METSÄNTUTKIMUSLAITOKSEN
TIEDONANTOJA 304

PROCEEDINGS OF THE

IEA TASK II MEETING AND WORKSHOPS ON CELL CULTURE AND COPPICING

IN OULU, FINLAND,
AUGUST 24-29, 1987

EDITED BY ARI FERM

KANNUS 1988

INTERNATIONAL ENERGY AGENCY
THE IMPLEMENTING AGREEMENT

The purpose of the cooperation under the Implementing Agreement is to establish increased programme and project cooperation between the participants in the field of Bioenergy. Bioenergy is defined as the production, the conversion and the use of material which is directly or indirectly produced by photosynthesis (including organic waste) to manufacture fuels and substitutes for petrochemical and other energy intensive products.

At the end of 1987 twelve countries had signed the Implementing Agreement on Bioenergy: Austria, Belgium, Canada, Denmark, Finland, Ireland, Japan, New Zealand, Norway, Sweden, United Kingdom and United States.

The Implementing Agreement has three Annex Tasks, which are in progress during the period 1986-1988. They have the following titles

Task II Improvement of Biomass Growth and Production Technology in Short Rotation Forestry for Energy

Task III Development of Improved Methods for Harvesting, Processing and Transport of Forest Biomass for Energy from Conventional Forests

Task IV Improvement of Methods for Converting Biomass Feedstocks into Usable Energy Forms

Keski-Pohjanmaan Kirjapaino Oy 1988

METSÄNTUTKIMUSLAITOKSEN
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(BULLETINS OF FINNISH FOREST RESEARCH INSTITUTE)

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PREFACE

The cooperation in the field of Energy Forestry under the auspices of the International Energy Agency (IEA) started in 1978. The objective was to develop a programme of voluntary cooperation and coordination in the planning and execution of national R & D programmes. The first phase of this cooperation was terminated in March 1986, and a new Implementing Agreement for the years 1986 - 1988 was signed in April of the same year. One of the three new tasks (Task II) was "Improvement of Biomass Growth and Production Technology in Short Rotation Forestry for Energy". This task has ten activities.

Between 24th and 29th of August, 1987 the workshops of the following activities of IEA Bioenergy Agreement Task II took place in Oulu, Finland: Cell, Protoplast and Tissue Culture of Short Rotation Species (Cell Culture), Developing the Coppicing Potential of Selected Hardwoods (Coppice), Production Technology, and Evaluation of Alnus Species and Hybrids (Alder Evaluation). The Technical Advisory Committee (TAC) for Task II had also a briefing session. Two study tours were arranged: 1) In the vicinity of Oulu to become acquainted with harvesting and utilizing energy wood from existing forests and, 2) In South Finland to visit study areas of short rotation forestry and to see some results of the studies on forest tree breeding.

The papers presented at the aforementioned workshops are included in this publication. On behalf of the Finnish Forest Research Institute I wish to thank the authors of the papers and the Ministry of Agriculture of Forestry, the University of Oulu, City of Oulu, Kemira Oy, the Foundation for Forest Tree Breeding and Imatran Voima Oy for valuable support in the arrangements of the meetings and excursions. Special thanks are due to the local organizers, especially the personnel of Kannus Research Station and Department of Botany.

Eero Paavilainen
Professor
The Finnish Forest Research Institute

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Programme

IEA/BA - TASK II, Meeting and Workshops in Finland, August 24-29, 1987

CELL CULTURE WORKSHOP

Sunday, 23. Aug.	Arrival and accomodation in Hotel Cumulus, Oulu
Monday, 24. Aug.	Breakfast in hotel
8.30	Bus transportation from hotel to University
8.45	Registration, mounting of posters
9.30	Opening of the meeting Prof. S. Kupila-Ahvenniemi, L. Zsuffa
	Session I, Modelling biomass production (Moderator V. Koski)
9.45	P. Pelkonen Annual rhythm as a component of frost resistance an productivity
10.30	Coffee break, preparation of posters
11.15	E. Vapaavuori Effects of environmental factors on photosynthesis in willo
12.15	Lunch at University
13.15	Demonstration of posters
14.00	Coffee break
14.30	Visit to Department of Botany, laboratories, and in case c nice weather botanical garden
17.00	The bus leaves for hotel
	Evening free
Tuesday, 25. Aug.	Breakfast in hotel
8.30	Bus transportation from hotel to University
	Session II, Cloning of high yeilding genotypes (Moderator S. Kupila-Ahvenniemi)
9.00	L. Ryynänen Achievements and perspectives with birch
9.45	Coffee break, posters
10.15	W.M. Cheliak Achievements and perspectives with poplar
11.15	T. Eriksson Achievements and perspectives with willow
	I. Lumme Experiments with inoculated ectomycorrhiza on *Salix*
12.15	Lunch at University

Session III, Hormonal regulation and genetic engineering
(Moderator W.M. Cheliak)

13.15 W.M. Cheliak

14.15 Coffee break

14.45 Voluntary reports, general discussion

16.00 The bus leaves for hotel

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Leisure time

20.00 Reception, provided by the City of Oulu

COPPICE WORKSHOP

Wednesday, 26. Aug.

8.15 Departure from Hotel Cumulus

8.30 Registration

9.00 Opening of the workshop
Prof. Eero Paavilainen

9.05 A. Ferm
Coppicing research in the member countries of IEA Coppicing Activity

9.30 D. Auclair
French working party on coppice
\- update

10.00 Coffee break, mounting of posters

10.30 L. Wright
Are increased yields in coppice systems a myth?

11.00 T. Bowersox
Second rotation growth and yields of *Populus*

11.30 C. Booth
Coppicing research in UK

12.00 Lunch, presentation of posters

13.30 I. Lumme
Improvement of biomass production in fast growing willows on mined peatlands in northern Finland

14.00 P. Pelkonen
Overwintering and coppicing potential of willow clones

14.30 Coffee break

14.45 A. Viherä-Aarnio
Coppicing ability of *Salix* clones and hybrids and its utilization in breeding for biomass production

15.15 W. Dawson
Biomass from short-rotation coppice willow

15.45 B. Hathaway
Short-rotation forestry research in New Zealand

16.30 Discussion, plans for future work

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17.00	Introduction to University of Oulu (with slides)
17.30	Visit to Energy Laboratory (of University of Oulu)
18.00	Sightseeing in Oulu
19.00	Return to Hotel Cumulus

PRODUCTION TECHNOLOGY WORKSHOP

Wednesday, 26. Aug., pm

I. Introduction of national representatives and other interested parties

II. Overview of activity's objectives by activity leader

III. Interim progress reports by participating countries (20-30 min. each)
- Canada, Sweden, U.K., U.S.A.
- voluntary reports

IV. Open discussion on needed R & D efforts towards activity objectives. Specific items to be discussed:
1. Form of resulting handbook
2. Responsibilities for parts of handbook

V. Closing summary by activity leader

ALDER EVALUATION WORKSHOP

Friday, 28. Aug., am

I. Introduction and welcome

II. Review of activity outline

III. Participant reports on results of greenhouse/nursery evaluation phase and other alder work:
1. Belgium
2. Canada
3. U.K.
4. U.S.A.

IV. Alder reports from other interested countries and individuals

V. Discussion of field study plan

VI. Discussion of further testing

VII. Plans for *Alnus* symposium in 1988 - location, timing, participants, content, output

VIII. Concluding summary

TECHNICAL ADVISORY COMMITTEE, Briefing Session

Friday, 28. Aug., pm

I. Introduction

II. Information exchange on national programmes

III. Operating agent briefing on progress in activities

IV. Other business

V. Next meeting

STUDY TOUR I

Thursday, 27. Aug.

7.30 Departure from Hotel Cumulus, Oulu

8.30 Visit to Muhos Research Station
- Introduction to the Finnish Forest Research Institute by station head Jukka Valtanen

9.00 Commercial fuelwood harvesting from softwood and hardwood stands; Juhani Mahosenaho, Forest Research Institute

11.00 Lunch in Muhos hosted by local banks

12.00 Tour of the district heating plant; Aarne Karjalainen, town engineer

"Economics and regional variation in energy use of wood in Finland"; presentation by Tapio Hankala, Forest Research Insitute, Department of Forest Economics

14.00 Peat as an indigenous energy source; Pentti Haataja, Vapo Oy

Energy wood plantation on a cut-away peat bog in Hirvineva, Liminka; Ilari Lumme, Research Institute of Norhern Finland

16.00 Return to Hotel Cumulus

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18.30 Bus leaves for Peuhu, Oulunsalo (20 km)

19.00 Banquet provided by Ministry of Agriculture and Forestry (dinner, sauna)

STUDY TOUR II

Saturday, 29. Aug.

