield was for *Salix burjatica* Korso - but only on one site where disease had not yet affected the crop.

Consistently high yields were recorded for *Populus* RAP, with an overall mean for both assessments of 10.7 dry tonnes/ha/year. Although no significant difference in yield was observed with site or rotation, yields were significantly higher when plantings were more closely spaced.

Nutrient removal

Regression analysis of stem nutrient content against stem diameter for different spacings and rotations showed no clear trends. Typical site nutrient capitals are 5-10 times greater than the maximum removal rates identified, indicating that even the most vigorous crops are unlikely to suffer from nutrient limitations in the short term.

Conclusions

- Yields of more than 10 dry tonnes/ha/year can be achieved on UK lowland sites using poplar or willow clones at 1 x 1 metre spacings. Maximum yields are substantially higher than those from either conventional forestry or traditional coppice crops.
- Improved stock could improve yields, and care is needed in the choice of species/clones, particularly in relation to disease resistance.

- Shorter rotations (two-year rather than four-year) give rise to a more rapid increase in the number of shoots per stool and more vigorous growth early in the life of the stool.
- Short rotation coppice requires a management intensity that is closer to agricultural rather than to forestry regimes. Good establishment practices, particularly rigorous weed control, are essential. Spacings of about 1 x 1 metre will give maximum biomass yields, but establishment costs need to be taken into account in any economic analysis.

COPPICED TREES AS ENERGY CROPS

Forestry Commission, Research Division

Project Objectives

This project is a continuation of the one reported in Report No: ETSU B 1078 and summarised above. Its main objectives can be summarised as follows:

- To develop further the models for dry matter production and nutrient removal for *Populus interamericana* RAP grown under close-spaced, short-rotation systems, and to validate the models over subsequent rotations.
- To investigate the coppicing ability and yield potential of three new poplar clones and to compare their performance with that of RAP under the same spacings and cutting cycles.
- To relate the results to other trials to predict yields on a wider range of site types and using different establishment techniques.

Methodology

The experimental plots used for the RAP assessments were those used in the earlier project. The third two-year cut at Alice Holt and Mepal, and the fourth two-year cut and second four-year cut at Long Ashton were carried out in February/March 1990. The fourth two-year cut and second four-year cut at Alice Holt and Mepal were carried out in January 1992 and included all four spacing/rotation options.

The sampling and assessment procedure was as described in Report No: ETSU B 1078. In addition, total plot green weights were obtained in 1990 by weighing material from each individual stool for comparison with results obtained from the diameter samples. Samples were also taken for nutrient assessment.

However, RAP is no longer an approved clone, and three new experiments were established using UNAL poplar clones *Populus interamericana* Beaupre and Boelare, and *Populus trichocarpa* Trichobel. The clones were planted as unrooted hardwood cuttings. All three clones were planted at Alice Holt and Long Ashton, and two, Beaupre and Trichobel, at Mepal. At Alice Holt and Mepal, the clones were planted on vacant plots that had been cleared of earlier plantings of species other than poplar. The Long Ashton planting took place on a completely new site.

Planting was completed in the spring of 1990.

Findings

RAP: assessment of yield and nutrient removal

Yields for the whole trial period are summarised in the table below and confirm an expected yield of 10-12 dry tonnes/ha/year. Yields from the third and fourth harvests proved to be slightly lower than those from the second harvest, and were probably the result of the dry growing seasons of 1988 and 1989.

Summary of yields (dry tonnes/ha/year) for *Populus* RAP

Spacing and rotation	Site	Year of assessment			
		1985/86	1987/88	1989/90	1991/92
Spacing: 1 x 1 metre Two-year rotation	Alice Holt	8.9	16.0	12.1	10.1
	Long Ashton	10.8	11.6	4.6	-
	Mepal	15.2	14.4	7.8	9.3
Spacing: 2 x 2 metres Two-year rotation	Alice Holt	2.0	8.8	9.6	9.7
	Long Ashton	9.4	9.3	4.2	-
	Mepal	9.3	10.7	5.4	4.4
Spacing: 1 x 1 metre Four-year rotation	Alice Holt	-	13.9	-	12.5
	Long Ashton	8.8	-	5.2	-
	Mepal	-	11.5	-	9.7
Spacing: 2 x 2 metres Four-year rotation	Alice Holt	-	9.2	-	10.2
	Long Ashton	6.0	-	6.0	-
	Mepal	-	9.3	-	8.0

Differences in the effects of spacing were generally not significant, except at Alice Holt where the 2 x 2 metre spacing continued to give significantly lower yields than the 1 x 1 metre spacing. However, more widely spaced stools tend to occupy more ground and produce more shoots as they mature than closely spaced stools. As a result, initial differences in yield are reduced in subsequent harvests. This trend was confirmed by two successive harvests of the “Nelder” trial at Alice Holt. This identified an optimum initial spacing of 1.2 x 1.2 metres for RAP.

The increase in stump size with initial spacing might present difficulties for mechanical harvesting equipment.

There were no significant differences in yield as a result of rotation. Therefore, within the limits tested (2-4 years), the choice can be based on harvesting and other costs rather than on yield considerations.

Maximum nutrient removal rates were as follows:

- Nitrogen: 100 kg/ha/year
- Phosphorus: 11 kg/ha/year
- Potassium: 40 kg/ha/year.

Average values for the 1 x 1 metre spacing and a two-year rotation were 70kg of nitrogen, 10kg of phosphorus and 35kg of potassium. Rates of nutrient removal of this order are unlikely to limit growth on these fertile sites, at least for the first few cutting cycles.

New clone assessment

Establishment of the small unrooted new clone cuttings at Alice Holt and Mepal required a rather heavy herbicide regime, and this may be an indication of the requirements of commercial plantations. At Long Ashton, the narrower spacing used, together with the rapid growth rate achieved on this particularly favourable site, reduced the weeding programme.

Of the new clones, Beaupre showed the best survival rate at the end of the first season.

Surviving plants were cut back at the end of the first year (early 1991) and, at the same time, all plots were beaten up to full stocking using one-year-old rooted cuttings. After cut-back, the UNAL clones, which were originally bred for the production of quality veneers, showed a tendency to produce one dominant shoot and a number of much smaller shoots. While this is a good trait for the production of quality timber, it is less likely to be ideal for maximising biomass production in short rotation coppice.

ESTABLISHMENT AND MONITORING OF LARGE-SCALE TRIALS OF SHORT ROTATION FORESTRY FOR ENERGY

Forestry Department, Aberdeen University

Project Objective

- To establish and monitor large-scale plantings of coppice willow and poplar to obtain information on costs, logistics, productivity and biology in order to evaluate their potential for producing wood for fuel.

Methodology

Various production trials were initiated between 1986 and the end of 1988, as shown in Table 1 below. A 0.89ha species screening trial was also carried out at Long Ashton.

Findings

Establishment and management

Establishment has largely followed standard agricultural practice for a spring-sown crop - complete cultivation and clonal selection of planting material.

The trials have shown that autumn ground preparation is optimal both to control weeds and to provide plenty of time for planting in the spring. The Long Ashton and Kincardine *Salix* trials were both established with spring cultivation and the former, in particular, experienced major weed control problems.

Fencing to protect the crop against various mammals was required on all except the Long Ashton site. Costs have varied both with site dimensions and with the type of fence required (the deer fencing used on the Scottish sites is more costly than the rabbit fencing used elsewhere).

Weed-free conditions are essential until the canopy is sufficiently developed to shade out competing weeds and provide a leaf mulch that will help to prevent the germination of weed seeds. The standard approach has been to apply:

- glyphosate to the grass sward in the autumn, before cultivation and spring planting
- a residual herbicide such as simazine to prevent the germination of annual weeds
- a herbicide such as aminotriazone as an overall application following cut-back at the end of the planting year, followed by simazine.

Table 1 Production trial summary

Site	Area	Production trial species
Long Ashton near Bristol	1.86ha	<i>Salix burjatica</i> Korso <i>Salix viminalis</i> Bowles Hybrid
Castlearchdale, N Ireland (Three phases)	9.70ha	<i>Salix viminalis</i> Bowles Hybrid <i>Salix burjatica</i> Germany <i>Salix x dasyclados</i> <i>Salix triandra x viminalis</i> Q83 <i>Salix viminalis</i> 683 <i>Salix x calodendron</i>
Kincardine, Inverness	0.23ha	<i>Salix x stipularis</i> <i>Salix spaethii</i> <i>Salix viminalis</i> Mullatin <i>Salix viminalis x caprea x aurita</i> Reifenweide <i>Salix viminalis</i> Bowles Hybrid <i>Salix x calodendron</i>
Guisachan, Inverness	0.72ha	<i>Salix viminalis</i> Campbell <i>Salix minimalis x caprea x aurita</i> Reifenweide <i>Salix viminalis</i> Gigantea <i>Salix viminalis x caprea x cinerea = x dasyclados</i> <i>Salix viminalis x caprea x cinerea = x calodendron</i> <i>Salix viminalis</i> Bowles Hybrid <i>Salix viminalis</i> Mullatin <i>Salix caprea x (aurita x viminalis) = x stipularis</i> <i>Salix spaethii</i>
Swanbourne, Buckinghamshire	1.82ha	<i>Populus trichocarpa x deltoides</i> RAP <i>Populus trichocarpa</i> Fritzi-Pauley <i>Populus deltoides x nigra</i> Dorschkamp <i>Populus trichocarpa x deltoides</i> Beaupre <i>Populus trichocarpa x deltoides</i> Boelare <i>Populus (trichocarpa x deltoides) x deltoides</i> 75028/3
Department of Agriculture Northern Ireland	2ha	<i>Salix burjatica</i> Korso

In some instances, simazine has proved ineffective, and experience to date emphasises the need for a greater array of appropriate chemicals.

Virtually all the planting material was unrooted cuttings of various clones. Planting was done by hand.

Willow spacings of 1 x 1 metre have been used at all but one site. The Castlearchdale trial used a 0.5 metre spacing within the rows, while maintaining a 1 metre spacing between rows to meet harvester constraints. This increased the speed of canopy closure, thereby reducing weed problems. However, the higher planting, cut-back and beating up costs outweighed any reduction in weeding costs.

Poplars were planted at 1 x 1.5 metre spacings, necessitating more weed control during the establishment stage.

Clonal susceptibility to rust was investigated, but no clear conclusions could be drawn. The indications are that certain clones such as *Salix burjatica* are almost universally affected, while others such as *S. viminalis* have tended to remain free of the disease. However, even this pattern is not consistent as there are stands of *S. burjatica* Korso that are largely disease free and stands of *S. viminalis* that are now seriously affected.

Aphids have been the only major insect infestation, seriously affecting *S. burjatica* Germany in Castlearchdale Phase II. Gall midge proved a problem at Kincardine, causing terminal tip death. The side shoots that develop subsequently are attacked by another midge generation.

Costings and economics

All trials have been managed by contractors, the aim being to secure maximum yield at least perceived cost. Actual and projected costs up to, but excluding, the first harvest are summarised in Table 2.

Table 2 Summary of actual and projected costs (£/ha at 1987 prices)

	LARS	SWAN	CAS 1	CAS 2	DANI	GUIS	Mean
Site preparation	183	203	49	90	92	557	196
Fencing	-	1224	1045	634	330	2946	1030
Planting	1183	876	1666	1268	1710	1649	1392
Weed 0	593	218	150	186	20	444	268
Cut-back	258	126	306	(230)	230	(230)	230
Beat-up	-	40	-	(16)	25	(16)	16
Weed 1	659	373	151	(331)	140	(331)	331
Fertiliser	73	(55)	70	(55)	22	(55)	55
Lime application	-	-	26	(10)	25	-	10
Weed 2	-	(25)	(25)	(25)	50	(25)	25
Weed 3	(50)	(50)	(50)	(50)	50	(50)	50
Fungicide application	87	(39)	31	(39)	-	(39)	40
Other	(274)	169	604	(274)	-	321	274
Total	3360	3398	4173	3208	2694	6663	3917

Key: LARS = Long Ashton Research Station; SWAN = Swanbourne; CAS = Castlearchdale; DANI = Department of Agriculture Northern Ireland; GUIS = Guisachan

Figures in brackets are projected costs based on the means of other trials where the particular operation has been carried out.

ESTABLISHMENT AND MONITORING OF LARGE-SCALE TRIALS OF SHORT ROTATION COPPICE FOR ENERGY

Wood Supply Research Group, Department of Forestry, University of Aberdeen

Background

One way of producing biomass for energy is short rotation forestry, and coppicing is a simple but efficient management technique for maximising productivity on 3-5 year cycles. The system involves techniques that are more closely related to agriculture than to forestry.

Project Objective

- To obtain information on the costs, logistics, productivity and overall biology of short rotation coppice crops in order to evaluate their potential for producing wood for fuel.

The first phase of this project was reported in Report No: ETSU B 1171 (summarised above).

Methodology

The sites used for the 1986-1988 trials were retained, and five additional sites were planted, as shown in the table below.

The trials, including screening trials, examined more than 100 clones, mainly of willow and poplar, but also of red alder and two varieties of *Eucalyptus*. The clones were evaluated for survival, productivity, growth characteristics, susceptibility to pests and diseases, and coppicing ability, on sites with a range of soil and climatic conditions.

Five of the trials were established on former arable sites using conventional agricultural machinery and procedures wherever possible.

Crops have been managed on coppice cycles of 1-5 years. Some trials have investigated growth with and without fertilisers. Studies have also been made of the incidence and severity of pests and diseases, particularly *Melampsora* leaf rust.

Harvesting trials have been carried out at Long Ashton, Swanbourne, Castlearchdale, Kincardine and Guisachan to evaluate the Loughry coppice harvester and motor-manual harvesting methods. Wood chip samples have been taken to quantify nutrient removals at each harvest and the calorific value of the fuel.

Details of additional trial sites

Site	Area	Production trial species
Water Eaton, Wiltshire	2.40ha	<i>Populus trichocarpa x deltoides</i> Beaupre <i>Populus trichocarpa x deltoides</i> Boelare <i>Populus deltoides x nigra</i> Dorschkamp <i>Populus trichocarpa x trichocarpa</i> Trichobel <i>Populus trichocarpa</i> Fritzi-Pauley <i>Populus trichocarpa x deltoides</i> Donk
Brahan, Ross and Cromarty	0.95ha	<i>Salix candida</i> <i>Salix viminalis</i> Bowles Hybrid <i>Salix caprea x (aurita x viminalis) = x stipularis</i> <i>Salix viminalis</i> Mullatin <i>Salix viminalis x caprea x cinerea = x dasyclados</i>
Markington, North Yorkshire	0.90ha	<i>Populus trichocarpa x trichocarpa</i> Trichobel <i>Populus (trichocarpa x deltoides) x deltoides x deltoides</i> 76.028/5 <i>Populus (trichocarpa x deltoides) x deltoides</i> 75.028/3 <i>Populus trichocarpa x deltoides</i> 69.039/4 <i>Populus deltoides x trichocarpa</i> 71.009/1 <i>Populus deltoides x trichocarpa</i> 71.015/1 <i>Populus deltoides x nigra</i> Dorschkamp <i>Populus trichocarpa</i> Fritzi-Pauley <i>Populus trichocarpa x deltoides</i> Beaupre <i>Populus trichocarpa x deltoides</i> Boelare
Parbold, Lancashire	0.91ha	<i>Salix viminalis</i> Mullatin <i>Salix burjatica</i> Germany <i>Salix viminalis x caprea x cinerea = x dasyclados</i> <i>Salix viminalis</i> Bowles Hybrid <i>Salix caprea x (aurita x viminalis) = x stipularis</i>
Buckfast, Devon	0.91ha	<i>Salix viminalis</i> Mullatin <i>Salix burjatica</i> Germany <i>Salix viminalis x caprea x cinerea = x dasyclados</i> <i>Salix viminalis</i> Bowles Hybrid <i>Salix caprea x (aurita x viminalis) = x stipularis</i>

Findings

Establishment and management

- Complete ground cultivation is important, with deep ploughing/ripping to improve soil permeability. Autumn ploughing helps to break down the soil. Discing improves soil water retention.
- Protection against mammals is necessary, particularly during the establishment stage.
- Weed control is essential during establishment to reduce competition for water and nutrients. The use of herbicides is recommended.

- Plantings should use unrooted hardwood cuttings from dormant one- or two-year-old shoots. Cuttings should be 1-2cm in diameter and 25cm long. Planting can be carried out manually, but machines will increase speed and accuracy. Optimum planting density lies between 5000 and 20,000 cuttings/ha. Spacing will vary with cutting cycle and harvesting machine availability. Cutting cycle will vary with market requirements.
- Shoots should be cut back at the end of the first growing season to initiate the coppice cycle. Contact or residual herbicides can be applied at this stage.
- Nitrogen (3-4 kg/oven-dry tonne of biomass removed) can be applied after harvesting when the shoots have regrown to 30-50cm. There appears to be considerable potential for using farm slurries and sewage sludge.
- Coppice plantings have a high water demand, so a good water supply is necessary.
- Leaf rust (*Melampsora* sp) has severely damaged some willows. Poplars and improved willow clones have shown greater disease resistance. Mixed clonal plantings may reduce the impact of disease, and natural control agents have been identified.
- The insects found on the crop, notably brassy beetles (*Phyllodecta* sp) have not caused significant loss in plantation productivity, although a *Rhabdophaga* midge removed the terminal buds of some varieties of willow. The effect of this has not been quantified.
- Productivity at first harvest reached 10 oven-dry tonnes/ha/year for some clones. Productivity should then increase to a maximum 5-6 years after planting and remain at that level for 20-30 years, depending on management.
- Fence type and cuttings costs are the major cost considerations during establishment. The former can be minimised by planting within existing farm boundaries and fence lines. The cost of cuttings should fall as markets become established and availability increases.

Harvesting

The Loughry coppice harvester has proved significantly more cost-effective than motor-manual harvesting methods using a brush-cutter or chainsaw. However, there have been some problems with traction on wet slopes, with cutting shoots 7m tall, and with clones with a large basal diameter, eg three-year-old poplar.

Leaving the harvested shoots at the edge of the field over the summer reduces moisture contents to 25-30% but makes subsequent chipping more difficult. It would be advantageous to combine harvesting and chipping, provided there is a market for chips with a 60% moisture content, or the chips can be effectively dried before storage.

Harvesting, chipping and transportation can represent more than 70% of the delivered wood fuel cost, and further work is necessary in these areas. The value of on-site or near-site utilisation would be very significant.

ESTABLISHMENT AND MONITORING OF LARGE-SCALE TRIALS OF SHORT ROTATION COPPICE FOR ENERGY: PHASE III

Wood Supply Research Group, Department of Forestry, University of Aberdeen

Project Objective

- To obtain information on the cost, logistics, productivity and overall biology of short rotation coppice crops to evaluate their potential for producing wood for fuel.

The first and second phases of this project were reported in Report No: ETSU B 1171 and Report No: ETSU B 1255. This report summarises the overall project findings.

Methodology

Seven *Salix* and three *Populus* coppice trials were initiated on sites representing a wide range of latitudes, climatic conditions and soil types in the UK. The trials were planted between 1986 and 1991 with a range of species and clones thought to have potential for biomass production in the UK. The production plots were on a larger scale than had previously been used for research, the aim being to provide technical and economic data that would better reflect commercial production. Various screening trials were also carried out.

Each trial has been managed individually in accordance with the state of knowledge at the time the operations were carried out. The data recorded cover management, growth, nutrition and health. The production plots were also used to test harvesting machines.

In addition to the *Salix* and *Populus* trials, a separate screening trial was carried out at Long Ashton. This examined the potential in terms of productivity, frost tolerance and coppicing ability of *Alnus rubra* Bong, two varieties of *Eucalyptus gunii*, two species of *Nothofagus* and various *Populus* clones.

Findings

The importance of site characteristics

The work has emphasised the need for careful site selection and complete ground preparation. Good access is needed, particularly in winter and sites should have minimal slope to facilitate mechanisation. Water and drainage characteristics are also important considerations: there must be sufficient water for coppice growth, but excess water can inhibit site preparation and the various mechanised operations, particularly harvesting.

The project has also shown how site characteristics can limit SRC production. The trials at Guisachan and Kincardine, both planted on marginal land, have, despite intensive

management, failed to become well established. If land of this type is to be used in future, further work will be required on appropriate site amelioration techniques.

Establishment

Establishment factors, eg poor plant material or soil conditions, have a considerable long-term influence. Sites such as Brahan, with a good soil tilth, healthy plant material and good weed control, have required little management, and the clones are in good health. However, plants that have not had good initial establishment because of poor quality cuttings or weed competition, have rarely recovered to produce vigorous growth, compounding post-establishment problems. A clone that does not grow quickly will not close the canopy and shade out the weeds. This increases weed competition and the cycle is repeated.

Of the Long Ashton screening trial plantings, *Nothofagus* did not establish well and several plots were replaced with poplar clones. The *Eucalyptus* and *Alnus rubra* plantations grew well initially but survival diminished substantially after cut-back.

A range of planting densities and cutting cycles has been used in the trials. The management regime chosen in each case depends on the feedstock requirement of the wood fuel conversion process, the limitations of planting and harvesting technologies, and the cost of planting material.

The poplar trial at Swanbourne was planted in monoclonal rows to allow replication across the site together with the testing of a number of new clones. The result has been intense interclonal competition, with the better clones outgrowing the weaker ones to give the impression that large differences in potential productivities exist. At Long Ashton, the same clones were planted in larger monoclonal blocks and the differences in productivity were much less marked. The conclusion drawn is that, although monoclonal row planting may help to minimise the impact of pests and disease, it may not be the best approach for poplar in terms of maximising yield and maintaining crop health and vigour. A possible compromise might involve planting broader bands of individual clones.

It is generally accepted that UK *Salix* crops should be planted at approximately 10,000 stools/ha (1 x 1 metre spacing) and be cut on a 3-4 year cycle. Although a twin-row planting pattern has been recommended to accommodate machinery for weeding, fertilisation and harvesting, none of the trials in this project has adopted this planting pattern.

Weed control

Weed control has been identified as one of the most critical management considerations to ensure crop health and vigour. A range of different chemical and application methods has been used during the project with varying degrees of success. Tractor-mounted boom sprayers proved the most cost-effective for application, but could only be used either before planting or after harvesting when the crop is low enough to permit access. Mechanical weeding using clearing saws proved a very costly and time-consuming method of remedial action.

There is no standard prescription for weed control: every site and crop situation needs to be assessed according to soil type, the species and quantity of weeds present, the stage of crop development, local weather conditions, availability of machinery etc. The main conclusion that can be drawn is that weed control operations that are inappropriate, inadequate or badly timed can result in recurring weed problems that require expensive remedial treatments and jeopardise the economic viability of the plantation.

Nutrition

Investigations at Swanbourne and Long Ashton have provided no conclusive evidence as to the effectiveness of adding fertiliser. However, these trials were on good quality arable land, and nutrient deficiencies may not become apparent until several harvests have been taken.

Pests and diseases

The two most promising genera in terms of yield and coppicing ability are *Salix* and *Populus*. However, *Salix* has proved to be more susceptible to pests and diseases, and in particular to the leaf rust *Melampsora* spp, which infected all but one (*S. candida*) of the willow production clones. The chemical control of rust is both impractical and environmentally undesirable. Biological controls have been investigated, but none has yet been shown to be capable of adequately controlling large rust populations.

The fact that a particular clone is susceptible to rust does not necessarily preclude its use for biomass production. Clones such as Gigantea, Campbell and Bowles Hybrid are all regularly infected by rust but do not usually suffer heavy defoliation or a reduction in yield.

Although poplars have also been shown to be susceptible to *Melampsora* spp, the disease is not thought to be a significant threat to biomass production in the UK at present.

The later stages of the project saw an infestation of the Brassy Willow beetle (*Phyllodecta* spp) that almost totally defoliated 1ha of Bowles Hybrid planted at Long Ashton and caused rampant weed growth and a high crop mortality. Chemical control of the beetles was considered both impractical and environmentally unfriendly.

Harvesting

Testing showed that the most recent Loughry coppice harvester prototype offered some potential, leaving clean-cut stumps and causing minimal damage. Further modification is still required to eliminate shoot feed and bundle ejection problems.

Several cut-and-bundle and cut-and-chip machines were also investigated, indicating that considerable development has taken place in this area over the last three years, improving the crop's potential for industrial-scale viability.

The growth form of different clones was shown to have a marked effect on harvesting efficiency. Clones with high productivities and straight, upright shoots are easiest to cut and

enable high machine productivities to be achieved. Clones that bend significantly at the base of the stool can cause harvesting problems.

Clonal productivity

Mean output from the main production clones ranged from 1.80 to 6.95 oven dried tonnes (odt)/ha/year for *Salix*, and from 2.01 to 9.76 odt/ha/year for *Populus*. These yields are lower than would be expected from commercial plantations. However, the stools are still at an early stage of development, and higher yields are expected in future rotations.

The development of non-destructive sampling techniques

The most common method of estimating coppice yield is by destructively sampling a portion of the crop: this is time-consuming and can only be carried out immediately before harvest if it is not to affect the integrity of the growing crop. There is clearly a need for a non-destructive method of yield estimation using parameters that can easily be measured while the stools are still standing.

Work in this area has shown that, for any given willow or poplar crop, there is a strong correlation between stem diameter, height and weight. Unfortunately, the correlation only applies to the crop from which it was generated. It cannot be applied to other crops or even to later rotations of the same crop.

One relatively simple way of estimating the yield of large monoclonal coppice blocks is to use a combination of destructive and non-destructive sampling. A correlation can be established between stem diameter at 10cm, stem height and fresh weight using a small (10-12 stools), selective, destructive sample. This provides a model specific to the crop being assessed. This model can then be used to calculate the weights of a much larger random sample of stools (40-50) from easily measured, non-destructive parameters. Total crop yield can be extrapolated from mean fresh stool weight, dry matter content, initial planting density and stool survival rate. This approach can benefit from the use of modern computer techniques.

THE CONTINUING STUDY OF POPLAR AS AN ENERGY CROP

Silviculture (S) Branch, Forestry Commission Research Division

Project Objectives

- To investigate the coppicing ability and yield potential of three new UNAL poplar clones, *Populus trichocarpa* Trichobel and two *Populus interamericana* clones, Beaupre and Boelare, on three sites: Alice Holt in Surrey, Mepal in Cambridgeshire and Long Ashton in Avon.
- To investigate yields from *Populus interamericana* RAP planted at Alice Holt and Mepal in 1982.

Methodology

The new clones were planted at two different spacings:

- 1 x 1 metre (10,000 stools/ha)
- 2 x 2 metres (2,500 stools/ha).

Plantings used a randomised block design with three replicates, and crops were harvested either every two years or every four years after initial cut-back.

The clones were also included in a “Nelder” spacing trial using a four-year rotation.

In 1990, all sites were cleared of vegetation using glyphosate. Cuttings 25cm long were planted in April and early May. Gaps were beaten up using one-year-old, two-metre rooted cuttings in early January 1991, and all plants were cut back.

Plots were kept weed-free with repeated herbicide applications.

Findings

Establishment

The low initial survival rates shown in Table 1 below probably occurred because planting was followed by a drought.

Table 1 Survival rate by site and clone

	Alice Holt	Long Ashton	Mepal
Trichocarpa	66%	47%	66%
Beaupre	59%	85%	55%
Boelare	53%	77%	- ¹

¹ not planted

Some stools blew over at the Alice Holt site and had to be staked in September 1992. This was due to root restriction along the old plough ridges on this site.

Regrowth from the cut-back stools was excellent.

Yields

Yields for the three new clones, in dry tonnes/ha/year, are summarised in Table 2.

Table 2 Yields by site and clone for two years (dry tonnes/ha/year)

	Spacing m	Rotation Years	Beaupre		Trichobel		Boelare	
			1992/93	1994/95	1992/93	1994/95	1992/93	1994/95
Long Ashton	1 x 1	2	8.2	8.5	7.4	6.1	9.6	7.9
	1 x 1	4		12.8		9.2		13.6
	2 x 2	2	6.6	7.5	4.0	6.1	5.0	6.7
	2 x 2	4		9.7		6.2		8.1
Mepal	1 x 1	2	2.8	7.6	5.4	4.4		
	1 x 1	4		7.1		5.7		
	2 x 2	2	1.6	4.4	2.1	3.6		
	2 x 2	4		4.7		4.3		
Alice Holt	1 x 1	2	1.7	7.2	3.9	8.1	2.4	7.3
	1 x 1	4		8.1		7.5		6.4
	2 x 2	2	1.0	4.1	1.2	4.1	1.1	3.9
	2 x 2	4		4.3		4.8		4.8

The following conclusions can be drawn:

- Yields varied between 1.0 and 9.6 dry tonnes/ha/year in 1992/93 and between 3.6 and 13.6 dry tonnes/ha/year in 1994/95.

- At Long Ashton and Mepal, the yields of *Populus interamericana* Beaupre and Boelare were usually higher than those from *Populus trichocarpa* Trichobel. This was not the case at Alice Holt.
- Significant differences were found in the yields from different spacings and different rotations. A spacing of 1 x 1 metre gave a higher yield than the 2 x 2 metre spacings in most instances. Furthermore, the difference was significant in four out of seven cases overall and was always significant for Beaupre. This suggests that the optimum spacing of 1.2 x 1.2 metres for *Populus interamericana* RAP is equally appropriate for Beaupre and Boelare.
- Trichobel, on the other hand appears to respond differently to space, and the increase in yield from Beaupre and Boelare over Trichobel is less marked at the 2 x 2 metre spacing. Results from the Nelder harvest suggest that a wider spacing may be more appropriate for Trichobel.
- The yield from a four-year rotation was between 70% and 22% greater than the yield from two two-year rotations. Furthermore, two two-year rotations will increase harvesting costs. The conclusion drawn is that, for poplars, maximum UK production is more likely to be achieved at rotations greater than those currently being employed.

The *Populus interamericana* RAP clones planted in 1982 and harvested every two years gave yields in the range 8.4-10.5 dry tonnes/ha/year at the January 1994 harvest. Repeated attacks of the rust *Melampsora larici-populina*, particularly the severe attack of 1993, so weakened the stools that die-back occurred over that winter and the following early spring. The decline of these stools continued during 1994 and 1995 to such an extent that the proposed harvest for January 1996 for this clone was abandoned.

3. SHORT ROTATION COPPICE CULTIVATION ISSUES

3.1 Planting, Fertilisation and Root Development

Report No: ETSU B/M4/00487/26/REP

Publication date: 1995

FURTHER EVALUATION OF PLANTING MACHINES FOR SHORT-ROTATION COPPICE

Technical Development Branch, Forestry Commission

Project Objectives

- To evaluate the performance of SRC planting machines in a comparative trial.
- To assess each machine for quality of engineering and operator ergonomics.
- To assess and quantify the quality of planting for each machine studied.
- To monitor the regrowth of cuttings in the first cutting season.

The Machines

Planting machines are potentially the most effective means of planting short rotation coppice on agricultural land. This project evaluated four existing machines:

- Austoft
- Salix Maskiner step planter
- Super Prefer UT
- Catkin

A prototype Turton was also demonstrated.

The Austoft planter represents a new type of system and has been used on a limited scale in Sweden since 1993 to plant large numbers of cuttings in dense rows. It is a relatively simple machine that takes cuttings from a hopper and drops them horizontally, at random, into a furrow.

The other machines are designed for the conventional planting of individual cuttings. The Super Prefer and Catkin planters plant graded cuttings vertically into the soil. The Salix Maskiner and prototype Turton both create cuttings from rod material carried on the machine. The Salix Maskiner pushes the cuttings into the ground; the Turton “digs” them in.

Costs (excluding VAT) are summarised in Table 1 below.

Table 1 Planting machine costs

Type	Model	Cost
Austoft planter	Single-row	£9600
Super Prefer	Two-row	£2620
Catkin	Two-row	£3000 approx.
Salix Maskiner step planter	Four-row	£25,000 approx.
Turton prototype	Four-row	not available

Three standard agricultural tractors were used for the trial: a 4WD John Deere 3050, a 4WD Ford 7840 and a 2WD Ford.

The Evaluation

All five planters were evaluated in March or May 1995 on the same relatively level, heavy clay field that had been ploughed in December 1994 and power harrowed in May 1995.

The landowner's planting requirements were as follows:

- paired rows, 0.7m apart, with 1.25m between pairs
- cuttings 0.8m apart within the rows
- a minimum of ten rows per machine, each row with an average length of 180m.

Three planting patterns were used:

- pure clone
- row mixture
- intimate mixture.

Results

Outputs and costs are summarised in Table 2 below. Outputs varied from 0.25 ha/standard hour for the Super Prefer to 0.89 ha/standard hour for the Salix Maskiner. Costs also varied widely, with cuttings accounting for 90% of the costs in this trial.

Machines planting four rows at a pass had significantly higher outputs than those planting two rows. The Austoft had a relatively high output but the standard of planting could not be compared with that of other machines.

Table 2 Planter outputs and costs

	No of operators	Output (ha/standard hour)	Cost (£/ha)
Austoft planter	1	0.65	35.18
Salix Maskiner step planter (pure clone planting)	2	0.89	41.65
Salix Maskiner step planter (mixed clone planting)	2	0.48	77.23
Super Prefer	2	0.25	104.24
Catkin	2	0.32	81.91

Planter output can be increased and costs reduced by reducing the stocking rate and/or adding extra planting units. Reducing the stocking rate to the level currently recommended - paired rows with 0.75 and 1.5 metre spacings - would increase output by 12-19%. Adding two units to the Salix Maskiner would increase its output when planting single clones by 50% to 1.34 ha/standard hour. This would reduce costs by 12%.

Planting acceptability varied. Planting by the Salix Maskiner came closest to the target spacing required. Mean cutting spacing within the row was 0.81m against a target of 0.80m. Mean spacing between rows was 1.24m against a target of 1.25m. The stocking rate achieved was 0.6% below target. This compares with the Catkin with a stocking rate 19% below target.