8.15 Departure from Hotel Hesperia (Helsinki)

9.15 Visit to the Alko Oy factory in Rajamäki, coffee

Use of industrial sludge in a willow plantation in Rajamäki; J. Hytönen, Finnish Forest Research Institute

10.30 Birch progeny trials in Röykkä; R. Hagqvist, Foundation for Forest Tree Breeding

11.30 Visit to Forest Tree Breeding Centre in Haapastensyrjä, flowering of birch, seed production of birch in plastic greenhouse, flower induction on conifers; R. Hagqvist

13.00 Lunch hosted by Kemira Oy (Nummela)

14.15 Micropropagation and clonal multiplication of trees; T. Törmälä, Kemira Oy (Kotkanniemi Experimental Estate)

16.00 Willow clonal tests; E. Jaatinen, Imatran Voima Oy

Dinner/sauna hosted by Imatran Voima Oy (Kopparnäs, Inkoo)

LIST OF THE PARTICIPANTS

Canada

Brian Barkley
Beth Beatson
W.M. Cheliak
Robert Gambles
Cecile Grander
J. Peter Hall
M. Hubbes
Louis Zsuffa

France

Daniel Auclair

Ireland

W.M. Dawson
Gerry McNally
Michael Neenan
Charles Shier
Dudley Stewart

New Zealand

Bob Hathaway

Sweden

Tage Eriksson
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Todd Bowersox
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John Ferrell
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Maija Salonen
Hanna-Leena Tela
Merja Tyynismaa
Christina Tigerstedt
Elina Vapaavuori
Anneli Viherä-Aarnio

Study Tour I:

Finland

Tapio Hankala
Juha Nurmi

Study Tour II:

Sweden

Gunnar Nilsson

UK

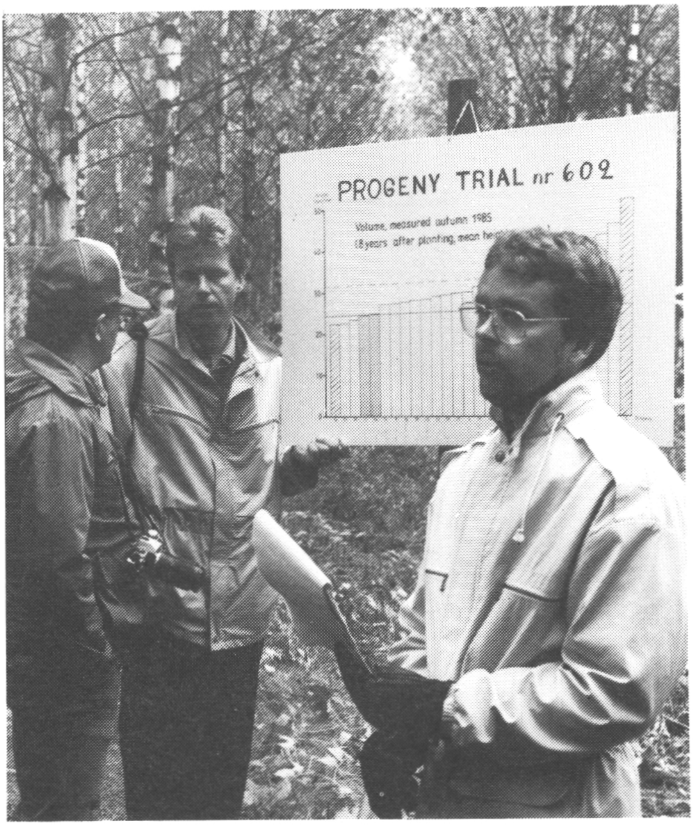
Ken Stott

Finland

Risto Hagqvist
Esko Jaatinen
Terttu Saarikko
Martti Seppälä
Timo Törmälä

Commercial fuelwood harvesting (above) and willow plantation on a cutover peat bog (below) were among the most interesting items in Study tour I.

Photos: Erkki Oksanen



Progeny trials of birch (left) and willow plantation fertilized with industrial sludge (below) were visited in Study tour II.

Photos: Erkki Oksanen

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POTENTIAL OF BIOTECHNOLOGY IN ENERGY FORESTRY

ABSTRACT

The status and potential of the biotechnologies relevant to energy forestry production is briefly discussed.

INTRODUCTION

The concept of forest biomass energy emerged rapidly after the energy crisis in the early 1970´s. Most often energy forestry is based on short rotation management. Intensively managed energy forests are still mainly in the experimental phase.

The basic aim in short rotation forestry programs is to produce biomass primarily for energy at a competitive price. Usually the most significant single factor affecting the economics of energy forestry is the annual net primary production, specifically the above ground woody biomass.

Traditionally, selection and breeding has been used to improve the biomass production of cultivated trees. The results have been very impressive especially in some clonally propagated species such as Salix sp. in Sweden and Eucalyptus sp. in Brazil (Sirén 1983)

More recently biotechnological tools have been applied to to trees that can be used in short rotation forestry (e.g. Bajaj 1986, Bonga & Durzan 1987). The practical application of biotechnology to short rotation forestry is presently in its initial stages. This article describes briefly the biotechnologies that can be employed in developing more productive short rotation systems.

MICROPROPAGATION

Process

Micropropagation is a relatively novel method for vegetative mass production of plants. It was first applied commercially with orchids, but in the 1980´s the scope of micropropagation has expanded to a wide variety of ornamental and foliage plants.

Micropropagation is a multistep process, which begins with the selection of the mother plant (George & Sherrington 1984). This is a crucial step since the plantlets produced will be identical copies of the mother plant.

Most commonly, apical and/or axillary buds are excised from the mother plant. This material must be free of fungi and bacteria that can grow on the nutrients used to grow the plant tissues. To avoid microbial contaminants the explant is surface sterilized (e.g. with ethanol or sodium hypochlorite). The original explant is then transferred to an initiation medium. The basic medium used in micropropagation as well as in other types of plant cell and tissue culture consists of mineral nutrients, vitamins and amino acids. Sugar is provided for energy and carbon source and medium is usually solified with agar.
The growth of the tissue is primarily controlled by plant growth regulating compounds.

In a few weeks a shoot or several shoots emerge from the original explant. These are transferred aseptically onto multiplication medium. Usually, the group of plant growth regulators known as the cytokinins are used in the medium to induce multiple shoot formation. After 4 to 8 weeks incubation (e.g. temperature ca. +25 °C , 1 500 - 3 000 lux light intensity, 16 hours light, 8 hours dark cycle) the new shoots (or nodal segments) are separated and transferred onto fresh multiplication medium. The multiplication factor during each culturing cycle generally varies between 3 and 10. Thus the number of shoots increases expotentially and a large number of plants (millions) can be produced from a single mother plant in a year.

When the desired number of shoots is produced, or the production schedule requires, the shoots are placed on a medium where rooting is induced, generally by the group of plant growth regulators known as the auxins. After root induction (2 - 6 weeks), the plantlets are transferred to soil. The transition from the sterile high humidity in vitro environment to harsher greenhouse conditions is the most critical step of the micropropagation process. The photosynthetic activity of the plants has been neglible in culture. The assimilition and photosynthetic activity and control of transipiration is achieved by a gradual decrease in humidity and increase in light intensity.

After the acclimatization period, the plants are grown as conventional plants in greenhouse nursery.

Application of micropropagation in energy forestry

The ultimate application of micropropagation to forestry is mass propagation of elite, highly productive genotypes for planting in the field. Currently, the micropropagation of forest trees is still in the experimental or pilot phase (Durzan & Bonga 1987). Probably closest the practice is radiata pine in New Zealand (Bajaj 1985).

It is not likely that micropropagation would be widely applied in the foreseeable future to species which produce high quality seed or which can be easily propagated vegetatively by cuttings. This is due to economic reasons, especially considering the low unit price of the harvested wood for energy production as compared to wood for timber or paper production. The situation may be different in species that grow fast and can not be readily propagated conventionally.

In energy forestry programs micropropagation is presently widely used as a rapid propagation method in breeding and selection projects (e.g. Lumme & Törmälä 1987).

It is also possible to screen material from breeding programs in the laboratory using micropropagated in vitro plantlets. A prerequisite for laboratory selection is that the selection criteria is reliable in the laboratory enviroment. Such traits may include cold tolerance, tolerance against salinity or herbicides. Generally, no clear relationships between in vitro growth and the actual biomass production in the field has been established. The advantages of in vitro screening induce increased accuracy under controlled conditions, reduced testing times and reduced costs.

CELL CULTURE TECHNIQUES IN GENETIC IMPROVEMENT

Somaclonal variation

An explant derived from almost any plant organ can be induced to form unorganized tissue (callus) on a proper culture medium (usually with an auxin). Callus can be subcultured over extended periods either on semisolid (agar based) or in liquid medium. When a culture in liquid medium is shaken it grows as a suspension of single cells or clumps of several cells.

In many species callus can be regenerated into plants. There are two physiological routes of regeneration: organogenesis and embryogenesis. In organogenesis shoots and roots are induced seperately mainly by manipulating the auxin: cytokinin ratios of the media. In embryogenesis structures similar to embryos of the seed are induced. The structures that originate from somatic cells are called embryoids and in many species they germinate like embryos of seeds.

As more data accumulated, it became obvious that some of the plants regenerated from callus deviated genetically from original mother plants. The phenomenon is called somaclonal variation. The changes in the genome range from point mutations to chromosomal aberrations. The mechanism behind somaclonal variation is random (similar to mutations to induced by chemicals or radiation) and to utilizing it one must have an effective selection system. Somaclonal variation as well as mutagenesis has the greatest potential, when the selection can be done in vitro. Traits that have been obtained thorugh somaclonal variation and mutagenesis include disease, herbicide and salt tolerance (Kochba et al. 1982, Vardi et al. 1986).

Protoplast techniques

The walls of plant cells can be digested enzymatically. The cells surrounded only by the cell membrane are called protoplasts. Protoplasts can be maintained for a limited period of time in osmotically regulated medium. In many species cell wall regeneration and cell division process can be induced and whole plants can be regenrated after a callus phase.

Protoplasts are an important tool in genetic improvement of plants. Foreign genes can be transfered into them. Protoplasts can also be mutated to increase the amount of variations in addition to somaclonal variation. One of the main advantages of protoplast is the high number (ca. 10^6 cells/ml) of individuals (cells) that can be manipulated and selected. Protoplast of sexually incompatible species have been succesfully fused and regenerated into hybrid plants.

Requlation of protoplasts in woody plants has been succesful only sporadically and some years will elapse before practical results can be expected.