Planting depth and the angle of cuttings in the soil was acceptable for the Salix Maskiner, the Turton and the Catkin. The Super Prefer lacked mouldboards to pull the furrow back, cover the cuttings adequately and firm them in. The Austoft uses a totally different planting system that has not been tested in the UK.

None of the planters provided any protection against extremes of weather or dust, and there was no electrical communication between operators and tractor drivers. Both should be provided. Operators were also required to get off the planters when the machines were turned and repositioned.

Conclusions

The four-row Salix Maskiner step planter gave the best results and offered the greatest potential for the efficient “conventional” planting of short rotation coppice material. The addition of extra planting units could further increase outputs and reduce costs. However, the machine has a high capital cost and is suitable mainly for large-scale planting or contract work. Machines with a lower output and more limited capital cost are more suited to use by individual landowners.

INITIAL SPACING OF POPLARS AND WILLOWS GROWN AS ARABLE COPPICE

Silviculture and Seeds Research Branch, Forestry Commission Research Agency

Background

Earlier Forestry Commission experiments¹ investigated the effect of initial spacing on yield over two- and four-year rotations. The findings suggested that a 1 x 1 metre spacing gives higher yields than a 2 x 2 metre spacing for both rotations, although the difference in yield is less pronounced with *Populus interamericana* Beaupre and Boelare than with *Populus trichocarpa* Trichobel.

An examination of yields from plots with a Nelder design indicated an optimum equivalent square spacing for *Populus interamericana* RAP of 1.2 metres with both first and second four-year rotations. The first four-year rotations for Beaupre and Boelare suggested optimum equivalent square spacings of 1.18 metres and 0.78 metres, respectively, although for the latter, there was little difference in yield at spacings of 1.17 metres. Similar findings were not observed for Trichobel, the optimum yield occurring at a 1.74 metre equivalent square spacing.

Project Objective

- To confirm the Nelder findings in plots with square spacings.

Methodology

Two sites were used for the trials: Wishanger in Hampshire and Downham Market in Norfolk. Willow and poplar clones were tested at six different spacings on each site, using a three-year rotation and a randomised block design with four replicates. The square spacings used were 0.8, 1.0, 1.15, 1.3, 1.4 and 1.5 metres.

The same two willow clones were grown on both sites: *Salix viminalis* Bowles Hybrid and *Salix caprea x cinerea x viminalis dasyclados*.

The poplar clones grown were:

- at Wishanger, *Populus interamericana* Beaupre and *Populus trichocarpa* Colombia River
- at Downham Market, *Populus interamericana* Boelare and *Populus trichocarpa* Trichobel.

¹ Reported in Section 2 of this volume: Report No: ETSU B/W2/00402/REP The continuing study of poplar as an energy crop.

At Wishanger the clones were planted in April 1992 and cut back in January 1993. The equivalent dates at Downham Market were 1993 and January 1994. Both sites were kept weed-free using contact and residual herbicides, and first-year survival was excellent (95-97% at Wishanger and > 99% at Downham Market).

The two crops were harvested, plot by plot, in March 1996 (Wishanger) and March 1997 (Downham Market) and weighed green. An earlier study of plot diameter distribution was the basis for a selection of 20 sample stems. These were chipped and thoroughly mixed. A sample of the mix was weighed green and then oven-dried and weighed again. The ratio of green weight to dry weight was used to calculate total plot dry weight. Dry tonnes/ha/year were calculated using the formula:

$$\text{Dry tonnes/ha/year} = \frac{\text{Plot dry weight (kg)} \times \text{No of stools/ha at plot spacing} \times 1 \times 1}{\text{No of stools/plot} \times \text{rotation} \times 1000}$$

Findings

The highest yield of 17.55 oven dry tonnes per hectare per year (odt/ha/year) was obtained from Bowles Hybrid grown at the closest spacing on water meadow at Wishanger. The yield for the slightly wider 1.0 metre spacing was only 12.68 odt/ha/year, a difference of 4.87 odt/ha/year. Assuming a 10ha field and a first harvest at the end of three years, the total first harvest penalty for using the wider spacing is 146 odt (4.87odt x 3 years x 10ha).

All clones achieved their maximum yield at the closest spacing in this first rotation. There was also a significant linear effect with yields declining as spacings increased. Furthermore, particularly for willow, the gradient of this linear relationship was steeper for the higher yielding clone. Two possible reasons can be suggested:

- Higher yielding clones are more tolerant of crowding.
- The upright *Salix viminalis* makes better use of close space than the more spreading *Salix dasyclados*.

This suggests that the new *Salix viminalis* x *Salix schwerinnii* hybrids should also be more responsive to closer spacing.

A similar but more limited linear effect was observed for poplars, but only at Wishanger. It remains possible that the optimum yield for poplars is still obtained at the currently recommended spacing of 1.0 x 1.0 metre.

Close initial spacings offer several advantages:

- rapid canopy closure
- optimum absorption of available radiation
- better use of available space

- rapid suppression of competing weed growth, with the associated cost and environmental benefits of reduced herbicide use.

These trials were planted in a square design, and the findings may not hold true for the rectangular spacings currently being favoured. Furthermore, in a twin-row design using alternate inter-row spacings of 1.5 and 0.75 metres, the intra-row distance would need to be reduced to 0.59 metres to increase the stocking to an equivalent 0.8 metre square spacing. This might increase competition without making maximum use of light and space in the wider inter-row spacing.

FERTILISATION OF SHORT ROTATION ENERGY COPPICE USING SEWAGE SLUDGE

WRc plc

Background

A 1994 study¹ of the carbon and energy budgets of short rotation coppice (SRC) production confirmed that the use of inorganic fertilisers to increase productivity is a very energy-expensive option because the production of such fertilisers requires large inputs of energy.

Organic wastes such as farm slurries and sewage sludge are already widely used in agriculture as sources of both nutrients and organic matter. They are normally available free of charge and, in the case of liquid sewage sludge, will usually be applied free of charge. It is possible that the use of such wastes in the production of fuel crops may increase crop yield without substantially increasing the energy input to the crop or the cost of its production.

Project Objectives

- To investigate the fertiliser requirement of short rotation energy coppice.
- To optimise crop yield by manipulating nutrient additions, plant stocking rates and harvesting frequency.
- To compare the use of sewage sludge and inorganic fertiliser as nutrient sources for a range of willow and poplar species commonly used in SRC.
- To investigate the impact of sewage sludge application on the incidence of fungal rust and weed growth.

Methodology

Three individual trials were set up in March 1992 on a level site adjacent to the River Thames. The soil was a well drained gravelly loam over gravel. It had a pH of 6.8 and a high level of water availability.

Trial A involved planting three varieties of poplar (*Populus trichocarpa x deltoides* Beaupre, *Populus trichocarpa x deltoides* Boelare and *Populus trichocarpa* Trichobel) and three varieties of willow (*Salix viminalis x triandra* Q83, *Salix viminalis* Bowles Hybrid and *Salix dasyclados*). The trials used three intra-row spacings (0.5, 1.0 and 1.5 metres), an inter-row spacing of 1.0m, two fertiliser treatments (sewage sludge and a 17:8:16 NPK inorganic fertiliser) and five fertiliser application rates (0, 50, 100, 150 and 200 m³/ha). The full

¹ Modelling of carbon and energy budgets of wood fuel coppice systems. Report No: ETSU B/W5/00337/REP

spectrum of inorganic fertiliser was applied to one *Populus* and one *Salix*: the other two varieties of each species received the median application equivalent to 100m³/ha.

The willows are being grown on a two-year rotation, with harvests in January 1995 and January 1997. The poplars are being grown on a four-year rotation, with a single harvest in January 1997.

Trial B was designed to screen seven *Populus* and eight *Salix* species/varieties for their productivity and their response to inorganic and organic nutrient sources. One variety, *Salix viminalis* var. *stipularis* is very prone to rust and was included to indicate whether sludge application has any influence on the incidence of rust. The trial involved control plots (no fertiliser) and plots receiving inorganic fertiliser (100m³/ha) or sewage sludge (100m³/ha) treatments. Stools were planted at 1 x 1 metre intervals. Willows are harvested annually and poplars biennially.

Trial C is investigating the interactions of sludge application and weed control with harvest frequency. Plots consisting of eight clones of *Salix viminalis* will receive one of four treatments: sewage sludge, herbicide, sludge and herbicide, and neither (control). The trees will be cut on four harvest cycles: one, two, three and four years after cut-back.

The application of glyphosate six weeks prior to planting was followed by ground cultivations, fencing against rabbits, and planting. Subsequent weed control consisted of an application of simazine + pendimethalin in March 1992, one week after planting, hand weeding in July 1992, and an application of a residual granular herbicide after cut-back (plus glyphosate on areas suffering from couch grass infestation). Some spot weeding was carried out in the summer of 1993. Following harvesting in Trials B and C in January 1994, glyphosate was applied as an overall spray. Trial B required some handweeding in June 1994.

In each trial, the pattern of sewage sludge application is after cut-back in early 1993 and again after harvesting.

Findings

Trial establishment and maintenance

The trials have been largely clear of pest damage since planting. However, the incidence of rust has had a significant effect on willow growth in Trials A and B, although *Salix viminalis* Bowles Hybrid suffered only a low level of infection in both 1993 and 1994. Although Trial B was affected by rust in both years, the degree of defoliation depending on the variety, the polyclonal plots of Trial C were largely unaffected.

Growth over the first year was generally good. In Trial A, the willows performed significantly better than the poplars. Of the poplar varieties, Beaupre and Boelare consistently outperformed Trichobel at all spacings. Yields increased substantially with stocking rates, although this differentiation in productivity is expected to decline as plantations mature.

In Trial B, the variation in productivity was greater among the willows than among the poplars. In Trial C there was no differentiation between the plots or blocks at cutback, and the trial mean compares favourably with the productivity of the varieties in Trial B.

Impact of fertilisers

Trial A plots receiving sewage sludge had higher foliar nitrogen (N) and phosphate (P) concentrations than did those receiving inorganic fertiliser. This effect persisted over two growing seasons, with leaf N concentrations increasing with increasing fertiliser application in the case of both willows and poplars.

There were no significant effects of fertiliser treatment on foliar concentrations in the willows of Trial B, but N concentrations in the stems were significantly higher for willows receiving sewage sludge than in stems sampled from organically fertilised or unfertilised control plots. In the case of the poplars, the N concentration in the leaves from the fertilised plots was higher at the end of the 1993 growing season than in those from the unfertilised plots, while stem nutrient concentration in the poplars was higher than for the willows.

Trial C has given early indications of yield benefits from the application of sewage sludge. A 12% increase in yield has been achieved on plots fertilised with sewage sludge. This is equivalent to an increase in income for the farmer of about £35/ha, assuming a wood fuel price of £30/oven dry tonne.

Nitrogen was the only nutrient consistently to show the effects of fertiliser treatment in plant concentrations.

Nitrate concentrations in drainage were significantly greater from sludge treated plots of *S. dasyclados* than from untreated control plots - but only until mid-February.

The uptake of heavy metals by foliage was generally lower for poplars than for willows, and there was no increase in foliar heavy metal concentrations as a result of the application of sewage sludge.

FERTILISATION OF SHORT ROTATION ENERGY COPPICE USING SEWAGE SLUDGE

Yorkshire Environmental Limited

Background

Sewage sludge disposal to short rotation coppice is known to produce changes in plant growth rate. However, the extent of the change is not sufficiently understood to establish the commercial viability of its application as a fertiliser. A series of trials is being undertaken nationally to determine the effect of different levels of low-grade domestic sewage sludge application to short rotation coppice plantations. The trial that is the subject of this report was the first to approach maturity and therefore the first to provide relevant quantitative information.

Project Objectives

- To compare the yield of different clones of willow and poplar short rotation coppice (SRC) fertilised at different rates with sewage sludge.
- To determine the nutrient content of wood fertilised with sewage sludge and compare this with a control.
- To determine the differences in nutrient uptake between different clones.

The first part of the project - trial establishment and initial monitoring - is the subject of Report No: ETSU B/W5/00215/REP, summarised above. This report examines the findings over an extended monitoring period.

Methodology

Trial establishment and initial procedures are summarised above in Report No: ETSU B/W5/00215/REP. Subsequent specific actions have included:

- visual assessment of the site prior to harvesting the two-year-old coppice
- soil, leaf litter and stem tissue analyses
- assessment of the calorific value of selected clones
- assessment of dry weight, ash and metal content of the harvested material.

Findings

Visual assessments concluded that fungus and pests were evident but that no serious damage appeared to have resulted. More specifically, evidence of rust was found in nearly all the willow plots, particularly Bowles Hybrid, and the conclusion drawn was that this could become a problem.

Mean fresh and dry yields from Trial A were shown to depend on species and spacing intervals. In Trial A/1, which compared *Populus* Beaupre and *Salix* Q83, the poplar produced significantly higher mean yields than the willow. In Trial A/2, which compared three *Populus* and three *Salix* varieties, the highest mean yields were from *Salix viminalis* Bowles Hybrid. Mean yields in both trials were significantly higher at the widest spacing interval, irrespective of species. Yields were not significantly influenced by fertiliser or sludge application rates although detailed analyses in Trial A/1 suggested that they may be affected by the type of fertiliser applied to individual species.

Mean % ash production in Trial A/1 was largely independent of species, fertiliser type, fertiliser application rate or spacing. However, detailed analyses revealed that fertiliser type applied to an individual species may significantly affect the mean % ash content. Similarly, the mean % ash content was found to be significantly different between the two species when treated with sludge.

In Trial A/2, while mean % ash content was not influenced by sludge application rate or spacing, a significant difference did occur between species, with *Populus trichocarpa* Trichobel producing a significantly higher mean % ash content than all the other species tested. Overall, low mean % ash content tended to be associated with species showing high mean yields.

Results from Trial B showed that the *Populus* species had a mean yield approximately four times that of the *Salix* species but a significantly lower mean % ash content. *Populus* Beaupre produced the highest mean yields. There was little significant difference between individual species within each genus.

The Trial B results also indicated that mean yields of control, inorganic fertiliser and sludge treatments were not significantly different between individual species/varieties in the *Populus* and *Salix* groups. In the *Populus* group, the mean % ash content was higher for trees given inorganic fertiliser treatment rather than control or sludge treatments.

Trial C results showed no significant difference in mean fresh yield, dry yield or % ash content between the four types of treatment.

Conclusions

It is difficult to draw overall conclusions for several reasons. The site has a high nutrient status which may have masked the effect of fertiliser treatments. Furthermore, plot differences in sludge and fertiliser application are likely to have been lost as a result of:

- mixing due to the high water table
- the flow of nutrients on to the site from adjacent land
- redistribution of nutrients during flooding.

However, certain broad conclusions, some of which require further research, may be drawn:

- Yields may be enhanced by planting at wider tree spacings, and by using *Populus* Beaupre rather than *Salix* species/varieties.
- The use of high yield species/varieties appears to have a significant effect on ash production: high yield species produce less ash.
- Because of the site's high nutrient status, yields have not been significantly affected by fertiliser application rates. Average yields from the harvesting of two-year-old coppice were 23.09 tonnes/ha/year (fresh) and 9.58 tonnes/ha/year (dry).
- Fertiliser type/application rate does not appear to have a significant effect on ash production.
- Herbicide treatment does not appear to have a significant effect on yield or ash production.
- There appears to be no difference in overall metals uptake with varying sludge application rates or spacing, although *Salix dasyclados* showed a decline in metal content with spacing for copper, lead and iron. However, individual species did respond differently to metal content, with poplars having a lower uptake of heavy metals than willows, particularly for lead, zinc and copper.

It is clear that further work is required on less nutrient-rich sites to identify the effectiveness of sludge applications. It is also possible that there may be a reduction in the nutrient status of even a nutrient-rich site with subsequent harvests.

A STUDY OF ROOT DEVELOPMENT IN SRC WITH PARTICULAR ATTENTION TO FIELD DRAINAGE

Sidney C Banks plc

Background

Willow grown as short rotation coppice (SRC) is ideally suited to damp areas or drained regions on arable land. However, the rooting habit of willow is not fully understood, and the potential damage to drains by roots is unknown.

Project Objective

- To examine the root development characteristics of 14 different willow varieties over five sites.

Methodology

Five commercial plantations were used for this project, two located near Norwich in Norfolk, two near Diss in Suffolk, and one at Sandy in Bedfordshire. Soil characteristics are summarised below.

Crown Point Estate, near Norwich (two sites)	Free-draining sandy loams
Stanton Park Farm, Diss	Variation from sandy loam through sandy clay. More free-draining away from the middle of the site
Church Farm, Diss	Uniform, very free-draining sandy loam
Sandy gravel pit	Reclaimed clay loam with tile drains approximately 50cm below the surface

The sites were planted at the end of April/beginning of May 1995 and were kept weed free. *Dasyclados* was grown at each location as a control.