Haploid culture

Many tree species are highly heterozygous and the production of pure lines requires an unacceptably long time due to the long generation time. Haploid plants can be induced in many species (including hardwood candidates for energy forestry) by culturing excised anthers, pollen or ovaries (Bajaj 1975). Because of only one set of alleles (also recessive traits) is present including any spontaneous variants or induced mutants there are no hidden traits.

The haploid chromosome number can be doubled with colchicine resulting in homozygous plants that can be used in breeding new hybrids.

GENETIC ENGINEERING

Genetic engineering of plants is a novel technique. The first gene was transfered in mid 1980´s in tobacco and other members of the Solanaceae family.

Plant tissue (e.g. leaf discs) or protoplasts are most often transformed with Agrobacterium Ti -plasmid vector. Agrobacterium is a soil borne bacterial plant pathogen which infects wounded plant tissues and causes tumors. The plant cells are transformed genetically by Agrobacterium´s Ti-plasmid (DNA), which acts as a natural gene transfer vector. Parts of the DNA of the Agrobacterium plasmid can be replaced by an isolated gene coding the desired traits. In addition to the useful gene the plasmid vector construction contains a selection marker, which enables the identification and selection of cells that have been succesfully genetically engineered. The most common selection member is a gene coding resistance against antibiotics. Then the selection for transformed cells can be conventionally done on a medium with the antibiotic.

The main problems of genetic engineering of trees today are: 1) isolation of useful genes, 2) the actual gene transfer (e.g. the Agrobacterium system does not work routinely with many woody plants) and 3) regeneration of the transformed cells into plants.

Perhaps the most significant achievement in genetic engineering of energy forestry species is the transformation with a gene inducing glyphosate (a broad spectrum herbicide) in poplar (Thomas et al. 1986, Fillatti et al. 1987). The most likely traits to be engineered into the trees include other types of herbicide resistance, insect and disease resistance. All these traits are encoded by one or a few genes.

BENEFICIAL MICRO-ORGANISMS

Many tree species that are candidates for energy forestry live in symbiosis with nitrogen fixing bacteria (e.g. alder and leguminous trees) or/and mycorrhizal fungi (most trees). Selection of effective strains and inoculation of the planting material may be one way of improving the biomass production of energy forestry stands (Linderman 1986).

The growth enhancing effects of microbial inoculation are most likely to occur in sites where the natural microflora is inadequate for efficient infection and establishment of a symbiosis beneficial to the plant.

In a cut over peatland in northern Finland inoculation of willow cuttings with ectomycorrhizae fungi resulted in increased growth of both the roots and shoot during the year of establishment (Lumme & Törmälä 1987). Whether the inoculation is beneficial in subsequent years remains open.

CONCLUSIONS

The applications of biotechnology to energy forestry are just emerging. Only micropropagation methods are presently available to a wide variety of species. Micropropagation will most probably be used as a tool in genetic improvement programs.

The application of cell and tissue culture techniques and genetic will probably be first used for improving the resistance of plants against the stress caused by biotic (pests, diseases) or abiotic (salt tolerance, cold tolerance) factors.

As a whole biotechnologies discussed in this paper must be considered as tools which complements are partially replacing traditional biological methods applied for increasing the productivity of plants.

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SELECTION FOR GLYPHOSATE-TOLERANT CELL CULTURES IN POPLAR

ABSTRACT

Leaf explants, callus tissue and cell suspension of *Populus nigra* x *P. maximowiczii* were consistently induced to form shoots. The effect of glyphosate on growth and organogenesis in callus and cell suspension cultures was established. Glyphosate at 0.35 mM completely suppressed the growth and shoot formation in subcultured callus tissue. In cell suspensions, it reduced the growth rate by 70% compared to control cultures. The cell suspensions constantly growing in the presence of 0.35 and 0.7 mM glyphosate were recovered. The variant cells when cultured on agar solidified, shoot induction medium with glyphosate, maintained vigorous growth, but shoot regeneration was inhibited.

INTRODUCTION

One of the potential benefits of forest biotechnology include modification of genotypes for specific traits such as disease, insect and herbicide resistance. Somaclonal variation has been shown to be a method for creating plant varieties with new phenotypic and genetic properties (Larkin and Scowcroft, 1981, 1983b; Sacristan, 1982; Evans and Sharp, 1983). These properties are induced as a result of passage of plant cells through the tissue culture process. Application of a selection pressure during the culture process allows the growth of only genetically altered cells. The selected cells if allowed to undergo organo/ or embryogenesis may lead to formation of plant with novel characteristics.

Attempts to produce herbicide tolerance using somaclonal variation and in vitro selection have already been made. Chaleff (1980) has reported the selection of several *Nicotiana tabacum* mutants with increased tolerance to picloram, Hughes et al. (1984) generated resistance to paraquat in tobacco cell cultures and partial resistance in plants, Chaleff and Ray (1984) recovered very effective resistance to chlorosulphuron (Glean) and sulphometuron methyl (Oust) in tobacco cell cultures. Most recently Wersuhn et al. (1987) regenerated potato plants with high tolerance to the herbicides SYS 67 ME (MCPA) and OMNIDEL (Na-2,2-dichloropropionate).

Glyphosate (N-(phosphonomethyl) glycine is the active ingredient in a herbicide VISION, recently registered for forestry application in Canada. It has been reported by Amrhein et al. (1980) that glyphosate inhibits 5-enolpyruvylshikimate-3-phosphate synthase (EPSP s thase), thus blocking production of aromatic amino acids. Increased tolerance to glyphosate has been achieved in several plant cell lines and include: *Petunia hybrida* (Stei rucken et al. 1986), *Corydalis sempervirens* (Amrhein et al. 1983), *Daucus carota* (Nafziger e al. 1984) and tomato (Smith et al. 1986). In all these studies it has been shown that the res tance was attributed to overproduction of EPSP synthase by the variant cells.

To date, reported success has been with annual plants. However, in our laboratory, we deal with woody plants. Members of the genus *Populus* are widely used in energy forestr because of their rapid growth and coppicing ability. In a program of advanced genetic modification, such as selection for somaclonal variation, progress is conditional on the response of the species. The prerequisite to the selection of variant cells and subsequentl plants, is the development of tissue culture and plant regeneration procedures for a give species. This involves establishing an adequate tissue culture protocol to perform selectio establishing the lethal dose of a given herbicide on a chosen culture system, and possibly application of mutagenic factors prior to selection to increase the frequency of variant cel formation. This report presents the results on plant regeneration from explants, callus tissue, and cell suspensions of *Populus nigra* x *P. maximowiczii*, and the effect of glyphosate c various tissue culture systems. It also deals with the preliminary attempts to regenerate plants from selected cells.

MATERIALS AND METHODS

Populus nigra x *P. maximowiczii* sterile shoot cultures were established on Murashige and Skoog (1962) (MS) medium. Shoots were subcultured onto fresh growth regulator-free medium every 4-5 weeks. This was done by excision of an apical shoot with 2-3 pairs of leaves and placing it in 100 x 25 mm petri dish with 20 ml of medium. 4-5 week old cultures were used as a source of leaves. The leaves were cut transversely into 3-4 segments and transferred onto MS medium supplemented with auxins and cytokinins, 3% (w/v) sucrose, and 0.7% agar in 100 x 15 mm petri dishes. The cell suspension was initiated by placing 1.5-2.0 g callus tissue into 25 ml of liquid MS medium with 0.5 or 2.0 mg/l 2,4-D and 2% (w/v) sucrose. After the cell suspension cultures were established, subcultures were performed in 7 day intervals. Glyphosate was added to the media as a commercial formulation of isopropylamine salt at 0.035, 0.17, 0.35, 0.52, 0.70, 1.75 and 3.50 mM. The effect of glyphosate on the growth and differentiation of callus tissue was monitored after 3 subcultures. Growth rates of control and glyphosate treated cell suspensions was evaluat by subculturing 1.5 ml packed cell volume (PCV) into 25 ml liquid medium (with or without glyphosate) and harvesting the cells, after 7 days, in centrifuge tubes by spinning at 350 rpm for 4 min..

RESULTS AND DISCUSSION

Leaf explants of *Populus nigra* x *P. maximowiczii* could be manipulated to produce either callus tissue or shoots. The effect of various growth regulators on explant response is summarized in Table 1. Medium with 2,4-dichlorophenoxyacetic acid (2,4-D) (0.5 or 1.0 mg/l) and kinetin (1.0 mg/l) was routinely used to induce formation of green and friable callus, whereas medium with naphthaleneacetic acid (NAA) (0.1 mg/l) and 6-benzylaminopurine (BA) (1 mg/l) consistently induced shoot regeneration. Calli could be maintained on the induction media for a few months but when transferred onto shoot regeneration medium, formation of bud primordia was observed after 6-8 weeks.

Table 1. Poplar leaf explant response on MS medium with various growth regulators after 4 weeks in culture.

Growth regulators (mg/l)	Response
-	100% explants necrotic
0.5 2,4-D	7% explants produced small calli
0.5 2,4-D + 1 kinetin	91% explants produced large, fiable calli
1.0 2,4-D = 1 kinetin	97% explants produced large, fiable calli
0.5 2,4-D + 1 BA	90% explants enlarged with small modular calli on the edges of explants
1 BA	56% explants produced shoot buds
0.1 NAA + 1 BA	73% explants produced shoot buds
0.1 NAA + 5 BA	28% explants produced shoot buds
5 BA	21% explants produced shoot buds

To establish the effect of glyphosate on shoot differentiation, calli pieces of approximately equal size were cultured on media with NAA and BA and various concentrations of glyphosate. Results shown in Table 2 (collected after 3 subcultures) indicated that glyphosate at 0.35 mM completely suppressed calli growth and shoot regeneration, only sporadic green areas were observed on otherwise necrotic tissue. No tolerant calli were recovered from these experiments. The same concentration of glyphosate was also inhibitory to the growth of donor shoots.