A profile wall was constructed in July 1995 to measure root growth and depth, and the sites were monitored monthly to observe root development. In January 1996, at the end of one season's growth, three willow clones of each variety were excavated and classified according to depth of penetration, lateral spread and root type. The findings were compared with observational results from the profile wall method.

Findings

The results showed that, in areas where the ground is waterlogged for long periods, root development is impeded, and roots are unlikely to infiltrate field drains within the first year's growth. In soils where the drainage is more free-flowing, root development is greater. However, no roots reached field drain depth within the first year, and further work is required to ascertain how quickly drainage systems are reached in subsequent years.

There is also some evidence to suggest that root development is independent of soil type since the variety *dasyclados*, which was common to all sites, produced a similar growth pattern.

3.2 Weed Control

Report No: ETSU B/W5/00211/REP

Publication date: 1993

WEED CONTROL AND SOIL MANAGEMENT SYSTEMS FOR SHORT-ROTATION COPPICE: PRESENT KNOWLEDGE AND FUTURE REQUIREMENTS

Avon Vegetation Research

Background

Weeds are clearly the main agronomic problem facing the grower of energy coppice, who must achieve maximum growth from the start in order to achieve an economic yield by the first harvest. While yields of more than 10 dry tonnes/ha have been achieved in well managed experimental plantations, there have been many failures because of uncontrolled weeds. This problem may now be more acute because many new plantings are sited on former arable land where high fertility combined with large weed seed populations result in vigorous weed growth.

It is during the establishment stage that a crop grown from cuttings is particularly vulnerable to weed competition. Uncontrolled weeds result in crop death or a severe reduction in crop growth during the first year. However, while the significance of weed competition during the first year is understood, the need for weeding in subsequent years is less well understood, and work is needed to define those situations where control is necessary.

Project Objective

- To identify appropriate weed control and soil management systems for short rotation coppice (SRC).

Methodology

Information has been gathered from various sources:

- a literature review, including a search of the “Weed Abstracts” database
- the 1992 International Energy Agency Handbook “How to grow short rotation forests”
- discussions with experts in agronomy and related disciplines
- visits to experimental and commercial plantings to examine the practical problems at first hand.

Findings

Current herbicide options and future requirements

Most successful plantations have been established with the use of herbicides. Weed control programmes have been developed that involve:

- pre-ploughing herbicide applications to suppress perennial weeds
- post-planting residual herbicide applications to control the germination of annual weeds for a period of three months or more.

There are some selective contact herbicides that can be used as overall sprays to control emerging weeds. Treatments are also available to control weeds in the second spring, between winter cut-back and canopy closure in the early summer. However, there are many situations for which no selective treatment is available. Late applications of overall sprays such as amitrole may, for example, be unacceptably damaging, particularly to poplar. There is therefore a need for safer and more selective contact herbicides and for better equipment for applying treatments directly to the weeds.

All herbicides used in coppice must have MAFF Approval, which is given after consideration of toxicology and environmental fate. Because farm forestry is a minor crop, only a few herbicides have manufacturers' recommendations for this use. However, several now have MAFF "Off-Label" Approval, permitting the use of specific products in coppice. There is a need to obtain more such Approvals to provide farmers with the range of herbicides required for efficient production.

Under the EC Harmonisation Directive, all pesticides are being reviewed between 1993 and 2003. This should ensure that only environmentally acceptable herbicides are available. Because of this review - and for commercial reasons - some of the currently recommended herbicides may not in future be available. It is therefore important to identify alternatives for key uses. Several different herbicides are in use abroad for the establishment of poplar and willow energy crops, particularly as post-planting sprays. Not all are available in the UK and, although some are too toxic for UK application, a few should be considered for future use.

Reducing herbicide use

There is pressure to reduce herbicide inputs to crops for both environmental and economic reasons. In the case of SRC, a major objective should be to reduce weed and weed seed populations prior to planting. Overall spraying should only be necessary in the first year of a plantation, and the average amount applied per year over a 20-year cropping cycle will only be around 0.5kg active ingredient per ha (ai/ha), compared with perhaps 1-4kg ai/ha/year on arable crops. Furthermore, the amount required is likely to decrease as modern low-dose herbicides are introduced into agriculture.

There is also a need for alternative techniques for weed control. Mechanical weeding methods are generally unsatisfactory: they are ineffective in wet conditions and fail to control weeds within rows. Furthermore, gaining access to the growing crop without causing crop damage is difficult. It may, however, be possible to combine herbicides with mechanical weeding methods, as successfully achieved in Sweden, provided the machinery currently available for weeding the growing crop is evaluated and improved.

Further research is required into other alternatives such as weed suppression by planting into dead vegetation or the planting of non-competitive ground-cover species with the crop.

Issues Requiring Further Attention

- The susceptibility of weed species to commonly used herbicides.
- How different coppice varieties respond to weed competition and to herbicides.
- The preparation of detailed growers' guides outlining the principles of weed management and giving details of control programmes.

EVALUATION OF RESIDUAL AND FOLIAR-ACTING HERBICIDES ON POPLAR AND WILLOW CULTIVARS

Avon Vegetation Research, Long Ashton Research Station

Background

Research has shown that effective weed control is essential to the establishment and rapid growth of newly planted short rotation coppice. Not only does failure to control weeds at an early stage require subsequent and expensive remedial action, but there is circumstantial evidence that poplar and willow, once severely checked, never recover to give maximum yields. There is therefore a need for safe and effective herbicides.

Project Objectives

- To test the tolerance of newly planted poplar and willow cultivars to residual herbicides at recommended and three times recommended doses.
- To assess the effect on crop growth of unchecked weed competition in the first year.
- To assess the tolerance of the same crop cultivars, after cutting back in the first winter, to overall and directed sprays of four contact herbicides.

Methodology

The land, a gently sloping field with a red/brown, poorly drained silty/clay/loam soil, was ploughed and harrowed and then planted with 25cm cuttings. The cultivars used were:

- *Populus trichocarpa* Fritzi-Pauley
- *P. Deltoides x trichocarpa* Boelare
- *Salix viminalis* Bowles Hybrid 115/34
- *S. x dasyclados* (Wimm) 043/03.

Planting was carried out in March 1989, March 1990 and March 1991.

Each individual treatment block consisted of ten stools, with two rows of five plants at 0.5 x 0.41 metre spacings. Treated plots were separated by a guard row. There were also two control plots. One was hand-weeded (hoed): the other was left totally untreated to show the effects of full weed competition.

Seven residual herbicides were used in various mixtures and were applied as overall sprays at two dose rates - the recommended rate and three times the recommended rate, as shown in the table below. Atrazine + cyanazine, which is known to be damaging to the crops, was also

tested. In each of the three years the cuttings were either dormant or at bud-burst when sprayed.

The residual herbicides tested and their applications

Herbicides	Dose rates (kg ai/ha)	
	Low	High
Metazachlor + pendimethalin	1.25 + 2.0	3.75 + 6.0
Metazachlor + propyzamide	1.25 + 1.5	3.75 + 4.5
Metazachlor + metamitron	1.25 + 3.5	3.75 + 10.5
Simazine + propyzamide	1.5 + 1.5	4.5 + 4.5
Isoxaben + propyzamide	0.13 + 1.5	0.38 + 4.5
Simazine + napropamide	1.5 + 2.25	4.5 + 6.75
Simazine + metazachlor + propyzamide	1.5 + 1.25 + 1.5	4.5 + 3.75 + 4.5
Atrazine + cyanazine	1.5 + 1.5	4.5 + 4.5

Assessments were made at intervals throughout the year to determine the effects of the treatment on both crops and weeds. The weed species present were also recorded.

The crop was cut back to just above ground level during the winter after planting. Both the fresh weight, the number of shoots and the number of shoots longer than the mean length for the hoed control plot were recorded.

The effect of four foliar-acting contact herbicides on one-year-old coppice was tested by applications at different growth stages in the spring. The same plots were used as for the residual herbicide experiments, although the unweeded plots and plots with the poorest growth were excluded. The herbicides used were amitrole, clopyralid, glyphosate and paraquat, and the doses chosen were, except in the case of clopyralid, those recommended for controlling emerging weeds in other crops. Overall spraying was used in 1990 and 1991. In 1992, the latest sprays to 30cm shoots of poplar and willow were applied as directed sprays to the inter-row area and to the base of the growing shoots.

Plant health was recorded at intervals. Shoot numbers, height and weight were recorded after harvesting in the winter following treatment.

Findings

Residual herbicide treatment

Atrazine + cyanazine only caused an appreciable reduction in poplar growth in one year. None of the other residual herbicide mixtures, whether at the recommended dose or at three times the recommended dose, had any adverse effects on shoot numbers, height or weight at the end of the first year when compared with the hoed control. However, the fact that atrazine + cyanazine, a mixture known to be damaging to the crops, only caused an

appreciable reduction in poplar growth in one year suggests that trial conditions were not conducive to damage. Further experience of all these herbicides is therefore needed before their widespread use can be recommended, particularly on light soil.

All residual herbicide mixtures gave good control of annual weeds during the summer, the best treatment being metazachlor + met amitron. The most effective control is achieved when the soil is wet at the time of application and appreciable rain, say 10mm, falls within one week of spraying. This ensures that sufficient herbicide is carried down to a depth of 1-2cm to kill the first flush of germinating weeds. A fine tilth is also important to ensure even distribution of the herbicide. Although optimum rainfall conditions were not fully met in any of the three trial years, this did not appear to influence weed control from year to year. A particularly cloddy seed bed in 1990, however, was believed to have contributed to a poorer than expected weed control for most of the treatments.

Foliar-acting herbicide treatment

Applications of the foliar-acting herbicides amitrole, glyphosate and paraquat to dormant stools or to stools at bud burst had little noticeable effect, although some instances of a reduction in yield, particularly on poplars, were observed. The later overall applications, in April and May, were more damaging, particularly to poplar. Directed applications to the base of taller plants in late spring were better tolerated, although glyphosate did cause a 30% reduction in poplar yield.

In the absence of safer herbicides, the overall application of these products can be justified in dormant or newly sprouting crops to remove competing weed growth. However, directed applications are likely to be safer once shoot elongation has occurred, particularly in the case of poplar.

The overall application of clopyralid had no long-term effect on growth or yield, irrespective of the growth stage at which it was applied. This herbicide is particularly valuable as a means of controlling creeping thistle and other *Compositae* weeds.

Control plots

The hoed control plot did not achieve completely weed-free conditions throughout the growing season, particularly during the wetter summers of 1989 and 1991. The wet conditions of 1991 necessitated hand weeding on six occasions.

Plots with uncontrolled weed growth showed a reduction in crop growth of 50-75% each year. The willow cultivar Bowles Hybrid, the most vigorous of the crops planted, was less affected by weed competition than the others. This suggests that any differences in the effect of weeds on specific crop cultivars may be attributable to crop vigour.

Conclusion

The high level of experimental error in the crop growth data indicates a need for further work with larger plots or more replicates to give a more precise evaluation of herbicide effects.

REPORT ON EXPERIMENTS ON WEED MANAGEMENT IN COPPICE: 1994-1995

Avon Vegetation Research

Background

Effective weed control is essential for the successful establishment and growth of short rotation coppice (SRC). Basic weed control programmes have been developed, but there is a need to establish the level of weed control required and the best methods of achieving this. In particular, more information on crop tolerance to herbicides is needed to ensure that a range of safe and effective treatments is available.

Project Objectives

- To ascertain the level of weed control required for the successful establishment and growth of short rotation coppice.
- To determine the best methods of achieving the level of weed control identified by providing more information on crop tolerance to herbicides.

Methodology and Findings

A series of experiments was carried out. Both experimental work and findings are summarised under the headings that follow.

The effect of first-year ground cover on crop growth

To determine the long-term effects of different levels and durations of ground cover in the establishment year for poplar and willow, cuttings of both crops were planted into different ground cover regimes in the spring of 1993. The resulting shoots were cut back in December 1993. The buds and new shoots were sprayed in March 1994 to give weed-free conditions during subsequent growth. The crop was hand-weeded after the June weed cover assessment. Spot treatment of both annual and perennial weeds was carried out in April and October 1995. Crop growth was monitored in both years to determine how the first year's growth check had affected subsequent growth.

The findings can be summarised as follows:

- The presence of ground cover vegetation in the establishment year reduced shoot weight at the end of that year by 60-90% compared with weed-free plots, but did not affect survival.
- Although growth under weed-free conditions during the second year was much greater, final shoot growth was proportional to stool size at the end of the first year.

- The efficacy of the herbicide mixture applied after cut-back was reduced on plots with a dense vegetation cover at spraying.
- Stem diameter measurements in December 1995 showed that plots had made a considerable recovery since the first year's growth check. Growth reductions were now only 30-50% compared with weed-free plots, but were proportional to first-year growth. This suggests that some competition from annual weed species during part of the first growing season may not have a long-term adverse effect.

The effect of weed control on poplar growth

Two types of poplar cutting were planted in the spring of 1994: cuttings with primary buds only, and cuttings where lateral shoots had been cut off. These were grown on in both weedy and weed-free conditions.

Results for weedy plots

Perennial weeds, particularly creeping thistle, dominated most weedy plots, reducing poplar growth by more than 90% by the end of the first year.

By the end of the second year, a year experiencing severe drought in July and August, most of the crop had died. The only plots where significant plantings survived were those on which annual weeds were dominant in the first year.

Although shoot length was greater at the end of the first year for plants grown from primary bud cuttings, the type of cutting had no effect on survival or growth during the second year.

Results for "weed-free" plots

At the end of Year 1, the main shoots of plants grown from primary bud cuttings were longer than those grown from cuttings with cut laterals, but shoot number and weight per plot was less. There was also a correlation between first-year growth and the degree of creeping thistle ground-cover that developed.

At the end of Year 2, cut lateral plants had greater shoot numbers and total stem diameter per plant. There was no correlation between creeping thistle ground-cover and growth at the end of the second year.

The need for weed control after harvesting

Five herbicide treatments were applied to recently harvested poplar at Swanbourne to compare weed control efficacy and crop tolerance. Amitrole and glyphosate + simazine used as overall sprays, and triclopyr used as a directed spray, gave optimum perennial weed control. Glufosinate + simazine was the least effective treatment. There were no long-term adverse effects on crop growth, but there was no apparent growth increase from weed control either.

In a second experiment, five herbicides were used to control creeping buttercup on recently harvested willow at Buckfastleigh. 2,4-D, glyphosate and paraquat applied in March gave long-term control. Good initial control using amitrole was followed by appreciable regrowth. Glufosinate was ineffective. There were no apparent benefits to crop growth of buttercup control. Other weeds, particularly couch grass, developed extensively, and it is clearly important to anticipate the likely species succession on sites with numerous perennial weed species, and plan a herbicide programme accordingly.

Crop tolerance to contact herbicides after planting

Foliar-acting herbicides were applied in early July to poplar and willow cuttings planted in April. The aim was to kill weeds emerging after planting where residual herbicides had either not been used or had been ineffective.

There were no adverse effects on the crop. Metamitron + oil, and pyridate, were well tolerated by the crop at either the recommended or three times the recommended dose. Both desmetryn and cyanazine (with or without terbuthylazine) caused necrosis of some sprayed leaves, but subsequent growth was generally unaffected. Although apparently useful herbicides for this purpose, more information on crop safety is required.

Crop tolerance to contact herbicides after cut-back

Test on container-grown plants

To assess the impact of foliar-acting herbicides on crops after cut-back, amitrole, glufosinate and glyphosate were applied at recommended and twice recommended doses to one-year-old container-grown poplar and willow at one hour, one day, three days, one week, one month and two months after cutting back in January or March. The findings were compared with control plants.

- Amitrole - both doses and all application dates - caused yellowing and some stunting of new growth in April and May. However, these effects were generally outgrown by June, and shoot lengths, weights and numbers recorded in September were the same as for untreated plants. The only treatment to cause long-term growth reduction was a May application, ie two months after cut-back when shoots were more than 10cm long.
- Most glufosinate applications checked growth initially and killed any shoots present. However, regrowth was rapid, and there were no observable effects on shoot health or length in June, or on shoot length, weight and number in September. Only the May application, two months after cut-back, caused long-term damage.
- All glyphosate applications, irrespective of date or dose of application, caused severe growth checks, the more severe checks associated with the higher dose rate. The top of the cut stools died back, and new growth came from near or below ground level. Poplar was more damaged than willow. The only treatment where final shoot height and weight was

not significantly reduced was the lower dose rate applied one month after cut-back (January or March).

Overall conclusions:

- Amitrole and glufosinate applied in spring should not damage cut-back poplar or willow significantly in spite of initial leaf chlorosis or growth check, provided new shoot growth is not too advanced.
- Glyphosate may be too damaging for general use except where there are intractable weed situations. The safest application time appears to be several weeks after cut-back but before growth recommences.

Field experiments using poplar

Herbicide treatments were applied at recommended doses in March, after cutting back one-year-old poplar. The results can be summarised as follows:

- Amitrole + simazine caused initial yellowing of new shoots, but effects were outgrown by June.
- Glufosinate + simazine initially killed some apical buds, but regrowth was rapid.
- Glyphosate + simazine caused the death of the top part of the stools and the death and stunting of the uppermost shoots. However, regrowth from ground level was very rapid.
- Overall, yield at the end of the year was not affected.
- Dichlobenil and atrazine + cyanazine had no visible effect on initial or subsequent growth.
- Herbicide mixtures containing amitrole or glyphosate gave the best control of a mixed weed population.

Long-term herbicide effectiveness

Mixtures of simazine with amitrole or glufosinate have given longer-term weed control than foliar-acting herbicides alone - and without significant crop damage. However, alternatives to simazine are needed because of restrictions on its use at some sites and because it is not always effective on resistant annual weeds.

Field experiments adding isoxaben and pendimethalin to the standard amitrole/simazine or glufosinate/simazine mixtures did not increase crop damage. Short-term weed control using isoxaben or pendimethalin mixed with amitrole or glufosinate was as effective as the amitrole/simazine and glufosinate/simazine mixtures, although long-term grass control was poorer. The amitrole mixtures in particular failed to control creeping buttercup and perennial grasses.

Tolerance of different cultivars to herbicides

Seven residual herbicides were applied to six container-grown poplar cultivars of differing parentage. Recommended and four times recommended doses were applied both to dormant cuttings and to shoots with three to five leaves.

The findings were as follows:

- There were no consistent effects relating to cultivar parentage.
- Recommended doses of cyanazine, lenacil, metazachlor and simazine caused severe damage to all cultivars at both stages, probably because of the very wet conditions in the month after spraying.
- Isoxaben, metamitron and pendimethalin were generally safe at the recommended doses. Furthermore, damage was not usually severe at the higher dose.

In a second container experiment, four poplar and two willow cultivars were sprayed with four residual herbicides and grown on under three watering regimes. Results were as follows:

- Diflufenican and isoproturon proved generally safe at the recommended dose.
- Isoproturon at higher doses was very damaging.
- Diflufenican is a potentially valuable residual herbicide for use in coppice, but requires further evaluation.
- Poplar cultivar Ghoy was less susceptible to metazachlor - shoots were relatively small at the time of spraying.
- Willow cultivar Germany was more susceptible to herbicides than Bowles Hybrid.
- Post-spraying overhead irrigation increased the level of herbicide damage.

Conclusions

Most of the herbicide treatments used in these experiments have no manufacturer's recommendation for use in coppice, particularly as overall sprays. However, many are covered by UK MAFF Off-label Approval arrangements, ie application is permissible at user's risk in relation to efficacy and crop tolerance.

Any evidence of weed control efficacy or crop tolerance reported here does not constitute a recommendation for use.

WEED MANAGEMENT IN SHORT ROTATION COPPICE: CURRENT STATUS AND FUTURE REQUIREMENTS

Avon Vegetation Research

Background

The successful production of short rotation coppice (SRC) depends on effective weed control, particularly during the establishment phase. There is now considerable evidence that weedy plantations will not achieve the yields of 15-20 dry tonnes/ha/year needed for economic viability. However, recent work has shown that the degree of crop check from weeds depends on the timing and type of weeds present.

Several conclusions can be drawn from recent research:

- Plots that are initially weed free but that become weedy in summer are less affected than those with a complete ground cover at the time of planting.
- Small quantities of the less vigorous annual weeds have not restricted crop growth in the establishment year as much as aggressive perennial weeds.
- Crops that were initially weedy but were subjected to effective weed control from Year 2 onwards have shown some compensatory growth.
- The presence of or invasion by vigorous perennial weeds - creeping thistle, hedge bindweed etc - will restrict growth and interfere with harvesting equipment.
- Some control of aggressive weeds such as bramble is needed after harvest.
- Certain agronomic factors can reduce weed growth. Use of the most vigorous clones, closer plant spacings and no defoliation from pests and diseases help to achieve canopy closure early in Year 2, thereby reducing weed growth.

More research is needed into the relative competitiveness of different weed types and species to prevent the over-application of herbicides.

Project Objective

- To provide an updated review of the current status of weed management in SRC.

Methodology

Information has been derived from recently published data; the findings of other SRC monitoring and experimental work carried out under the same consultancy; small-scale experimentation; and observation.

Findings

Non-chemical weed control methods

Non-chemical methods of weed control are attractive on environmental grounds but have not been developed in the UK. Mechanical systems - comb harrows - are used in Sweden, but are only likely to be effective, as are steerage hoes, on light soils and in relatively dry conditions. The use of organic or plastic film mulches is unlikely to be economic for energy coppice. The costs of buying and laying the mulch is high and, with paper film, weed control may be inadequate. The weed control implications of applying sewage sludge to short rotation coppice as a fertiliser have not yet been clarified.

Weed control using herbicides

Weed control systems based on herbicides are well developed. Effective systems have several components:

- pre-planting control of perennial weeds by applying glyphosate and by deep ploughing the autumn before planting
- a pre-planting spray with a contact herbicide such as glufosinate, glyphosate or paraquat (or a shallow cultivation) to kill annual weeds where several weeks or months have elapsed between soil preparation and planting
- the application of post-planting residual herbicides to give long-term weed control during the first season and ensure maximum crop growth
- follow-up spraying with contact herbicides
- treatment after harvest.

This type of programme is expensive, particularly as the cheapest and generally most effective residual herbicide for newly planted coppice, simazine, is currently not Approved for use in the year of planting. Recommended treatments include isoxaben, metazachlor and pendimethalin, although the first should not be used later than March, while the second can cause leaf damage to emerging shoots.

It may be possible to reduce herbicide inputs and costs by using the “stale seed-bed” technique. This involves delaying planting until the first flush of weeds has emerged. These are then killed by shallow cultivation or use of a contact herbicide. Subsequent control should then be possible, provided there is minimum soil disturbance, by inter-row contact

spraying with a low-cost contact herbicide. Glufosinate and amitrole are relatively safe for this purpose, but glyphosate contamination of shoots is lethal and glyphosate should be used in the growing crop with extreme care and only for weeds for which no other herbicide is effective. There is a real need to evaluate the efficacy and tolerance of other low-dose herbicides now available for cereal crops.

The main weed problems after harvest are bramble, nettle, creeping thistle and couch grass. Applications of amitrole + simazine give the best suppression of long-term perennial weeds, although nettles remain a problem, and the need remains to evaluate the best treatments for the most aggressive weed species. Glufosinate + simazine is only effective on emerged annual weeds. Although both treatments can give a short-term check to the growing crop, long-term growth is rarely affected. Glyphosate can be used before new bud growth begins, but it may also be needed on dense couch grass infestations.

Herbicides: legislation, properties and efficacy

The use of herbicides is regulated by legislation, and only herbicides Approved by MAFF for forestry use can be applied. Application must be in accordance with conditions prescribed on the herbicide label. These cover field of use, operator and wildlife protection, maximum dose, application method and spray volume rates. The use of a greater number of agricultural herbicides has been permitted since January 1995, but there is still a need for the specific Off-Label Approval of products for several important uses.

It is important to minimise the environmental impact of herbicide use in short rotation coppice, and there is now sufficient information available on the type of action, properties and costs for growers to be able to make their own selection, as appropriate. Some herbicides, for instance, are only foliar-acting, while others are soil-acting. A small number are both foliar- and soil-acting. At the same time some products are predominantly for overall use, while others require more carefully directed spraying on to weeds. Herbicides also vary widely in their toxicity, solubility, mobility and persistence.

Costs vary widely, with approximate figures for February 1996 ranging from £8/ha for simazine to £110/ha for propyzamide.

The susceptibility of annual weed species to most herbicides is already clearly understood. The response of perennial weeds is less well known, although observation between 1992 and 1996 has provided information on the most successful treatments for the most difficult coppice weeds - bindweed, bramble, creeping buttercup, couch, dock, nettle, thistle, willowherb and many more.

The need for integrated weed control systems

The greatest need for the future is the development of integrated growing systems in which weed control methods combine effectiveness with low cost and minimal environmental impact. This will require a greater understanding of the periodicity of weed competition in the crop, particularly during the establishment period and after harvest, and will necessitate analyses of species succession following different herbicide treatments. It is also important to

evaluate new, low-dose, environmentally benign agricultural herbicides for coppice use. Such treatments will help to maintain the vigorous crop growth essential to productivity.

It is particularly urgent to reduce the costs of weed control, and current thinking indicates that the best way forward may be to maximise pre-planting weed control and use inter-row spray equipment to apply low-cost contact herbicide treatments.

MECHANICAL PRE-PLANTING WEED CONTROL IN SHORT ROTATION COPPICE USING DEEP FORESTRY PLOUGHING TECHNIQUES

Border Biofuels Ltd

Background

Recommended conventional ground preparations involve:

- sub-soil cultivation to a depth of 40cm to fracture any compacted soil layers
- conventional agricultural ploughing to a depth of 25cm to invert the top soil layer and bury any surface trash
- powered rotary cultivation to produce a fine seedbed tilth.

However, in practice, cultivations are often not made to the required depth: compactions are not broken down, and it is impossible to plant the 20cm cuttings so that the tops are flush with the surface level of the seedbed.

Weed control options are very limited with short rotation coppice. Herbicides are restricted primarily to forestry herbicides and MAFF Off-Label Clearance for products with Approval for use in cereals. Furthermore, one of the most critical factors in the failure and poor productivity of plantations is failure to control perennial weeds, especially couch grass, particularly in the season before planting.

Using a deep plough that can plough to a depth of 60cm is becoming standard practice in Denmark where herbicide restrictions are even greater than in the UK. The success of this approach lies in:

- the deep tilth which, with the placement of topsoil at depth, aids root development and nutrient take-up
- the more consistent placement of cuttings
- the burial of weed seeds at a much greater depth.

Project Objectives

- To compare the establishment and productivity of willows planted into ground prepared by the deep plough with that of willows established using conventional techniques.
- To compare any subsequent variation in weed seed germination.

Methodology

Three plough trial sites were identified in Cumbria and Yorkshire, as summarised in the table below. Each site was ploughed and power harrowed to produce a suitable seed bed. Herbicides were applied and the sites were then planted with willow cuttings at a planting rate of 12,000/ha. Twin-row beds were used, with 75cm between each row and 125cm between the beds. Cuttings were spaced within the rows at 80cm intervals.

Summary of plough trial sites

Site	Field area (ha)	Trial area (m ²)	Soil type	Clones planted	Herbicide used
Moorhouse Hall	1.15	7500	Fine sandy loam over clay loam subsoil	Mix including Aage, Henrik, Steffan, Gustav, Christina, Bowles Hybrid	Simazine @ 3 litres/ha + isoxaben at 1 litre/ha
East Lilling	11.3	1500	Sandy loam over boulder clay subsoil	Jorr	None
Youlton Lodge	10.7	480	Silty clay over boulder clay subsoil	Ulv	Simazine at 3 litres/ha + pendimethalin at 4 litres/ha

Findings

Plough output and effectiveness

Once properly calibrated for the site, the single-furrow deep plough achieved an output of approximately 0.25 ha/hour compared with 0.8 ha/hour for a standard six-furrow reversible plough. However, the plough may only be suited to lighter, relatively stone-free soils. On soils with a considerable clay content in the sub-soil, deep ploughing would bring large clods of clay to the surface. This could dry out and prove impossible to break down into a suitable tilth for planting. Deep ploughing a very stony sub-soil would bring large numbers of stones to the surface, again making planting difficult.

Weed germination levels

Observation of weed germination was carried out at four, eight and 12 weeks. The size of the weeds on the conventionally cultivated areas made it impossible, after eight weeks, to distinguish between different plants. However, on the deep plough sites, weed assessment was possible because of the delayed and reduced levels of emergence. Overall, deep ploughing reduced the seed germination levels of many annual weed species and reduced infestation levels of perennial weeds. While this implies a possible reduction in the use of herbicides for controlling annual weeds, perennial weeds should still be controlled in the season prior to planting.

Biomass productivity

A non-destructive assessment of biomass productivity was based on stem height and diameter measurements for sample stools in each cultivation area. The findings showed that, compared with willows planted in conventionally prepared ground, willows planted on deep-ploughed land had:

- an improved survival rate (97% as against 87%)
- a substantially greater biomass productivity.

Costs

The costs of deep ploughing have been assessed at £130/ha, including tractor and fuel, compared with £45/ha for conventional ground preparation. If the cost of herbicide (£60-£70/ha) is added to the conventional cultivation cost, the costs of the two techniques are broadly comparable.

Conclusions

The initial conclusion to be drawn from these findings is that deep ploughing provides better conditions for rooting, establishment and weed suppression. Further investigation is now required, and this should include comparisons between autumn and spring ploughing on fields of different soil types; an assessment of the effect of a period of fallow; and an examination of the potential for reducing herbicide applications. Consideration should also be given to the three-furrow version of the deep plough recently produced by the Danish manufacturer as this should improve output and reduce cultivation costs.

3.3 Pests and Diseases

Report No: ETSU B 1258

Publication date: 1992

EVALUATION OF THE BIOLOGY AND IMPORTANCE OF DISEASES AND PESTS IN WILLOW ENERGY PLANTATIONS

Long Ashton Research Station

Background

By 1989, it was clear that, unless methods of control were developed, rust disease caused by the fungal pathogen *Melampsora* could well become the single most important agronomic factor limiting the productivity of coppice willow for energy cropping. At the same time, there had been little systematic investigation of willow rust anywhere in the world, and even less relating to the disease in willow energy plantations.

Project Objectives

- To carry out annual surveys of diseases and pests in willow plantings in England, Scotland and Northern Ireland (as part of wider surveys for an International Energy Agency project).
- To quantify losses in coppice yields caused by different amounts and patterns of rust development.
- To characterise the most important factors influencing the spread of the rust pathogen in clonal plantations.

Findings

Annual surveys

Annual surveys carried out between 1987 and 1991 in England, Scotland and Northern Ireland confirmed that rust disease caused by the fungal pathogen *Melampsora* spp was a serious limiting factor in the productivity of willows for energy cropping.

Some clones, eg *Salix viminalis x triandra* SQ83 and, at some sites, *S. x dasyclados* Wimm, have been little affected by the disease. However, there is evidence of changing reactions to rust. *S. viminalis* Bowles Hybrid has become more susceptible to the disease, while *S. dasyclados* Wimm suffered from severe rust, including cankering on young shoots, at a number of sites in Northern Ireland. The only clones without rust were *S. candida* and *S. sitchensis*.

Overall, the number of clones affected by rust increased over the period, and premature leaf fall is now associated with lower rust severity levels than previously. Furthermore, although

rust is not a universal problem in the UK, it is capable of spreading and becoming a problem even in areas where only isolated willow plantations exist.

Other fungal diseases and insect pest problems occur only on a local scale, but feeding damage associated with Chrysomelid leaf beetles and the death of terminal buds caused by *Terminalis* midge could both spread and become more severe.

Effect of rust on coppice yield

Once infection has started, rust increases continuously within a plantation of a susceptible clone during the period of willow growth. Infection rates are governed by the susceptibility of the host, but also by quantitative fluctuations in environmental factors such as temperature and moisture.

The disease commonly causes reductions in biomass yield of 25-30% - occasionally up to 40% - in highly susceptible clones such as *S. burjatica* Korso. Although this does not apply to Korso, yield reductions in many susceptible clones are less when the rust arises later rather than earlier in the season. Yields of other clones such as *S. viminalis* Bowles Hybrid and *S. x dasyclados* Wimm were maintained in the presence of common leaf-infecting forms of rust. On the other hand, it was observed that stem-infecting forms can reduce yields in the otherwise less susceptible Bowles Hybrid.

Applications of the fungicide Systhane were found to suppress rust development.

Sources and life-cycle of willow rust

Of at least three species of *Melampsora* encountered on willows grown for energy cropping in the UK, *M. epitea* var. *epitea* is the most prevalent. The European Larch (*Larix decidua*) is the only significant alternative host plant for *M. epitea* and is required for completion of the full life-cycle of most forms of rust. It is likely, although not yet proven, that larch plays an important role as a source of rust variability in the UK.

Evidence suggests that, at least in Korso, the rust pathogen can overwinter in dormant rootstock buds that became infected during the previous year. Occasional infected shoots developing from these buds in spring serve as foci for subsequent epidemics. On *S. viminalis* clones, the pathogen overwinters as stem cankers and bud infections. It can also overwinter as the telial stage in dead willow leaves.

Rust on *Salix viminalis*

Rust exists in two forms on *S. viminalis*: one form infects only the leaves; the other infects only young leaves but also causes stem cankers. Stem-infecting rust overwinters in the stem cankers and in buds associated with these cankers. It arises earlier in the season than the leaf-infecting form and poses special dangers for the spread of rust in willow propagating material.

Pathogenic “races” of the willow rust pathogen

Extensive use of an *in vitro* method, developed for examining the pathogenicity of rust isolates to different clones, has shown that there are at least eight “races” or “pathotypes” of *M. epitea* in the UK. The pathotypes correspond to five known “form species” of *M. epitea*, three of which alternatively infect larch. The wide variability in rust populations is the most important consideration when breeding rust resistance into willows and developing rust management strategies.