Table 2. Glyphosate effect on shoot regeneration from poplar calli cultured on MS + 0.1 mg/l NAA + 1 mg/l BA.

Glyphosate concentration (mM)	Response
0	90-100% calli regenerated shoots
0.035	90% calli regenerated shoots shorter and lighter in colour
0.175	10% calli regenerated shoot primordia lack of elongation
0.35	0% regeneration, sporadic green areas on calli
0.5	0% regeneration, necrosis
0.7	0% regeneration, necrosis
1.75	0% regeneration, necrosis
3.5	0% regeneration, necrosis

The cell suspension, when established on media with 2,4-D, was composed predominantly of cell aggregates of 5-30 cells and, occasionally, single cells. Most cells were elongated and only approximately 10% cells were spherical. These cells when plated onto agar medium with NAA and BA (shoot induction medium) grew into small calli and after 2nd subculture (6-8 weeks), shoot bud regeneration occurred. However, when the cells were precultured in liquid medium with NAA and BA for a few weeks, prior to plating onto agar medium, shoot bud formation occurred after 4 weeks (1 subculture). Cell suspensions growing on medium with NAA and BA had a different morphology. All cells were spherical and aggregated, forming green, compact, nodular structures. Earlier shoot regeneration from precultured cells is possibly due to the lack of carry-over effect of 2,4-D, which in this work (see above) proved to be inhibitory to shoot organogenesis. The 2,4-D suppression of organ differentiation in callus cultures was also reported by Venverloo (1973) for *P. nigra.*

Growth of the cell suspension in presence of 0.35 mM glyphosate was reduced by 70% compared to control (Fig. 1) however after several subcultures into medium with the same glyphosate concentration, the growth rate became comparable to growth rate of control cultures. This could indicate that a selection of possibly variant cells with higher tolerance to glyphosate had occurred. Selection of cells with the ability to grow in the presence of 0.35 mM glyphosate could also be achieved by cell transfer into medium with increasing concentrations of glyphosate as it was reported for *Petunia hybrida* by Steinrucken et al. (1986). Using the same approach, the cells of *P. nigra* x *P. maximowiczii* initially growing in medium with 0.35 mM glyphosate have recently been successfully cultured in the presence

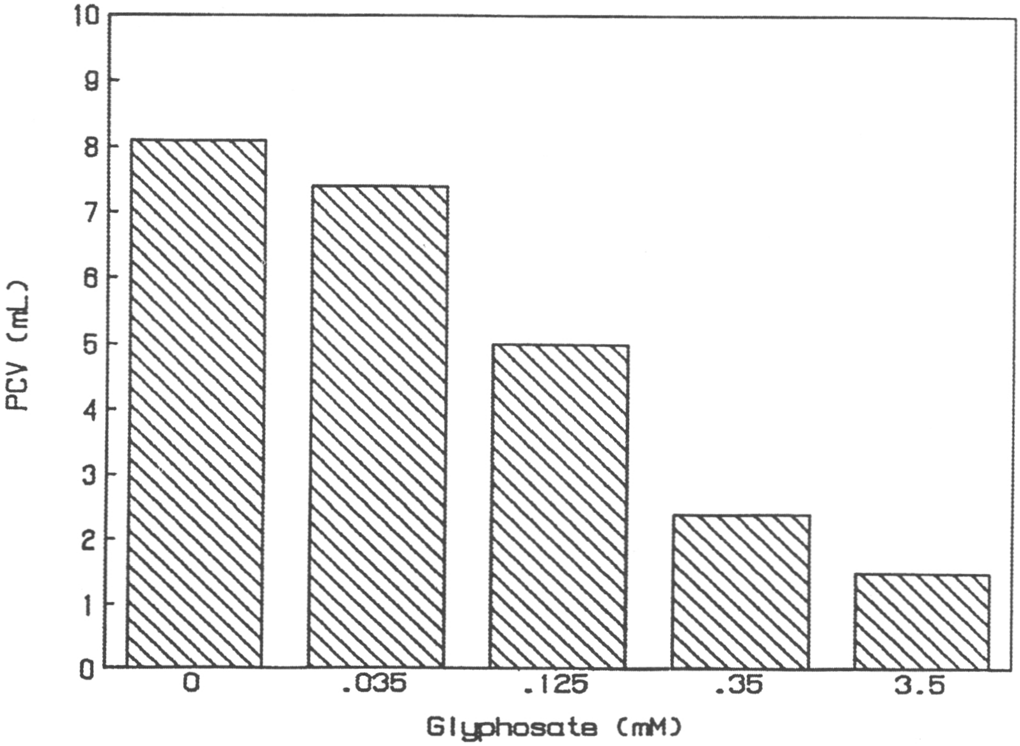

Figure 1. The effect of glyphosate on growth rate of poplar cell suspensions (results shown after 7 days of culture with the initial inoculum of 1.5 ml PCV.

of 0.7 mM glyphosate. Microscopic observation of the cell suspension in glyphosate medi revealed a conspicuous lack of the spherical-shaped cells and the presence of very long cells forming a network of long "filaments". The attempts to regenerate shoots were performed with cell suspensions growing for 8 and 13 weeks on medium with 0.35 mM glyphosate. The cells were plated onto agar shoot induction medium without or with 0.35 mM glyphosate. Calli had the ability of vigorous growth for three subcultures onto glyphosate medium but no shoot regeneration occurred. Moreover, at the end of 3rd subculture, calli started to necrotize. On medium without the herbicide, shoot buds could be detected after 2 subcultures. To provide further evidence that the lack of regeneration wa due to glyphosate, the 4th subculture was done onto glyphosate free medium on which shoot primordia were formed by a few calli after 3 weeks. However, it remains to be seen the regenerated shoots will retain the capacity to grow on medium with glyphosate as the cells did. It has been demonstrated by Smith et al. (1986) that variant tomato cells could regenerate shoots in the absence of glyphosate and, although they were abnormal and failed to root, the tolerance was maintained in differentiated tissues. For further experime tation on selection for glyphosate tolerance only poplar cell suspensions will be used, sinc they are composed of small cellular units in which the cross-feeding effect is much smalle than in callus cultures.

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CLONING OF BETULA PENDULA AND B. PUBESCENS BY MEANS OF TISSUE CULTURE

ABSTRACT

Cloning of adult trees of special form of *Betula pendula* var. *carelica* (Merklin) "curly-birch" was introdused recently. The same method is suitable to normal types and juvenile individuals of *B. pendula*. For *B. pubescens* the method indicated genetic differences between families in *in vitro* redifferentation.

INTRODUCTION

Among broad leaved species *Betula pendula* Roth and *B. pubescens* Ehrh. are commercially most important in Finland. Due to its high combustion value and fast growth at young age birch is a promising alternative for short rotation energy forestry, too. Acquisition of ordinary planting stock is rather easy, because abundant seed crops are frequent, and sufficient amounts of genetically improved seed can be produced in plastic covered seed orchards. Vegetative propagation is, however, preferable in special cases. Some desirable characteristics e.g. "curly-birch" *B. pendula* var. *carelica* (Merklin), are based on a specific gene combination that segregates during sexual reproduction. Suberb triploid genotypes (Sarvas 1958) are practically impossible to reproduce sexually.

Explants from young seedlings of *Betula* spp. can rather easily be made to plantlets (e.g. Chalupa 1981, Simola 1985). Selection for commercially important quality traits is only possible after the juvenile period. Recently a method for micropropagation of mature trees of *Betula pendula* var. *carelica* was developed (Ryynänen and Ryynänen 1986). Later on experiments were continued and extended to *B. pubescens*.

The aim of this paper is to introduce the present version of the method and give preliminary results about *B. pubescens*.

MATERIAL AND METHODS

Vegetative buds were used as explants. Selected trees from three sources formed the basic material. General information is as follows:

Code nr	Site	Age	Remarks
Betula pendula			
E 9165	Green house Punkaharju	5	origin Otesevon, YU
B. pendula var. carelica			
E 8469	Field, Punkaharju	25	cultivated
E 8999	-"-	25	
E 9000	-"-	25	
E 9141	-"-	25	
E 1092	-"-	55	triploid, so-called Olli-birch
B. pubescens			
V 5939	Field test, Somero	10	Controlled crossings between plus trees
V 5940	-"-	10	
V 5941	-"-	10	
V 5942	-"-	10	
V 5943	-"-	10	
V 5944	-"-	10	

Murashige and Skoog's medium, MS (1962) and woody-plant-medium, WPM, (Lloyd and McCown 1980) were used. The procedure for propagating diploid curly-birch and normal birch described in details in the publications by Ryynänen L. & Ryynänen M. 1986

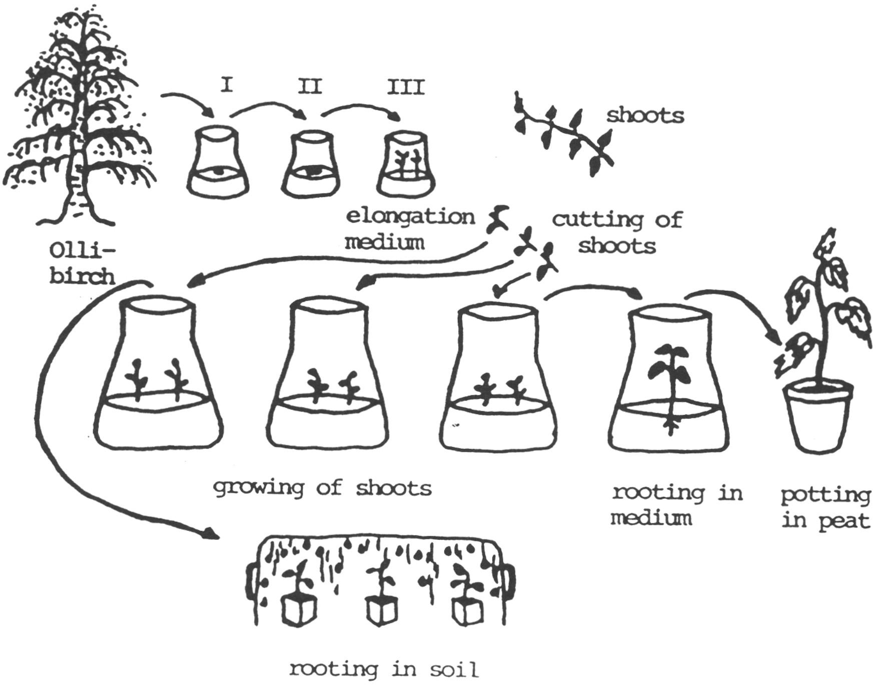

Fig. 1. Propagation of Olli-birch.

and Ryynänen 1987. The prodedure used for propagation of triploid Olli-birch is as follows: from elongation medium used for all curly-birches Olli-birch tissue was transferred to WPM containing 0,5 ppm BAP and 0,2% sucrose and at the same time the shoots were cut into pieces about 0,5 - 1 cm long, each comprising from two to three leaves (Fig. 1). Each piece of shoot gave start to from two to twenty new shoots. While parts of the new shoots were transferred to the rooting treatment, the remaining shoots were again cut and cultured in fresh medium. This gave a continuous supply of new shoots. The rooting of Olli-birch happened after the procedure used for diploid curly-birch (Ryynänen L. & Ryynänen M. 1986) or direct in soil, consisting of two parts of peat and one part of perlite. During rootformation the pots were kept in propagators, containing as high humidity as possible (Fig. 1).

The propagation of B. pubescens was made in MS or in WPM, containing either 0,5 ppm BAP and 0,2% sucrose or 2 ppm BAP and 2% sucrose. The organ initiating medium which was tried with B. pendula was a liquid MS containing 225 ppm BAP. That was dropped on the explants after four weeks of culturing and was allowed to stay there for one week.

RESULTS AND DISCUSSION

Propagation of B. pendula, both "curly-birch" and normal birch succeeded quite well (Table 1.) From the six clones under test plantlets were got from four of them, curly-birches E8999, E9141, and E1092 as well as normal birch E9165. The plantlet yield varied from some plantlets of E 9141 to thousands of E8999. Each started culture of E8469 contaminated very soon after transferring the buds into medium and no regenaration of new buds or shoots was obtained. E9000 stayed alive for some passages, but no plantlets were obtained.

Table 1. Propagation of B. pendula.

	clone	no. of cultures	stages between the start and plantlets	plantlets
B. pendula var. carelica	E8469	30	-	-
"	E8999	23	16 *69%*	10 *43%*
"	E9000	53	32 *60%*	-
"	E9141	57	22 *39%*	1 *2%*
"	E1092 (Olli-birch)	60	28 *47%*	3 *5%*
B. pendula	E9165	8	3 *38%*	3 *38%*

By using the procedure of Ryynänen L. & Ryynänen M. (1986) it was possible to get only a few plantlets from triploid E1092. This problem was solved by changing the medium from MS to WPM and by cutting the shoots into pieces, transferred into WPM. On this medium the shoots grew soon to full length and if they were allowed to stay there from one to two months at the lower end of the shoots there was callus formation, from which new shoots were growing up. The longer the explant was growing in this medium, the higher the number of new shoots was until the nutrients of the medium were finished and the leaves of the shoots turned yellow. This growing of new shoots saved much cutting and transferring work of shoots. (Fig. 2).

In order to shorten the procedure, an experiment was made in which the shoots were transferred from WPM direct into soil for rooting, instead of rooting in vitro. At the same time, as Olli-birch shoots were transferred into rooting medium in vitro part of them, 137 shoots, were transferred into soil for rooting cf. e.g. Chalupa 1974. The pots were kept in propagators and sprayed several times a day in order to keep the relative humidity as high as possible. The shoots rooted in soil, but the rooting happened much more slowly in soil than in vitro (Fig. 3). Because there was no growth chamber with automatic control of humidity in use, the rooting in soil saved neither time nor work. Besides, when rooting in vitro every shoot will root, but when rooting in soil the plantlet yield was lower, only 88 of the shoots rooted, which is 64%.

Fig. 2. Curly-birches made by tissue culture in the nursery. On the left triploid Olli-birch planted in soil in April 1987, next in March 1987 and third in Febryary 1987. On the right diploid E8999 planted in soil in July 1985.

Fig. 3. The picture has been taken two month later than the shoots have been transferred to the next stage for rooting. The day the two plantlets on the left have been potted in soil for rooting is the same as the two on the right have been transferred into the rooting medium in vitro from which the ready plantlets have been potted after two weeks of rooting.

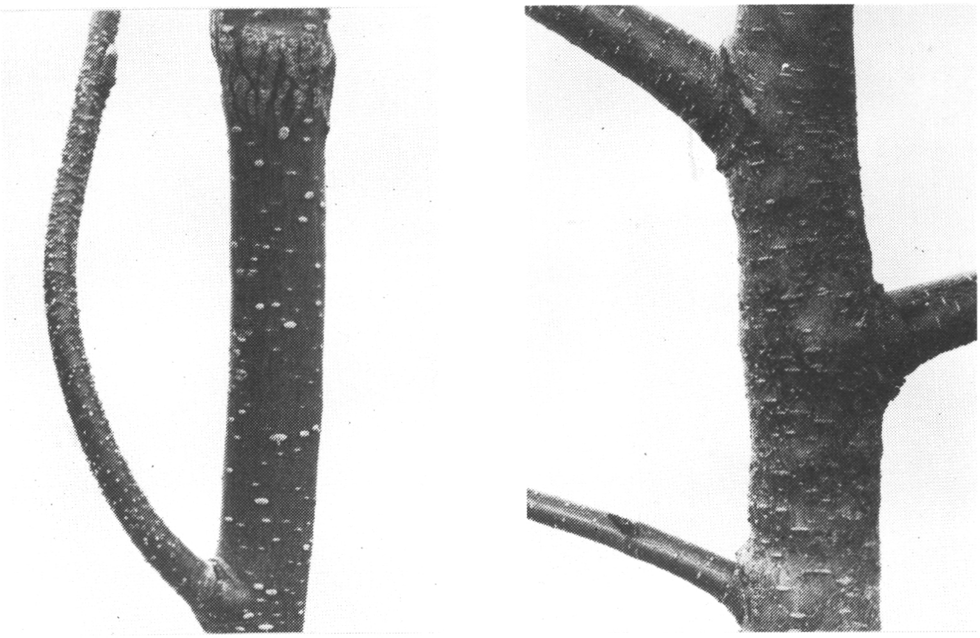

Fig. 4 a and b. Stem of curly-birch plantlets at the end of third growing season. On the left E8999 with a neck, on the right E9141 with protuberances.

When growing seedling of curly-birch it takes about 10 years, until the outer marks, protuberances, necks, stripes and rings of curly-wood can be seen. When growing these plantlets started by tissue culture from adult trees, it was noticed that the marks of curling can be seen at the end of the third growing season (Fig. 4 a and b). So these plantlets are adult rather than juvenile ones.

Because starting cultures from the only *B. pendula*, E9165, in our study was so exceptionally easy, the effect of an organ initiating medium was tested upon explants of four weeks old cf. e.g. Cheng 1975. Anyhow, the only result was that these handled explants died completely during the week they had a connection with organ initiating medium.

Propagation of *B. pubescens* was done according to the same procedure as the others, except that in addition to MS also WPM with 0,5 ppm BAP and 0,2% sucrose was used. Two of the trees, V5939 and V5941 did not redifferentiate in either media and no plantlets were got. Unfortunately all the buds were used with these media and no other cultures could be done. Two of the trees, V5940 and V5944 redifferentiated on both media. Now, of V5940 there are plantlets from four cultures, started in WPM. Of V5944 the corresponding figures are one and three. The cultivation of V5942 and V5943 were started like the others, but the explants died almost immediately. Because there were still buds to be used of these two trees, new cultures were started using WPM2, containing as growth regulator 2 ppm BAP and 2% sucrose. These cultures grew very well in this medium and it was possible to transfer them into the next stage which was the same as with the others. In the next stages the cultures are anyhow dying little by little. The weakest one lived only through one passage, and the strongest ones which are still alive have gone through five passages, but it is envident that no plantlets will be got by this method (Table 2.).

Table 2. Propagation of *B. pubescens*.

♀		♂	plus tree	no. of cultures MS (WPM)	*WPM2*	stages between the start and plantlets	plantlets
E5213	*x*	*E5165*	*V5939*	4 (6)	-	- (-) -	-
E5166	x	E5209	V5940	7 (5)	-	4 (3) -	4 (3) -
E5166	x	E5209	V5941	4 (4)	-	- (-) -	-
E5213	*x*	*E5165*	*V5942*	7 (12)	*10*	- (-) *10*	- (-) -
E5213	*x*	*E5165*	*V5943*	10 (8)	*8*	- (-) *4*	- (-) -
E5166	x	E5209	V5944	6 (7)	-	3 (3) -	1 (3) -

The *B. pubescens* trees studied in this experiment are growing in the field test, no 672/1, in Somero. When the test was measured the best trees were selected to plus trees and at the same time branches of these trees were collected for tissue culture. When after some month of cultivation the background of these trees was cleared up it was noticed that V5939, V5942, and V5943 originated from the same crossing and V5940, V5941, and V5944 again from the same crossing (Table 2.). When looking at the ability of these two groups of clones to redifferentiate in vitro, it seems to be evident that there is some genetical background for redifferentiation in vitro. As well it can be said that with plenty of experimental work it is possible to find out a medium and a procedure, suitable for propagation of every clone.