The project also reported the first successful attempts to hybridise rust pathotypes for studying the genetic basis of rust virulence and willow resistance. Genetic mechanisms are tentatively proposed for the control of virulence in the rust pathotype from Korso.

Biological control

A hyperparasitic fungus, *Darluca filum*, that is capable of naturally controlling rust in field plantations has been discovered, isolated and grown on a range of artificial media in pure culture. Its potential for the biological control of rust is judged to be considerable.

Conclusions

The rust problem is not insurmountable. The findings of this project and other research currently in progress, strongly indicate that viable and economic rust management strategies can be developed that will contribute to an expanding and profitable willow energy industry.

INTERACTIONS OF RUST DISEASES WITH WILLOW BIOMASS CLONES AT DIFFERENT SITES

Long Ashton Research Station

Background

Surveys of willow plantations at sites in Europe and Canada indicate that rust occurrence and severity varies markedly between sites and clones, and also within the same clone at different sites. These surveys, and other observations, have shown that certain clones appear to have become progressively more susceptible to rust or have suddenly become susceptible after being virtually immune. The likely explanation is the intrinsically variable nature of rust populations and their adaptability to new willow varieties. The planting of larger areas of a limited number of clones may also have a part to play.

To date there is little knowledge about the extent to which each pathotype is distributed between different regions of the country, or about the pathotype composition of different rust populations and whether this changes with time. It is also important to know the comparative sensitivity of individual clones to the rust populations prevailing in different regions.

Project Objectives

- To compare rust occurrence and to characterise and evaluate the pathotype composition of rust populations in terms of rust development on 24 selected willow clones planted at three sites in the UK, each site representative of a different biomass production region.
- To assess the sensitivity of the willow clones to rust and other diseases and pests at the three sites, and to establish their suitability for studying interactions between pathotypes and environmental conditions.
- To identify a set of willow clones suitable for characterising rust pathotypes as a standard method.
- To compare the results with those available from similar experiments in Sweden and Canada.

Methodology

A series of trials was conducted at Long Ashton Research Station near Bristol, at the Horticultural and Plant Breeding Station, Loughgall, Northern Ireland, and at Craibstone in Scotland. Similar trials were set up in Canada and Sweden under a global programme funded by the International Energy Agency (IEA).

Twenty-four different willow clones were planted in replicated blocks on each site in 1991. Each block consisted of 25 stools planted in a 5 x 5 metre square at 1 x 1 metre spacings. The clones, 12 from the UK, six from Sweden and six from Canada, were chosen for their ability to segregate rust pathotypes, to cover a wide range of sensitivity to rust, and for their commercial biomass potential.

Strict comparison between sites was achieved by:

- using a standard rust assessment protocol developed at Long Ashton under the auspices of the IEA Bioenergy Agreement, Tasks V and VIII Pest and Disease Activity programmes 1989-1994
- using a standardised technique for pathotype screening the many rust samples collected annually from each site.

Records were also made of other major diseases and pests, and biomass yields were assessed annually for each site.

Findings

The range and spread of pathotypes

Rust populations were found to be composed of a large range of different pathotypes. These can attack different groups of willow clones grown for biomass production. Most of the pathotypes encountered cause leaf infection, resulting, in extreme cases, in premature defoliation. Other pathotypes cause stem infections resulting in cankers. Some rust species and pathotypes were widespread: others were more restricted in distribution. The pathotype composition of rust populations differed between sites.

A complex, wide range of pathotypes occurred at both Long Ashton and Loughgall. There have been extensive plantings of many species and clones of coppice willows at both sites, together with vigorous rust attacks over a long period of time. By contrast, Craibstone showed a relatively simple pathotype structure. This is a more isolated site that has experienced milder rust attacks in the past. Furthermore, some of the pathotypes that are persistently prevalent at the other sites have not yet become established in Scotland.

Many of the pathotypes occur widely in the UK, and infections can develop quickly on susceptible clones once they are planted on a large scale.

The development of new pathotypes

New pathotypes can also develop, often infecting clones that were previously rust-free. For example, in 1994, a pathotype designated LET4 was found attacking the high-yielding clone *S. mollissima* Q83 at both Long Ashton and Loughgall. This clone had previously been grown for several years without any rust infection. Two other previously unknown pathotypes, LET5 and LET 6 were also identified during the study, although their appearance had been predicted.

The rapid development of new pathotypes is the result of sexual recombination on the alternate hosts (usually European larch for most leaf-infecting pathotypes) that are necessary to complete the life-cycle of most rusts that attack willow. Such rapid development is less likely with stem-infecting pathotypes. These do not appear to require an alternate host but exist on the willow as asexual populations. They evolve slowly and are likely to remain more stable.

Rust on Canadian and Swedish clones

The Canadian clones planted on the UK sites were much more lightly infected with rust than their UK and Swedish counterparts. This suggests that the European pathotype populations were not well adapted for infecting the Canadian clones, which are readily infected in North America. The evidence indicated that Swedish rust populations are similar to those in the UK.

Rust species

Until recently, the most prevalent leaf-infecting rusts in the UK have belonged to the species *Melampsora epitea*. However, *Melampsora capraearum*, which can infect both leaves and stems, is becoming increasingly prevalent on the willows of *S. caprea* parentage that are becoming popular in biomass plantations.

The stem-infecting pathotype SIF is still largely limited to *S. viminalis* Bowles Hybrid, even though this clone is often grown in close proximity to other *S. viminalis* clones.

Pathotype LET1 was the most prevalent rust form encountered, readily infecting *S. viminalis* and its hybrids. This may prove to be important if future willow breeding programmes rely on *S. viminalis* parentage.

Response of different clones

The relative response of different clones to rust pathotypes was similar between sites. At all three sites, *S. x stipularis*, *S. burjatica* Korso and possibly the Swedish *S. viminalis* 79046 were the most severely infected.

Of the 24 clones, only those from Canada remained either rust-free or only lightly infected.

Rust became more intense on *S. burjatica* Germany during the period of the study, even though the pathotypes involved were the same each year.

Biomass yields

Biomass yields differed from site to site and were greatest at Long Ashton and least at Craibstone. In general, clone ranking with respect to yield was similar between sites and years. With the occasional exceptions, severely infected clones yielded much less than those sustaining little rust infection.

Conclusions

Continued monitoring of rust pathotype populations and changes will aid the detection of sudden or gradual changes in clone rust sensitivity. It may also encourage the anticipation of changes in clonal susceptibility over time.

A REVIEW OF THE STATUS AND CONTROL STRATEGIES OF KNOWN AND PERCEIVED INSECT PESTS ON *SALIX* AND *POPULUS* IN NORTH-WEST EUROPE

The Game Conservancy Trust

Background

At present there is little coherent information on the insect pests potentially affecting short rotation coppice (SRC) plantations. The most comprehensive reviews date back to 1983 and 1986, but these do not make adequate assessments of the status and possible control of the different pest species that are important, given the advances in energy forestry technology since their publication. In addition, clonal choice has dramatically increased and new pests have appeared. As a result, there has been an increase in the damage recorded in existing plantations, both in the UK and elsewhere.

Project Objectives

- To review the literature on the actual and potential insect pests affecting cultivated willow (*Salix*) and poplar (*Populus*) in Northwest Europe.
- To provide a baseline from which an integrated pest management strategy can be developed alongside the willow and poplar SRC industry.

Methodology

A computer literature search was undertaken to locate studies on the insect pests of cultivated willows and poplars using the keywords “insect” and “arthropod” linked with “*Salix*” and “*Populus*”. Additional information based on personal observations and discussions with growers has also been included.

Findings

The database retrieval plus additional searches for more general texts produced 816 reference items. The associated findings are presented under six main headings, corresponding with six groups of poplar and willow insect pests. A further heading examines resistance and control issues.

Coleoptera: Chrysomelid leaf beetles

The insect group that causes most damage to cultivated willows and poplars, particularly SRC, in Northwest Europe comprises 11 main species of Chrysomelid leaf beetle. Of these, the brassy willow beetle appears to be the most significant pest in UK SRC at present. This

and other Chrysomelids have been recorded on most willow and poplar hybrids and at most sites (except for some in Scotland).

The adult Chrysomelid tends to eat holes in willow and/or poplar leaves, or to eat young shoots: the larvae skeletonise the leaves. Defoliation can be extensive, reducing growth and biomass yield. The adults overwinter in the soil, in the crop or in nearby trees and bushes. They emerge in the spring and start feeding before laying their eggs on the undersides of leaves. The larvae hatch and graze on the leaves before pupating in the soil. A few days after pupating, the adults emerge to feed and lay eggs and the cycle is repeated. Chrysomelids may go through two or possibly more generations in one season, and populations build up over several years.

Although Chrysomelids can be controlled using an insecticide, this is unlikely to be economically acceptable. Natural controls involving parasitic and predaceous insects on Chrysomelid eggs and larvae can significantly reduce the incidence of this pest, while most of the insectivorous song birds that live in or near SRC will eat adult and larval Chrysomelid beetles.

Coleoptera: beetles other than Chrysomelids

This group comprises mainly wood borers that tunnel into the roots, stems or shoots of poplar and willow. Those most often encountered in UK plantations of cultivated willow and poplar are the small and large poplar longhorn beetles (*Saperda populnea* and *S. carcharias*) and the osier weevil (*Cryptorhynchus lapathi*). The longhorn beetles bore into stems and stools, causing breakages and creating entry sites for disease. The osier weevil bores galleries in willows and can kill stools.

Chemical control can be effective when applications are matched with adult emergence. Natural enemies can also play an important role, with parasitic and predatory insects and birds being the main natural control species.

Lepidoptera: butterfly and moth larvae

Almost all moth larvae in the UK feed on *Salix*. They cause damage by defoliation or by boring into stems, roots and shoots. Adult Lepidoptera are typically short-lived but active, and may lay hundreds of eggs in a week. Some have two or three generations per year.

There is considerable evidence for clonal resistance or susceptibility based on the chemical composition of different species and hybrids. Poplar trees appear to have distinct defence mechanisms against various insect species, making it impossible at present to find a clone that is resistant to all the insect pests. Certain willows are attractive to certain Lepidoptera: others have an antibiotic effect.

Lepidoptera populations can be effectively suppressed by parasitic and predatory insects. Predation by songbirds - and even by owls and mice - can also have a significant effect, while viral diseases appear to offer potential for biological control in the future.

Hemiptera: plant bugs and spiders

The main Hemipteran pests of willow and poplar in Northwest Europe are aphids, plus some scales and plant bugs. Most suck the sap from growing shoots, extracting nutrients, interrupting the flow of sap and creating cracks and holes. The large or giant willow aphid (*Pterochlorus salignus*) and the black willow aphid (*Pterocomma salicis*) occur widely as colonies on the stems and shoots of willow SRC plantations throughout the UK. Damage is difficult to quantify, but stems are easily weakened, causing growth loss and, in extreme cases, dieback. The damage also provides entry sites for invading organisms that can kill stems or whole trees.

Female aphids may produce ten or more generations per year. Natural enemies include ladybirds and parasitic wasps, and mixed plantings can minimise the effects of infestation.

Diptera: midges

Midges that gall or mine leaves, young shoots and buds can cause significant damage to willow and, to a lesser extent, poplar. Gall midges that damage shoot tips are the most damaging pests, and only small numbers are required to cause economic damage. Some midge larvae gall shoot buds, killing them and damaging subsequent shoot growth. Others gall leaves, causing leaf edge rolling, thereby reducing effective leaf area and growth.

Midges can have many generations in one year, so populations can build up rapidly. Insectivorous birds and parasitic insects may act as natural controls by attacking the larvae inside the gall.

Hymenoptera: sawflies

Although not widely reported as pests in SRC willow and poplar in Europe, defoliating and galling sawflies can be found in plantations in the UK and are noted as pests in general forestry texts. They may become a more widespread pest as larval defoliators and gallers.

Resistance and control

Willow and poplar hybrids range from highly susceptible to insect attack to completely resistant. The chemical composition of the leaves is the main factor influencing resistance to Chrysomelids, although the processes involved is not fully understood.

The most practical approach to control combines natural control with resistance breeding and the selective use of mechanical and chemical controls. Research into natural control mechanisms is under way, the aim being to provide practical management steps that can be implemented to encourage the colonisation of SRC plantations by beneficial species. Such steps are likely to include the introduction of beneficial plant communities within and around the crop: where these include shrubs, hedgerows and trees in addition to ground flora communities, they will improve the wildlife and landscape value of the crop.

POTENTIAL FOR BIOCONTROL OF WILLOW RUST WITH THE HYPERPARASITE *SPHAERELLOPSIS FILUM*

Long Ashton Research Station

Background

Rust diseases caused by fungal pathogens of the genus *Melampsora* are one of the most important factors limiting the production of biomass as a renewable energy source from short rotation coppice (SRC) willows. Of the various control options available, potentially the most effective, economic and environmentally sympathetic is the use of *Sphaerellopsis filum*. This is a hyperparasitic fungus that occurs naturally in UK energy coppice and parasitises willow rusts.

Project Objectives

- To quantify the pathogenicity of *Sphaerellopsis* to different pathogenic races of *Melampsora* rust and to characterise the conditions for optimum *Sphaerellopsis* activity.
- To measure the seasonal development of rust and both natural and artificially introduced hyperparasite populations in established willow plantations.
- To acquire a basic knowledge of the hyperparasite's life-cycle, distribution, seasonality and occurrence in willow plantations, and of the mechanism of its antagonism to rust.
- To produce and test an experimental rust biocontrol approach.
- To develop a related simulation model to assess the effectiveness of the hyperparasite in limiting rust progress, to identify gaps in knowledge and to test assumptions about the relationship between willow growth and colonisation by rust and *Sphaerellopsis*.

Methodology

The ecology of introduced and natural *S. filum* populations was studied under controlled environmental conditions and in field plantations containing monoclonal blocks. In most cases two pathosystems were used:

- *Salix viminalis* Bowles Hybrid, with leaves infected by rust pathotypes LET1 of *Melampsora epitea* f. sp. *Larici-epitea typica*, and with leaves and stem infected by the stem-infecting form of rust (SIF).
- *Salix burjatica* Korso, with leaves infected by the LR1 pathotype of *Melampsora epitea* f. sp. *larici-retusae*.

A third pathosystem was used in the field study at Markington:

- *Salix dasyclados* Wimm, with leaves and stems infected by *Melampsora capraearum*.

Findings

Hyperparasite occurrence

The hyperparasite was found to occur naturally on a wide range of *Melampsora* species and pathotypes infecting many willow clones. This suggests that its use as a biocontrol should not restrict the choice of clones that can be grown.

In a mature plantation of *Salix viminalis* Bowles Hybrid infected by the stem-infecting form of rust, *S. filum* occurred as two culturally distinct forms:

- the asexually reproducing organism *S. filum*
- the sexual state, *Eudarluca caricis*.

If *E. caricis* is functional, it would allow sexual recombination to occur, which would increase genetic diversity and allow the hyperparasite to respond rapidly to changes in its habitat. *E. caricis* was not found parasitising leaf-infecting rusts, which suggests that the hyperparasite life cycle can be completed only on those clones that are susceptible to stem-infecting rust. It is possible that the sexual form results from the interaction of two culturally different forms, though this was not specifically investigated.

Environmental requirements

Studies in a controlled environment showed that a dew period of ≥ 6 hours is required for rust to be colonised by *S. filum*, and that this process is efficient at 10-26°C. *S. filum* is therefore active at temperatures below 18°C, the optimum for rust activity. Observations of *S. filum* on grass rusts in a willow plantation in January 1993 and January 1994 indicated that the hyperparasite is tolerant of low temperatures. Since conditions early in the season are more likely to favour the development of *S. filum* than rust, biocontrol can be expected to be effective.

Natural hyperparasite populations

The findings of field experiments can be summarised as follows:

- *S. filum* activity is slowed by removing its sources through harvesting. It also migrates slowly within and between blocks. This suggests that neither annual harvesting nor monoclonal planting will provide the right conditions for effective rust biocontrol. However, these practices did not prevent the hyperparasite from occurring on the subsequent crop nor its eventual extensive development.
- The hyperparasite can only overwinter, and thereby provide sources early in the season, in association with the stem-infecting form of rust.

- The development of *S. filum* throughout the season is encouraged more by stem-infecting rust than by leaf-infecting pathotypes, possibly because water-borne *S. filum* disperses more easily to the stem and leaf midrib, which are attacked by stem-infecting rust, than to the underside of the leaf lamina.
- *S. filum* can spread actively, albeit slowly, from a planting of a clone with stem-infecting rust to one with leaf-infecting pathotypes. Field studies also showed that rust spore production on leaves can be reduced by 50% with a single pycnidium (fruiting body) of *S. filum* in each rust pustule.

These findings suggest that practicable, natural biocontrol can be promoted by planting blocks in which clones susceptible to stem-infecting rust are mixed with clones susceptible to leaf-infecting pathotypes. However, the inclusion of clones that are susceptible to stem-infecting rusts may not be the whole answer as the species *Melampsora capraearum* also infects and overwinters on stems of *Salix x dasyclados* and it, too, is colonised by *S. filum*.