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COPPICING RESEARCH IN THE MEMBER COUNTRIES OF IEA COPPICING ACTIVITY

ABSTRACT

Coppicing research activities in the IEA countries are shortly reviewed on the basis of an inquiry. Factors affecting the coppicing of trees are also surveyed. Prolific coppicing is the key to successful establishment and management of short rotation intensive plantations. It is therefore surprising that so few people have dedicated themselves to studying the biological basis of coppicing mechanisms in trees. We need several types of orientated approaches: physiology, production, silviculture and breeding. However, there is a special need for more fundamental research carried out in a more sophisticated manner to fill the gaps in our knowledge of coppicing phenomenon in trees.

INTRODUCTION

Activity titled "Developing the coppicing potential of selected hardwoods" is one of the ten joint projects in the IEA Bioenergy Agreement, Task II. The objectives of the Activity are:

- To investigate the morphological, physiological and cultural factors affecting the coppicing of trees
- To exchange information on coppicing experiments and studies performed and being performed, and to accomplish mutual research
- To determine the best means of improving, controlling and steering the coppicing vigour in tree plantations

The participating countries and national representatives are Canada, T.J. Blake & B. Barkley; Finland (leader), A. Ferm; U.K., P. Mitchell; and U.S.A., T. Bowersox.

It has been agreed in several meetings, workshops and negotiations of the Activity that the research areas of interest are 1) morphology of coppiced trees compared to the single stem system (initiation, structure and development of buds and sprouts, root systems) 2) physiology of coppiced trees compared to the single stem system (photosynthesis, metabolism ie. carbohydrates, phenols, ethylene, hormones) 3) cultural factors (cutting season, cutting equipment, stump diameter and height, root pruning rotations) 4) herbicide work from the coppicing point of view. What has remained somewhat obscure, however, is what is the coppicing research like in the participating countries and what is its volume.

A questionnaire designed to provide information for a state-of-art review on coppicing research was distributed to all the Activity participants. Some inquiries were sent to non-participants such as Sweden and Ireland. The results of the questionnaire have made it possible to summarize the coppicing work accomplished and also to have an overlook of the gaps in our knowledge. A total of 19 research projects were identified and 37 researchers contacted. In addition, a considerable number of papers, offprints and abstracts concerning various coppicing studies were received.

SUMMARY ON THE COPPICING RESEARCH ACTIVITIES

According to the results of the questionnaire, the number and research fields of the scientists dealing with coppicing research are as follows:

CANADA	2 persons	
	- coppicing physiology	2
FINLAND	9 persons	
	- SRIC coppice trials	4
	- silviculture	3
	- coppicing morphology and physiology	2
UK	18 persons	
	- SRIC coppice trials	8
	- yield modelling	3
	- agroforestry	3
	- policy, economics	4
USA	8 persons	
	- silviculture (SRIC)	7
	- coppicing morphology	1

It would appear that only a few people in IEA countries are involved in studying the coppicing mechanisms of trees. Most of the researchers have a silviculture-orientated approach in which coppicing is considered from the cultural point of view.

In Table 1 we take a closer look at the institutes which have coppicing projects, and also at the studies and experiments made in the different countries. The most common tree genera in the investigations are *Populus*, *Salix* and *Alnus*. Research is more application-orientated than basic. In addition, coppicing studies are considered from many points of view. There is a gradient from tree morphology to socio-economic aspects of society.

SUMMARY OF THE LATEST COPPICING RESEARCH RESULTS

There are only a few up-to-date reviews of the coppicing mechanisms in trees (Blake & Raitanen 1981, Blake 1981, 1983, Ferm et al. 1983, Auclair 1987). The content of this short synopsis is based on factors affecting coppicing ability of trees and the information has mainly been gathered from the papers and publications received in answer to the inquiry.

Species

Many fast-growing harwood trees sprout prolifically. However, there are great differences between species and even clones in their response to multiple cuttings (Geyer et al. 1985).

For instance, while *Populus* clones are often screened for rooting ability, it appears that coppice production and survival are also clone related. Thus selected clones should be screened for both characteristics (Geyer et al. 1985). Perhaps tree breeders will be able to select strains of trees which combine coppicing ability with other desirable characteristics, including frost tolerance and high productivity.

Sprout origin

The sprouts usually arise from suppressed or concealed buds in the stumps. Various types of buds can be responsible for coppicing. For example, sprouts of *Alnus incana* may originate from three different kind of buds. The

Table 1. Coppicing research in the member countries of IEA Coppicing Activity

COUNTRY	INSTITUTE	EXPERIMENTS	SPECIES	COMMENTS
Canada	Univ. of Toronto, Ontario	Tree physiology, coppicing physiology (photosynthesis, water relations, metabolism)	Mainly *Populus*	
Finland	Univ. of Joensuu	Overwintering and coppicing potential	*Salix* clones	
	Univ. of Oulu	Morphology and physiology of coppicing (structure of buds, nutrients, metabolism, photosynthesis, crown morphology)	Mainly *Betula*, also *Alnus*, *Salix*	
	Inst. of Northern Finland	Coppicing characteristics of trees cultivated on mined peatlands (productivity, winter hardiness, fertilization)	*Salix* clones	
	Finn.For.Res.Inst. Parkano Res.Stat.	Season-of-harvest	*Alnus*, *Betula*, *Salix*	
	Finn.For.Res.Inst. Suonenjoki Res.Stat.	Cultural factors	*Salix* clones	
	Finn.For.Res.Inst. Kannus Res. Stat.	Production studies, cultural factors, natural coppice/SRIC plantations on mined peatlands	*Betula*, *Alnus*, *Salix*	- Regular circular covering recent publications on coppicing work as done by IUFRO groups
U.K.	Aberdeen	Large-scale trials of short rotation 2 yr./4 yr. cycle fertilization (comprehensive: operations, costs)	*Populus*, *Salix*, *Eucalyptus*, *Alnus*, *Nothofagus*	
	Long Ashton	Clonal selection, herbicides, spacing cutting cycles	Mainly *Alnus*	- Interests in cultural factors, rotations, herbicide work - Research now broadening, will maybe contribute to coppicing physiology
	Oxford	Production studies in the forest	Seminatural breadleaved coppice, mainly *Quercus*	- Suspect their interests outside the mainstream of IEA's programme - But believe there is still scope for producing growth models for extensively managed woodlands

	Inst. Terrestrial Ecology, Scotland	To record light interception and light use efficiency and to predict biomass production using light use efficiencies	Salix, Populus	- If real progress is to be made, then four components: 1) amount of light intercepted 2) light use efficiency 3) dry matter matter partitioning to wood 4) the loss of dry matter needs to be measured to see which are genetically variable and/or can be most readily manipulated by cultural factors
	Bangor, N. Wales	Density studies	2 Salix clones	
	Open University	Agroforestry: combining coppicing with other crops		
	Reading	Policy, economics, implementation		- Consideration of costs and determinants of financial performance of coppice plantations
U.S.A.	Raleigh, North Carolina	Cultural factors, harvesting cycles	Platanus, Liquidambar	- Particular interest in coppice root systems as well as silvicultural applications to maximize productivity
	Olympia, Washington	Cultural factors, spacing, morphology	Alnus, Populus	
	Rhinelander, Wisconsin	Juvenile coppice growth, cultural factors, spacing, repeated harvests, rotation	Populus	
	Manhattan, Kansas	Cultural factors, clone differences, rotations	Several species (Acer, Ulnus, Robinia, Catalpa)	
	Pennsylvania, Univ.	Comprehensive approach (growth, operations, energy and financial analyses)	Populus hybrids	
Ireland	Agr. Inst. Oakpark	Species trials, yield studies	Salix, Populus, Alnus	- Clones with a small number of erect branches are to be preferred - Amount of nutrients removed is important, no need to go into photosynthesis work or root studies at this stage when we still do not know which species is best - The critical factor in coppicing is weed control

initiation, structure and number of buds at the base of the tree may have a great effect on sprouting success (Kauppi et al. 1987, 1988).

The sprouts rarely originate from adventitious buds situating at the cut-end of the stump. This has been noticed with teak, some temperate trees and also with birch (Rinne et al. 1987). It has become evident that true endogenous buds adventitious origin also occur in the trunk-bark of some temperate tree species (Fink 1983).

Physiological basis of coppicing

It has been hypothesized and to some extent empirically tested that the phenomenal early growth of coppiced trees is due to:

- The advantage conferred on the sprout by the parental root system
- Sprouts arising from more juvenile zones of the tree
- Also, sprouts arise from dormant buds which retain many of their juvenile characteristics and are formed relatively early in the life of the trees
- Carbohydrate levels have been shown to be adequate for coppicing under most conditions. On the other hand, sprouting vigour has been attributed to the more direct effect of auxin or cytokinin levels or gibberillin quality changes at the time or after cutting (Blake 1983).
- The photosynthetic capacity of sprouts has been shown to be better than seedlings, at least in the case of birch (Kiviniitty et al. 1987). This may be due to the higher foliar chlorophyll and nitrogen content of the sprouts, but the contribution of the altered root/shoot ratios to the availability of water and nutrients is also indispensable in photosynthesis.
- A causal relationship between water relations and coppicing vigour has been observed with young hybrid poplars after decapitation (Blake & Tschaplinski 1986). A major increase in the root/shoot ratio in decapitated plants would increase photosynthesis and growth by overcoming water deficits found in the intacts plants.

Although there is no satisfactory hypothesis or theory to explain rejuvenation phenomena, a number of morphological and physiological changes are apparent in sprouts forming on decapitated trees.

Season of cutting

The dormant-season harvest has clearly been the best with *Populus* species, hybrids and clones (eg. Strong & Zavitkovski 1983), *Salix* (Hytönen 1985), *Acer*, *Ulmus*, *Robinia* and *Catalpa* (Geyer 1987) and *Platanus* (Roeder

1986). Harvesting time was by far the most influential factor affecting stump mortality and sprout development by red alder (DeBell et al. 1986).

Cutting method

The cutting method does not generally affect coppicing as long as the stumps are not excessively damaged (Crist et al. 1983, Hytönen 1985).

Tree or stump size

As tree size increases, coppice production increases. However, this only occurs up to certain diameter limits, which are in most cases 20-35 cm (Blake 1983) or 25-40 cm (Mroz et al. 1984). Particularly in the case of willow but also birch these limits are considerably lower (Ferm et al. 1985).

Stump age

The results indicating greater coppicing ability with increasing tree diameter are mainly due to increased growth rates rather than to size.

Red alder stands 10 years old or less may be reproducible by coppice; stands less than 6 years old appear to be the best candidates for coppice regeneration (Harrington 1984).

Stump height

The effect of stump height on coppicing is negligible in most cases (eg. Crist et al. 1983) but, for instance, the coppicing of *Acer saccarinum* and *Ulmus pumila* improved with increasing stump height (Geyer 1987). In order to maximize red alder sprouting, the stumps should be taller than 10 cm (Harrington 1984). In some species, on the other hand, the stumps should be kept short to concentrate growth on a few sprouts (eg. Strong & Zavitkovski 1983) and, to avoid butt rot, cutting the stump low is recommended.

Site alteration

Coppice growth increases with increased site quality. In some sites, nutrient depletion may result in lowering yields during subsequent coppice rotations (Torreano & Frederick 1986). However, fertilization may increase the decline of the stools when coppiced in very short rotation (Bowersox, personal communications).

Weed control appears to be just as important in successful coppice as it is with hardwood plantations (Roeder 1986). On the other hand, weed control and fertilization had little effect on coppicing growth with *Acer*, *Ulmus*, *Robinia* and *Catalpa* (Geyer 1987).

Cultivation

Cultivation can improve the vitality of the coppiced stock, mainly through the proliferation of root systems. Deep ripping (root pruning) increased the percentage of stumps which regenerated coppice from around 80 % in the control (unripped) treatment to around 93 % survival with *Eucalyptus grandis* (Blake, personal communication). The reason for root pruning was to reduce root competition prior to coppice cutting in an attempt to reduce stump senescence, which is a major problem in closely spaced eucalypts plantations.

Thinning

As a rule, the thinning of sprout clumps at a very early age is not recommended. It has veen shown that the growth of the remaining stem of pruned trees is not greater than that of the main stem of multiple-shoot trees (Tschaplinski & Blake 1986). Only 24 % of the labelled CO_2 passed to the upper stem of pruned trees, while in multiple-shoot trees as much as 65 % of the newly fixed assimilates were translocated to the upper leaves and stems. The secondary shoots thus perform a storage function and are not in continuous competition with the main stem.

Spacing, harvest cycles and rotations

According to many of the latest reports (eg. Ek et al. 1983, Blankenhorn et al. 1985) we can conclude that:

- The closer the spacing in the plantation, the higher the mortality and also the fewer the sprouts per stump when coppiced in several short rotations
- High yields are achieved early with close spacing but the yields with wider spacing eventually catch up and surpass those of closely spaced plantations
- Coppice yields decrease with repeated harvesting of 1- or 2-year-rotations

- Even the shortest-lived tree species like *Salix* spp. have shown increased yields with increasing harvest interval
- In many cases renewal of the root system has been the key to viable coppicing of certain species with a specific rotation

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GROWTH AND PHYSIOLOGY OF COPPICE

ABSTRACT

Several French research teams are interested in physiology and growth of coppiced trees, and meet each year to discuss their methods and results. The topics treated are the following : growth and growth models ; bud formation, birth and growth in the first years ; annual growth patterns ; root activity ; root-shoot relations ; carbohydrate reserves and nutrient cycling.

INTRODUCTION

Since 1982, French research scientists from various institutes and universities have been meeting regularly to discuss their work and projects concerned with coppicing, and mainly with the scientific basis of coppice production.

One leading idea in coppice studies is the difference between growth curves in coppiced or single-stemmed trees. Most physiological and morphological studies are an attempt to bring some explanation to these differences. They have been mainly undertaken on "traditional coppice".

GROWTH CURVES

One important study has been undertaken on sweet Chestnut (*Castanea sativa* Mill.) coppice distributed throughout the country. This has lead to the construction of biomass growth curves (BEDENEAU, 1988). Figure 1 shows mean and current dry biomass annual increment for the "average" chestnut coppice stand. It can be noticed that the maximum annual biomass increment is reached at a very early stage : current increment at four years and mean increment before ten years.

The usual coppicing age in this type of "traditional" stand lies between 20 and 30 years, and at that age the current increment has decreased very sharply : it can reach 6 dry tons per hectare at age 4, but at 30 it is only 1 ton per hectare.

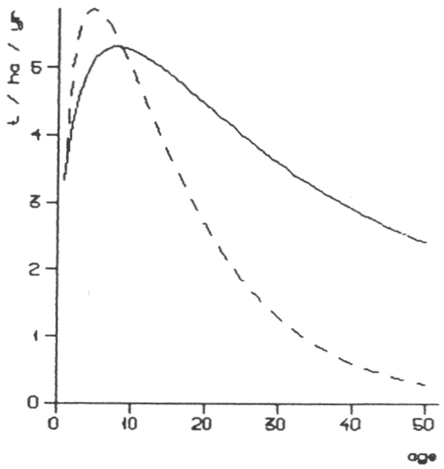

Figure 1 : Mean (solid line) and current (dashed line) dry biomass annual increment for Chestnut coppice. Average curve for France. (after BEDENEAU, 1988).

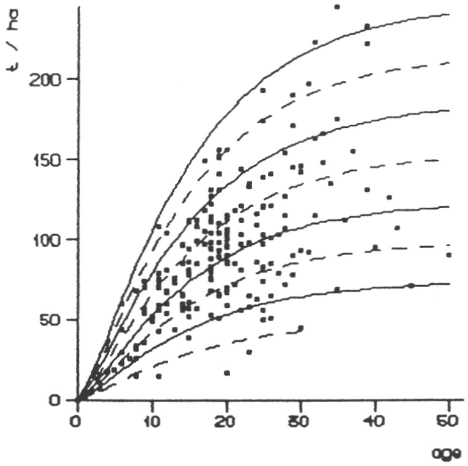

Figure 2 : Total standing dry biomass in French chestnut coppice stands. Theoretical curve from a logistic model. (after BEDENEAU, 1988).

Figure 2 shows the great variations observed in the sampled stands. These stands can be qualified as "natural" : no other silvicultural treatment than a clearcut is applied.

Many explanations can be given to these variations : soil productivity, climatic differences, stand density, rotation length, genotypic differences, or "history" of the stand (number and length of previous rotations).

It is interesting to observe that the high yielding stands produce a mean increment of 10 dry tons per hectare per annum at 10 years of age, with no silvicultural management. This figure is similar to those obtained with artificial intensively cultivated short rotation coppice. Although no direct conclusion can be made, it may be useful to keep these figures in mind when experimenting on intensive culture.

The particularity of coppice is most noticeable on height growth curves : figure 3 shows height growth current annual increment for the average chestnut coppice stand. Maximum height growth is reached the first year, and deceases afterwards. Some stands can grow above 5 metres in the first year.

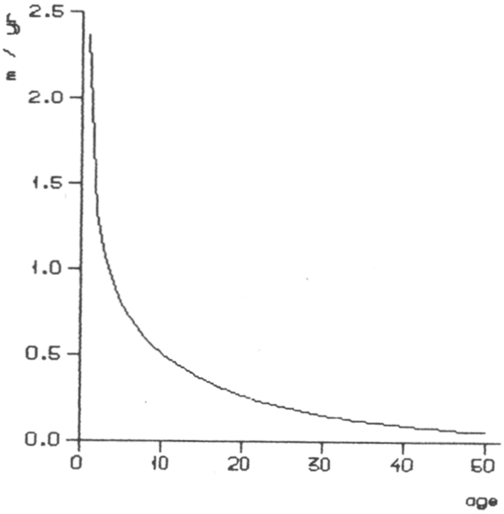

Figure 3 : Height growth annual increment for chestnut coppice. Average curve for France. (after BEDENEAU, 1988).

BUD FORMATION, SHOOT DISTRIBUTION, AND EARLY GROWTH

Some studies have been concerned with the growth of chestnut buds, as influenced by various environmental parameters, particularly temperature (AUFORT, 1982). The growth potential of shoot axillary buds seems to be greatly hindered by nutrient deficiency (SI-MOHAMED, 1985).

There are no French studies concerning the physiology of bud formation at the stump level, as those of Oulu university (KAUPPI *et al.*, 1987). Buds have been observed and followed mostly after budbreak.