Augmenting natural hyperparasite populations

Experiments using potted willow plants and spore suspensions of *S. filum* in plantings of Bowles Hybrid infected with stem-infecting rust showed that it was possible to augment a low background population level of the hyperparasite. *S. filum* spread slowly from the sources and in an aggregated manner that was consistent with water dispersal. However, the same studies also showed that effective biocontrol is only achieved if the hyperparasite is introduced at numerous points throughout the plantation. Further investigation into practical ways of achieving this is now needed.

Conclusions

Overall, the study showed that there is considerable potential for achieving a significant degree of biological control over rust by exploiting the populations of *S. filum* that occur naturally in mature plantings of coppice willows. However, attention needs to be given to sustaining natural populations of the hyperparasite by encouraging overwintering in stem cankers on clones harbouring these forms of rust. It is also clear that hyperparasite spread will only keep pace with rust development in mixed clonal plantings in which clones susceptible to stem-infecting rusts are planted in intimate mixtures with others. The next step is to carry out a more explicit examination of the spread and development of the hyperparasite in plantings of clonal mixtures that, in themselves, are designed to suppress rust development.

EPIDEMIOLOGY, POPULATION DYNAMICS AND MANAGEMENT OF RUST DISEASES IN WILLOW ENERGY PLANTATIONS

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Background

Diseases and pests are significant factors affecting the successful establishment of willow as a UK arable energy crop. In particular, rust diseases, caused by species of the fungus *Melampsora*, can develop severely in plantations, notably where susceptible clones are grown as monocultural blocks.

The proportion of UK plantings being damaged by rust is increasing, with some previously resistant clones now becoming susceptible. This indicates a significant level of variability in rust populations, which needs to be better understood. Furthermore, because rust fungicides are not used commercially (for economic, practical and environmental reasons), it is important to develop effective alternative methods of control.

Project Objective

- To define practicable methods of suppressing rust based on clonal resistance and cultural and agronomic options.

Methodology

The study monitored naturally occurring UK rust populations, backing up the findings with detailed studies of host/pathogen genetics to gain an understanding of the factors that affect the evolution of these populations. The information was examined in relation to field studies evaluating the use of mixed clone plantations to limit rust development to non-damaging levels.

Findings¹

Forms of rust in UK plantations

The pathotype composition of rust populations varied from region to region, with more pathotypes occurring at sites where there were long-term willow plantings containing a range of willow species and clones than at sites where naturally occurring *Salix cinerea* and *Salix caprea* were predominant.

¹ Recommendations produced as a result of this study are designed to help growers develop an appropriate plantation design. They are published by ETSU as an Agriculture and Forestry Fact Sheet (SRC 14).

Five new pathotypes of *Melampsora epitea*, all in the form species *larici-epitea-typica*, were identified: LET4, LET5, LET6, LET7 and LET8. Evidence suggests that these probably arose as a consequence of genetic exchange within *larici-epitea-typica* during its sexual life-cycle on the larch alternative host. The pathogenicity of LET 1 and LET4, 5, 6, 7 and 8 was confined to *Salix viminalis* and its hybrids. LET1 was predominant, causing severe infection on some of the older biomass clones. Since *S. viminalis* remains an important source in the willow breeding programme, LET1 represents a major challenge to the development of new rust-resistant varieties.

The *larici-retusae* pathotypes LR1 and LR2 are restricted to *S. burjatica* (syn. *S. dasyclados*) clones. LR1 is already responsible for a yield loss of up to 40% in *S. burjatica* Korso. Current findings suggest that LR2 can cause similarly severe attacks in susceptible clones.

The stem-infecting rust form is largely confined to *S. viminalis* Bowles Hybrid, although it also causes slight infection of *S. viminalis* 3106 and 79046. Because this form of rust exists on willow solely as an asexual population, it is likely to evolve more slowly than the sexually reproducing forms and is therefore less likely to pose a serious threat to clones and hybrids that are currently resistant to it.

Melampsora capraearum occurred on *S. caprea* and *S. aurita* hybrids and has become increasingly dominant on these. It infects both leaves and stems and, when severe, causes defoliation and stem die-back. Levels of infection varied, with only two of the four study sites experiencing severe infection. Little is yet known of the population biology of *M. capraearum*. This is cause for concern because hybrids of both *Salix* varieties are increasingly finding favour in UK biomass willow plantations.

Genetics

The study has shown that the LET, LR and *larici daphnoides* (LD) pathotypes are genetically different populations, so it is unlikely that new pathotypes that are virulent to both *S. burjatica* and *S. daphnoides*, and to both *S. viminalis* and *S. burjatica* will arise in the foreseeable future.

Within a single form species, many pathotypes hybridise randomly. The *M. epitea* pathotypes incorporate sexual recombination within their life-cycle, and their larch alternate host is widely planted in the UK. As a result, pathotypes of the same genetic population will increase in number. However, this variation in pathogenicity would largely be restricted to the infection of willow clones of the host species and their hybrids.

In crosses made between LET1 and LET4, most of the offspring actively infected the hosts, demonstrating that virulence is dominant over avirulence. This runs contrary to findings with several other rusts in arable crops, where avirulence is dominant.

Inheritance of rust resistance (initial studies)

Crossing *S. Viminalis* Bowles Hybrid with *S. Burjatica* Korso produced less susceptible species. This resistance appears to be polygenically inherited and is therefore likely to be more durable than resistance controlled by single genes.

Molecular characterisation of rust pathotypes

Although it might be possible to apply new molecular technologies to improve the speed and accuracy of population studies, isozyme techniques were found to be of little value. However, RAPD (random amplified DNA polymorphisms) techniques have proved to be a simple, effective and consistent means of examining the molecular profiles of willow rusts. They have already been used to show that the stem-infecting form is distinct from LET1, and they are likely to provide a simpler and quicker technique for identifying the stem-infecting form than conventional pathogenicity testing.

The risks of rust disease

Rust causes serious yield losses in short rotation coppice willow plantations, principally by accelerating the rate of defoliation. Fungicide control is unlikely to be effective because of the need for multiple applications in any one growing season.

The most damaging rust species is *M. epitea*. This causes infection over a broad temperature range, the optimum temperature being 18°C, and a 12-hour leaf wetness period. Such conditions are common in the UK during the summer, and the study has begun to define regional risk criteria based on present knowledge of rust biology, local rust populations and historical meteorological data.

However, the aggression of individual pathotypes - and therefore the degree of yield loss - varies between susceptible clones. At the same time, the study has demonstrated that the aggression of individual pathotypes enables the rust population to respond rapidly to introductions of genetic resistance, ensuring the dominance of the most virulent pathotypes.

Mixed clone plantations

Field experiments showed that mixed clonal plantation designs offered certain advantages:

- a delay in disease onset of 7-10 days
- a lower rate of rust development
- a higher yield than that expected from the individual components.

However, rust control was shown to depend on a sound knowledge of the local rust population and of the provenance of clones available for selection. Careful planting design is also required to ensure that barriers of immune stools are formed between components susceptible to the same rust pathotypes. It is not yet possible to attribute the improved yield performance of mixtures to rust control, although this must have some influence.

**PHENOLOGY AND POPULATION DYNAMICS OF WILLOW BEETLES
(COLEOPTERA: CHRYSOMELIDAE) IN SHORT ROTATION COPPICED
WILLOWS AT LONG ASHTON**

Long Ashton Research Station

Background

The regular coppicing of fast-growing trees such as the *Salix* species produces plant stands that are dominated by young, vigorously growing shoots of uniform age and size. Such monocultures, especially when planted in very large blocks, are prone to the invasion and build-up of herbivore populations that may ultimately give rise to pest epidemics.

Among the commonest ubiquitous pests of coppiced willows in Britain are the leaf-feeding Chrysomelid beetles *Phyllodecta* (= *Phratora*) *vulgatissima* (blue willow beetle), *Phyllodecta vitellinae* (brassy willow beetle) and *Galerucella lineola* (brown willow beetle). Their populations reach epidemic levels in some years, causing considerable defoliation, poor growth and, sometimes, the death of developing shoots. Although appropriate insecticides do exist, their application to willow coppice is technically difficult, probably uneconomic, counterproductive in terms of long-term integrated pest management, and damaging to the environment. Alternative methods of control are needed, and research on the integrated management of such pests must be given a high priority.

Project Objectives

- To determine the life cycle and make an initial study of the population dynamics of the three willow beetles identified above.
- To identify possible key mortality factors and crop-habitat management features that have a potential value for the natural control of these pests.
- To map the UK distribution of this guild of species and to establish, if possible, the geographical variation in life-cycles.

Methodology

Investigations were carried out during 1994/95 in an experimental plantation of short rotation coppiced willows (*Salix viminalis* Bowles Hybrid) at Pearces Farm, Long Ashton. Specific activities included:

- regular sampling of willow rods throughout the year, including a careful search for eggs, larvae and adult beetles

- an extensive survey of hedgerows around the site in February 1995 to identify the overwintering sites of adult beetles
- the use of hibernation trap-bands in autumn 1995 to study the onset of hibernation and the distribution of hibernating beetles in the vicinity of the willow plantation
- the monitoring of adult flight activity each week throughout the year using window traps
- the establishment of pot-grown willows in the field to augment observations of beetle behaviour in spring and autumn
- the use of exclusion cages in summer to estimate the natural mortality of eggs, larvae and pupae (experiment abandoned because of wasp attacks and damage)
- laboratory measurements, under controlled environmental conditions, of the fecundity of adult beetles and the development of eggs, larvae and pupae.

Data on the occurrence of the three species of beetle in different parts of the UK were obtained from the National Chrysomelid Recording Scheme.

The potential effect of insect herbivory on the growth and biomass yield of *S. viminalis* Bowles Hybrid was investigated experimentally by the artificial hand defoliation of pot-grown plants (eight replicates of 27 defoliation treatments (10-90% of leaves removed in June, August or on both occasions) and an undefoliated control.

Findings

Life cycles and phenology

The blue willow beetle (*P. vulgatissima*) was the commonest species at Long Ashton in 1995. There was one generation of beetles during the year. Overwintered adults emerged from hibernation in April and, after a short feeding period, began to breed. Egg-laying took place between early May and late June. Females surviving more than 70 days in laboratory conditions laid an average of 137 eggs/beetle. Larval stages were found from mid-May into July and developed through three instars before pupating. The new generation of adult beetles appeared in July/August and fed until hibernating in the autumn. The total development time from oviposition to adult eclosion was about 65 days (in the laboratory at 15°C).

Hibernating adults were commonly found under moss and loose bark on hedgerow trees and in cracks on fence posts. Some beetles hibernated in the plantation, either on willow stools (mainly in the lesions and cankers caused by stem rust) or on the ground among dead weeds and leaf litter.

The flight dispersal of adult beetles in the autumn from willows to overwintering sites appeared to be fairly localised - largely confined to a radius of about 100m of the willows on which the beetles developed. This suggests that crop management strategies that reduce the

potential for overwintering in and around plantations may help to minimise spring re-invasion and damage. Practical measures might include:

- planting well away from surrounding hedgerows and woodland
- combining the removal of plant debris, prunings and other vegetable rubbish with good weed control
- adequate control of stem rust disease in susceptible willow clones.

Although based on more limited observations, the biology of the brassy willow beetle (*P. vitellinae*) and the brown willow beetle (*G. lineola*) appear to be similar to that of *P. vulgatissima*. However, the literature says that both the former species can have two generations in some years.

Population dynamics

Field sampling revealed several mortality factors affecting the hibernating adults of *P. vulgatissima*. It also indicated a high level of mortality among eggs and larvae during the summer, although the possible causes were not identified. However, the estimated losses associated with these mortalities did not account for the observed difference between the spring and autumn populations of adult beetles recorded in flight traps and hibernation sites. Clearly, longer-term studies are required before a full understanding of population dynamics can be achieved.

Geographical distribution

Biogeographical data suggested that *P. vulgatissima* and *P. vitellinae* were ubiquitous throughout the UK, whereas *G. lineola* was confined to more southerly latitudes. This suggests that crops in some parts of Scotland and northern England may be less at risk of attack by the latter species than crops growing further south.

Biomass yield

The leaf-thinning experiment showed that both early and late defoliation reduced biomass yield, with a strong correlation between level of defoliation and yield loss. There was some evidence to suggest that plants could partially compensate for and recover from early, but not late, defoliation, while the greatest reduction in biomass yield was consistently associated with defoliation at both periods.

Although the study made no attempt to simulate willow beetle damage precisely, the results suggest that moderate or even slight damage could have a significant impact on the biomass productivity of coppiced willows.

AN APPLIED STUDY OF CLONAL RESISTANCE TO WILLOW BEETLE ATTACK IN SRC WILLOWS

Institute of Arable Crops Research - Long Ashton Research Station

Background

In recent years, the defoliation caused by several species of leaf-feeding willow beetle (Coleoptera: Chrysomelidae) has been a serious limiting factor to the economic production of biomass from short rotation coppice willows. The commonest and most widespread of these beetles are *Phyllodecta* (= *Phratora*) *vulgatissima* (blue willow beetle) and *Phyllodecta vitellinae* (brassy willow beetle), although *Galerucella lineola* (brown willow beetle) and *Plagioderma versicolora* (in some countries referred to as the imported willow beetle) may be locally important in some years.

Research in the UK and elsewhere suggests that some *Salix* species and clones are much less susceptible than others to feeding damage by these beetles, and that the various species of beetle differ in their host-plant preferences. The exploitation of clonal “resistance” could be a significant step towards the control of these pests. It would also provide a sound basis for future integrated pest management in short rotation coppice plantations.

Project Objectives

- To quantify and compare the host-plant preferences of three species of adult willow beetle (*P. vulgatissima*, *P. vitellinae* and *Plagioderma versicolora*) in a range of 106 *Salix* clones.
- To classify (or score) the clones for resistance to willow beetle attack.

Methodology

The leaf material used in the experiments came from pot-grown plants propagated from vernalised hardwood cuttings and kept throughout the study in an unheated glasshouse. Beetles were collected during the summer from natural populations and were kept in a controlled environment room until required for experiments. All the feeding tests followed a standard laboratory procedure:

- Leaf discs were cut from young, fully expanded leaves collected from the pot-grown plants. These were placed on moist filter paper in covered plastic Petri-dishes. Each dish contained 12 leaf discs, fastened in place by small pins.
- Ten beetles, kept unfed for 3-4 hours prior to the experiment, were put into each container and left in a controlled environment room for 24 hours.

- The beetles were removed and the leaf discs were mounted on glass microscope slides. The leaf disc area eaten by the beetles was measured.

There were three separate experiments:

1. A comparison of the host-plant preferences of adults from all three beetle species in a “multiple-choice” test using all 106 *Salix* clones.
2. A comparison of the host-plant preferences of male and female *P. vulgatissima* in a multiple-choice test using 12 *Salix* clones.
3. A corroborative examination of the host-plant preferences of adult *P. vulgatissima* in a “no-choice” feeding test using the same 12 *Salix* clones as those used in Experiment 2.

Findings

Host-plant preferences of each beetle species

Experiment 1 gave the following results:

- The three species of willow beetle could readily discriminate between different willows, consistently selecting and eating some clones in preference to others.
- The three species of beetle differed widely in their specific host-plant preferences.

P. vulgatissima preferred single-parent or hybrid clones of *S. aurita*, *S. caprea*, *S. cinerea*, *S. phylicifolia* or *S. viminalis*. Most of the willows rejected were clones of *S. fragilis*, *S. pentandra*, *S. purpurea* and *S. triandra*.

P. vitellinae strongly preferred clones of *S. fragilis*, *S. pentandra* and *S. purpurea*. The least preferred clones included *S. aurita*, *S. alba* and hybrids of *S. caprea*, *S. cinerea*, *S. phylicifolia* and *S. viminalis*.

The clonal preferences of *Pl. versicolor* differed substantially from the above. Many of the tested clones were more or less rejected by this species, with feeding often being confined to two or three willows, especially *S. cinerea*.

- Several of the willows tested appeared to be generally unpalatable and were rejected by all three species. This applied particularly to *S. adenophylla*, *S. miyabeana* and *S. triandra*. These and other unpalatable willows could be of considerable value in plant breeding for broad resistance to willow beetle pests.
- The willows used for the tests varied widely in their susceptibility (or resistance) to these beetle pests.

Host-plant preferences of male and female P. vulgatissima

Experiment 2 indicated that the clonal feeding preferences of male and female *P. vulgatissima* were more or less identical.

Host-plant preferences in “no-choice” feeding tests

Experiment 3 showed that willows unpalatable to *P. vulgatissima* in multiple-choice tests were also rejected by this species when no alternative food was present, thereby confirming the validity of the multiple-choice experiments.

Classification of host-plant susceptibility to willow beetles

The results of Experiment 1 were used to classify the palatability of willow clones on a standardised scale of 1 (most preferred) to 10 (least preferred). This classification was then consolidated into five groups, so that the overall susceptibility (or resistance) of each clone was represented by a single score. Thus willows in Group 1 are very susceptible to at least one species of beetle, while those in Group 5 are more or less resistant to all species of beetle.

Most of the clones currently recommended by the DTI (ETSU) and the Forestry Commission for commercial short rotation coppice planting are in Groups 1 and 2, ie they are susceptible to one or more of the willow beetles tested. They comprise all clones of *S. candida*, *S. sitchensis*, *S. spaethi* and *S. viminalis* and hybrid clones of *S. aurita*, *S. caprea*, *S. cinerea* and *S. viminalis*. Monoclonal and mixed commercial plantings of these particular willows are therefore probably at constant risk of beetle attack, particularly by *P. vulgatissima* and possibly by *G. lineola*.

The remaining four clones on the recommended list(s) are resistant or moderately resistant to all three species of willow beetle (Group 3 or Group 4). These comprise *S. burjatica*, *S. bebbiana* and two very similar *S. triandra* hybrids. These willows are probably the best choice for monoclonal planting. It is not clear how beetle infestations might be affected if these resistant willows are planted in mixed stands with more susceptible clones. Further research is needed.

The findings of this study as they relate to *P. vulgatissima* are probably also relevant to a fourth willow beetle species, *Galerucella lineola*.

4. RELEVANT CASE STUDIES

Report No: ETSU B/W2/00527/REP

Publication date: 1997

MONITORING THE PROGRESS OF NFFO-3 PROJECTS: SHORT ROTATION WILLOW COPPICE - AGRONOMY AND ECONOMICS

Sidney C Banks plc

Background

The EC's implementation of its set-aside programme, requiring arable farmers to set aside, on a rotational basis, 15% of their arable land, had serious implications for many farmers, and Sidney C Banks plc and its subsidiary company, Banks Agriculture, considered a range of possible alternatives, including industrial crops which emerged as strong contenders.

At the same time, prior to the third tranche of the Non-Fossil Fuel Obligation (NFFO) scheme, it was clear that there were companies looking at the possibility of developing biofuelled power stations based round the production of short rotation coppice (SRC).

Sidney C Banks plc therefore linked with South Western Power to act as their sole fuel supplier on projected biofuel wood power stations. Two such stations, at Eye in Suffolk and Cricklade in Wiltshire, were approved under NFFO-3 in December 1994. Willow was chosen as the SRC fuel crop, and recent proposals to grow SRC on set-aside land have been agreed by the EC. Crops will also be eligible for the Woodland Grant Scheme Establishment Grant. There is therefore considerable incentive for growers to establish this crop.

Project Objectives

- To establish a network of SRC growers to produce fuel for a NFFO project.
- To monitor the success of the enterprise.
- To implement a programme of constant improvement to optimise the fuel supply strategy.
- To provide valuable information about the performance of the SRC crop under large-scale commercial production.

Methodology

Commercial-scale trials were established at seven sites in the East of England - in Bedfordshire, Suffolk, Norfolk and Northamptonshire - in 1994 and 1995. The farmers approached were all innovative farmers, who recognised the potential of SRC as a new crop and were curious to see how it grew. The sites encompassed a wide range of soil types, altitude and climate, and included reclaimed gravel pits and flint quarries on the basis that future growers were more likely to plant on poorer land, thereby improving its fertility and/or

drainage and increasing its profitability. The trials examined the whole range of production and supply issues and also assessed the environmental implications of SRC growth.

Prior to the NFFO-3 awards, Banks Agriculture actively recruited potential SRC growers in those areas where wood-burning power stations were expected to be built. Details of all interested parties were taken, and “Letters of Intent” to grow and supply SRC to Banks Agriculture were signed and collected. These, in theory, could have been turned into supply contracts once the NFFO-3 contracts had been awarded, and planting could have gone ahead immediately. In practice, no further progress was made in this area up to 1997 because of the current high profitability of arable farming and uncertainty over the building of the power stations at Eye and Cricklade. Growers were actively discouraged from becoming involved because of the volatile/non-existent nature of the wood chip market and the impossibility of guaranteeing any return on the crop.

Findings

The establishment of SRC willow requires a fine seedbed in which to plant the cuttings. Furthermore, a suitable weed control programme is essential and must begin during the autumn prior to planting. Weed control varies with soil type, but is crucial during the first two years of growth, with both the growth rate and the form of the willow being influenced by the level of weeds. By the end of the second year, the willow had outcompeted most of the arable weeds as a result of shading, competition for moisture and nutrients, and willow root growth. However, creeping thistle and nettles were major weeds that did continue to grow.

Plantation yield is heavily influenced by the choice of clone/variety. Decisions on clone suitability cannot be made on the first year’s growth as growth rates and forms vary during the first 2-3 years. However, while a mix of varieties must still be used to reduce disease and insect pressures, new clones have been bred in the UK and Sweden during the last five years, and these either yield better or have better disease and pest resistance than those planted during the Banks Agriculture trials.

Yield is also influenced by the availability of moisture. The lower than average rainfall figures for Eastern England between April 1994 and April 1997, and the correspondingly low soil moisture levels, certainly influenced trial yields overall.

Self-propelled harvesting machines such as the Claas or Austoft proved to be the most reliable chip producers, and harvesting is probably best carried out as a contract operation. However, tractor-mounted forage harvesters are worth considering for those farmers with small areas of SRC who wish to carry out the operation in house.

If a power station is to be fuelled by SRC, it is most appropriate to use a cut-and-chip harvesting system to supply the wood relatively soon after harvest, and stick harvesting for the material that is to be supplied after a significant period of storage.

Transportation and handling costs may account for between 25% and 50% of the total delivered cost of the wood chip. These costs are highest where sticks are delivered to the power station for chipping. The handling costs of direct cut-and-chip systems are far lower

than in stick-harvesting systems: stick bundles are difficult to handle and have a lower bulk density.

Conclusions

Prior to the NFFO-3 contracts, the economics of SRC production were based on plantations of more than 10ha. This scale of operation allowed farmers to use larger machinery for planting, spraying, cut-back and harvesting: it also reduced fencing and labour costs. The current situation is very different for three reasons:

- a lack of interest in developing specialised, modified or purpose-built harvesting and planting machinery because of the lack of a significant SRC market
- the reduction in set-aside levels between 1994 and 1996
- the upturn in the agricultural economic scenario over the same period.

Currently, the SRC plantations being developed are smaller in scale - usually no more than 2ha in size - and the economics of production at this scale have not shown that it is possible to produce cost-effective wood fuel that can displace either fossil fuel or bought-in wood fuel.

Furthermore, high establishment costs and an income-gap of four years between planting and the first harvest mean that SRC is not attractive to the majority of arable farmers in the areas around the NFFO-3 wood burning power stations. There are, however, niche opportunities for coppice-derived wood fuel to replace fossil fuels in small-scale local heating markets.

THE FARM WOOD FUEL AND ENERGY PROJECT

R H and R W Clutton

Background

Short rotation coppice (SRC) comprises closely planted, fast-growing willow and poplar clones. The crop is coppiced one year after planting and is then harvested at intervals of 3-5 years. The harvested product consists of chips, billets or whole stems for use as a renewable fuel source for the generation of both heat and electricity. The crop is a substitute for fossil fuels and, being “carbon dioxide (CO₂) neutral”, can contribute to an overall net reduction in CO₂ emissions at the local, national and global level.

The Farm Wood Fuel and Energy Project was launched in October 1991 as part of the UK Government’s strategy to develop potential sources of renewable energy. Its specific aim was to break the “no market, no crop - no crop, no market” cycle that existed for SRC.

Project Objectives

- To demonstrate how SRC could be grown as a commercial farm enterprise that was economically attractive and environmentally acceptable.
- To develop and demonstrate energy markets for the SRC crop.

This report summarises the project’s main activities and findings. Report No ETSU B/W2/00199/REP summarises the ADAS findings on crop performance. An environmental monitoring report is currently in preparation.

Methodology

Five sites, plus a sixth reserve site, were selected from a large number of applicants. The sites were located in Cornwall, Devon (2), Somerset, Oxfordshire and Essex, and covered a range of farming systems and soil types.

Ten hectares of SRC were planted at each of the five main sites over a three-year period between 1992 and 1994. Yield assessments were undertaken on the poplar clone Beaupre and the willow clone *dasyclados*. Harvesting trials were carried out by the Forestry Commission and by Aberdeen University. Two storage trials examined the potential for conditioning the crop using cheap, low-volume fans. The growers themselves attempted to penetrate the energy market.

Findings

Crop production and yield

Growers made their own management decisions about how to grow the crop and hence developed different systems, many of which are now considered as “standard” by the industry.

There were wide variations in the productivity of the two clones for which yield assessments were made. The mean for both species was 7 oven dry tonnes per ha per year (odt/ha/year), with actual yields varying from 2 odt/ha/year to 15 odt/ha/year. Yields are expected to increase in subsequent harvesting cycles.

Growth and productivity was found to be affected by a range of factors including site exposure, climate, soil type (reduced yields in shallow soils, shorter crops on gravel outcrops), quality of cuttings, planting method, plant density, weed control (especially control of perennial weeds prior to planting and general weed control during the establishment phase), pest control (rabbits, deer, hares and squirrels all caused some damage) and disease. The highest standards of husbandry were required during the establishment year to ensure maximum productivity in subsequent seasons.

The costs of establishing an unfenced crop are around £1350/ha (exclusive of grant). The provision of rabbit fencing for a 4ha field costs about £2/metre and increases the total cost to around £1750/ha. The growers have already achieved significant savings over early indicative costs by developing the appropriate expertise and techniques. Costs are expected to fall further as the price of cuttings declines.

Harvesting and storage

Harvesting trials, using a range of mechanical harvesters, were undertaken by the Forestry Commission and by Aberdeen University. In the opinion of the growers, none of the systems used was considered to be ideal, and a range of problems was identified:

- the size and weight of the harvesters, which could result in soil compaction, difficulties in negotiating lanes and gateways, and high operating costs
- the inability of non-tracked machines to climb even shallow inclines
- the required size of headland and the associated damage and compaction
- rutting within rows
- transportation from the field.

Some crop areas were harvested by the growers using motor-manual methods (chain saws or clearing saws). These techniques were relatively expensive and, in some cases, regarded as “hard work”, but they may be suitable for the small grower producing for home consumption.

The choice of harvesting technique (direct cut and comminution to the required size (chips or billets) or whole stem harvesting) will depend on the end user’s fuel specification. Growers

preferred whole stem harvesting because the crop can be left to dry naturally with the minimum of dry matter loss. They also recognised that double handling would increase costs. Storage trials showed that it was equally effective to “blow” or “suck” air through heaps of chips using low-volume fans. However, the degree of air movement is important: where air flow is inadequate, there are problems of heating, dry matter loss and spore production. Billets stored better than chips.

Market development

Initially the growers investigated the formation of farmer co-operatives for supplying energy markets. When this approach proved unsuccessful, they acted as individuals to develop both energy and non-energy markets for their crops.

Despite considerable effort, growers’ attempts to penetrate the energy market were limited. One grower installed a heating plant at his farm; one won an ALTENER contract to develop heating systems in the South-west; and one developed a tractor-mounted SRC planter.

The growers and members of the project team were also involved in the preparation of a national marketing strategy for SRC. This advocated the replacement of fossil fuels equivalent to one million tonnes of oil each year. Although the strategy was not adopted by Government at the time, these activities did result in the creation and development of the trade organisation, British Biogen, which is following up many of the strategy strands developed in the proposed marketing strategy.

The inability of the growers to achieve more in the local heating market was attributed to lack of confidence in the systems and an unwillingness on the part of potential users to forego the convenience of fossil fuels. In addition, the overall price advantage of SRC fuel was too low: combustion units were several times more costly than fossil fuel burners, and the price of oil in the mid-1990s was very low.

Several growers entered bids for electricity generation contracts under NFFO-3 and NFFO-4, but were unsuccessful.

Some non-energy markets were developed for the crops, including cuttings, mulch, chipboard, hurdles and river-bank protection, but these were all small-scale.

Conclusions

- The project has demonstrated that SRC can be grown under normal conditions within a variety of farming systems, with growers developing commercially based, environmentally sound husbandry techniques that have driven down establishment costs.
- The project has shown that wood fuel has the potential to be competitive with fossil fuels.
- The project has been responsible for creating the industry Trade Association and its marketing strategy. It has also been the catalyst for other initiatives, eg improving public awareness.

- Harvesting and storage methodologies need to be re-examined, and methods for capturing a share of the energy market need to be reappraised.

FARM WOOD FUEL AND ENERGY PROJECT - CROP PERFORMANCE MONITORING

ADAS

Background

Details of the project background are provided above in Report No: ETSU B/W2/00197/REP. ADAS was retained to provide assistance in selecting the five project sites, to monitor and record growers' activities in the production of short rotation coppice (SRC), and to observe the progress of crops in the field.

Project Objectives

- To demonstrate how SRC could be grown as a commercial farm enterprise that was economically attractive and environmentally acceptable.
- To develop and demonstrate energy markets for the SRC crop.

This report summarises the ADAS findings on crop performance. Report No: ETSU B/W2/00197/REP summarises the project's main activities and findings.

Methodology

Thirteen short-listed sites were visited, and five were selected on the basis of criteria agreed between all the parties involved in the project, including ADAS. These criteria were strongly influenced by the need for the sites to be demonstration farms. The sites chosen were ideal in terms of grower interest, location, access, variation in farm type, soil and climate, and opportunities for different types of market development. At the same time they were atypical of farming businesses in their locality. As a result, instead of using the five farms to monitor the impact of SRC on whole farm business, effects were modelled for several farm types.

ADAS monitored and recorded growers' activities in the production of SRC and regularly observed the progress of crops in the field.

ADAS recorded all items of income and expenditure and assessed the contribution of SRC to farm profit. Figures derived from the project sites were applied to typical farm enterprises in the modelling exercise referred to above.

Findings

Agronomy

Although the project has shown that SRC can be grown on a commercial scale within the South of England, the likely yield performance of the crop would at best have been marginal. There were several contributory factors:

- The crop was largely grown on a trial and error basis, and not enough was known about important aspects of crop husbandry at the outset.
- Water and nutrient levels can have a significant impact on production levels, and growing SRC on marginal sites with inadequate resources can result in uneconomic yields.
- The growers seemed to lack any economic motivation to produce viable crops.

Several agronomic lessons were learned:

- Considerable attention must be paid to detail at the establishment stage.
- On vulnerable sites, the crop must be protected from rabbits.
- The crop remains vulnerable to worsening pest and disease attacks.
- The advantages of cutting back poplar after Year 1 appear to be heavily outweighed by the disadvantages.
- Willow outperformed poplar in the longer term and, with the development of more and better clones, willow may become the more favoured species for SRC production.
- Mechanisation can give cost savings, but the opportunities are limited and are vulnerable to weather conditions.
- The economics of producing cuttings from extensive field systems is dubious.

Overall, there is a need to develop site/clone interaction and improve general husbandry techniques.

Project site economics

The project provided no information on harvested yield or price. There was no proper harvesting operation to give useful yield estimates. No sustainable markets were developed for the product.

Differing levels of support for agricultural enterprises and SRC mean that the latter does not compete, in economic terms, with mainstream enterprises. It does compete on set-aside land

because the options are more limited. However, the reduction in the set-aside figure from 17.5% to 10% in 1995/96 and to 5% in 1996/97 is encouraging farmers to think that set-aside will remain at low levels in the future. They are therefore wary of planting long-term crops with a limited potential, eg SRC, on set-aside land.

A farm-gate value for wood chips of £35-£40/oven dried tonne (odt) would, over the life of the crop, give a gross margin of about £100/ha/year.

Crop establishment costs fell by £568/ha over the three plantings. Spread over a potential eight harvests or 24 production years, this would increase the gross margin by £24/ha/year.

The crop integrates well with other farm enterprises in terms of labour and machinery use. Fixed cost requirements are low as the main operations are carried out by contractor.

Grant aid

All project sites received the maximum grant aid available to them at the time. This had a considerable influence on choice of enterprise size but did not necessarily coincide with the most effective use of the land or the most economic size of enterprise.

Whole farm economics

At current yield and price expectations (12 odt/ha/year and £38/odt), farmers growing SRC on mixed farms will normally have their income reduced. This is also true for the dairy farmer and the typical lowland cattle and sheep farmer growing SRC on arable land that is peripheral to the main enterprise, although the crop could relieve farmers of the management problems associated with cereals as a minor enterprise.

Cereal farms and general cropping farms, which tend to carry some livestock at low levels of intensity, might opt to minimise the livestock enterprise in favour of SRC, although this would also take some land out of arable production.

The future of SRC depends on the availability of a market with long-term price guarantees of at least £45/tonne. It will be influenced by changes in arable margins, and the medium-to-large-scale arable farmer's perceptions of future set-aside rates. Farmers may also find it more appropriate to spread the risk, increase flexibility and maximise opportunities by growing SRC in conjunction with other biomass enterprises.

Farm diversification

Contrary to expectations, energy coppice does not seem to provide multiple land use opportunities, other than sporting, that can be widely exploited.