These buds appear to be dormant or adventitious, and budbreak and subsequent growth are influenced by environmental factors, as well as human interference : most buds appear on parts of the stump exposed to sunlight, and the height of the stump and the cutting tool seem to have a slight effect on their subsequent growth (CABANETTES and PAGES, 1987). The chainsaw slightly reduces height growth of the dominant shoot from each stool, at least during the first year.

Several studies have been concerned with the development of coppice in the first years after coppicing, showing a rapid decrease in number of shoots per stump or per hectare (Figure 4).

In chestnut coppice, the shoot population rapidly reaches a stable structure, and after three years about 70 percent of the first-year shoots have died. The dominant shoots acquire their social position at three years (RULLIER, 1985 ; PAGES, 1985 ; CABANETTES, 1986).

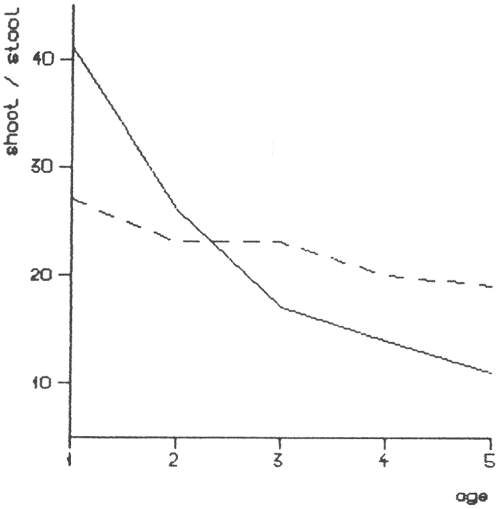

Figure 4 : Shoot demography in the first years after coppicing solid line : chestnut ; dashed line : oak.
(after CABANETTES, 1986).

GROWTH PATTERNS

Coppice sprouts have been shown to return to "free growth", with an increased growth rate and an extended period of growth, at least for the first growing season.
JAY-ALLEMAND (1985), showed that coppiced walnut could experience budbreak up to 20 days before 7-year old trees of the same clone, and therefore have a longer growing season. However sprouts from 30-year old coppiced trees only appeared 10 to 20 days later than on younger trees, probably due to the thicker bark.
PAGES (1985) showed that black locust root suckers appear later than stump sprouts. These root suckers remain dominated, and can only take part in the dominant stand if they appear at a sufficiently far distance from stumps, avoiding competition from stump sprouts. Sprouts also show more frequent growth flushes than single-stemmed trees (JAY-ALLEMAND, 1985) : figure 5.

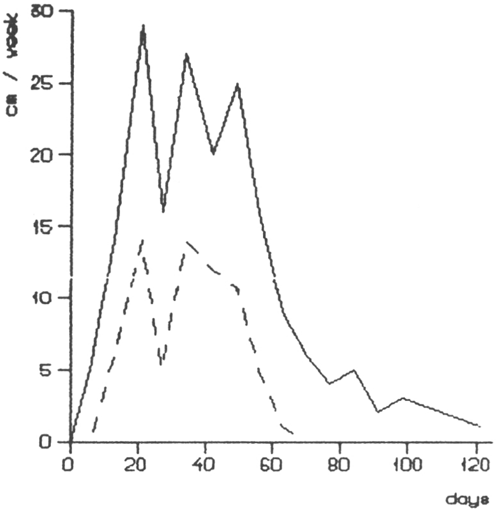

Figure 5 : Growth patterns of walnut shoots from the same clone, treated as single stem (dashed line) or coppiced (solid line).
(after JAY-ALLEMAND, 1985).

ROOT GROWTH

Root growth following coppicing has been shown to have different patterns for different species.

At each new rotation, birch coppice roots severely reduce their activity for two to four years, then regain normal radial growth. Very few small roots appear, and they do not survive very long.

Chestnut seems to have a quite different root pattern, giving birth to several new roots at each rotation, while some of the older roots remain, and others die.

This may explain the traditional practice which suggests using birch coppice for three or four rotations only, before the production decreases, whereas chestnut can be coppiced many times. (BEDENEAU and PAGES, 1984 a).

Total underground biomass remains constant, or slightly decreases, at the time of coppicing, and the root/shoot ratio becomes very large in the first year, inducing a very rapid shoot growth.

In order to try to determine the evolution of a root system after several rotations, PAGES *et al.* (1983) showed that, as in stems, root radial growth is annual. It is however difficult to trace back root evolution up to the original seedling, as some roots die while others are replaced. Root rings are also more difficult to observe than stem annual rings.

ROOT-SHOOT RELATIONS

The distribution of sap from roots to coppice shoots has been studied in birch and in chestnut coppice, using phytocides. The results seem to be very variable, according to species or to coppice age. In young birch coppice (one-year shoots) there is no very clear root-shoot relation : some of the shoots nearest to a treated root may be directly related, but in some cases the most distant ones are the most related. (BEDENEAU and PAGES, 1984 b).

In chestnut the relations betweeen root and shoot seem much more direct, one given root feeds preferentially the nearest shoots, but there is always a slight connection with all the shoots of one stump. (AYMARD and FREDON, 1986). Similar results were obtained, using a radioactive tracer (tritiated water), by CARLIER (1987).

CARBOHYDRATE RESERVES

An estimation of the seasonal development of carbohydrates in the stump of chestnut coppice showed that most of the reserves are stored in the large roots, both as starch and other molecular types : hemicellulose, heterosides, lipids. These reserves are used in the spring following coppicing for the formation of new shoots. (DUBROCA, 1983).

Photosynthesis and transpiration have been monitored, both in the field and in the laboratory, to estimate the contribution of leaves to the biomass of first-year shoots. It has been shown that until the end of June the new leaves only contribute partly to shoot biomass increment, and from the beginning of July they provide most of the carbohydrates used for shoot growth (PONTAILLER *et al.*, 1984).

Part of the carbohydrates may also be restored by the end of the first growing season, however, after three one-year cutting cycles the glucose reserves are depleted by about fifty percent.

A similar study was undertaken on young *Populus* shoots coppiced at different seasons, and showed that the total glucose content increases drastically in January. This increase is very compatible with the fact that the fastest shoot growth was observed on shoots coppiced in late January. (BONICEL and GAGNAIRE-MICHARD, 1983).

The most appropriate time in the year for coppicing would then be from December to mid-March, at the time when starch content is maximum in the roots.

NUTRIENT CYCLING

A study of mineral content of chestnut coppice in relation to age of the stems is under way. An interesting conclusion of various nutrient cycling studies is the fact that the most intensive types of cultivation, as for example short rotation coppice, have a very detrimental effect on soil quality. First, mineral nutrients are extracted at a very high rate, and secondly, intensive sylvicultural methods, based on frequent mechanical and chemical treatments, modify the organic matter and physical structure of the soil.

These plantations with a high depletion rate should theoretically occupy the best sites, whereas poor soil types should be devoted to longer rotations. This is in contradiction with the traditional practice which has the tendency to keep the best sites for high quality wood production. (RANGER and BONNEAU, 1986).

Figure 6 shows the amount of nutrients exported from a short rotation (7 years) poplar coppice in its second rotation, in relation to the harvested biomass. Nutrient exportation increases when smaller woody compartments are harvested, but the most drastic nutrient depletion would come from harvesting the leaves. (RANGER *et al.*, 1988).

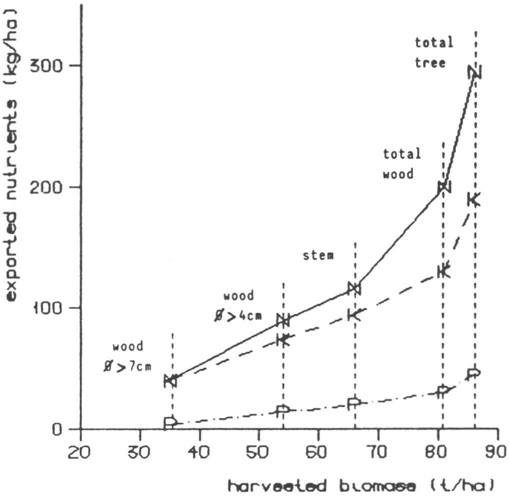

Figure 6 : Nutrients exported from a short rotation black cottonwood coppice in relation to harvested biomass. (after RANGER *et al.*, 1988).

CONCLUSIONS

The present results, obtained by members of the french coppice working party, contribute to the explanation of differences between growth curves for coppiced or single-stemmed trees : the early and high peak for maximum annual increment, and the low yield for traditional coppice.

Early and high maximum annual increment.
This can be explained by :

- shoot distribution and early growth : the great number of sprouts appearing on stumps leads to a very rapid occupation of the land by young shoots, and to a very important leaf area at an early stage. The number of living sprouts then decreases very quickly, leaving only the dominant shoots as early as the third year. Species which have the ability of producing root suckers may have an advantage in this sense, as root suckers can occupy the empty spaces ;
- underground reserves : carbohydrates in the stump provide the necessary reserves for rapid shoot growth in the early stages. Photosynthesis then takes over before the end of the first growing season ;
- root-shoot ratio : the very high ratio leads to tremendous height growth in the first year. Biomass yield however reaches its peak a little later, after canopy closure ;
- root growth : as the underground system occupies a large area, the amount of soil prospected by the roots is very important.

Low yield for traditional coppice.
Several causes can be put forward :

- the shoots may not always be well related to a vigorous root system, and vascular connections can suffer degradations. The instrument used for cutting can be slightly detrimental, and the height of coppicing can influence sprout growth.
- in many cases stump density is quite low. This may be due to an ageing of the underground system, the importance of which can depend on the species ;
- in traditional coppice the rotation is kept very long, much beyond the maximum mean annual increment. Therefore the total yield is lower than for shorter rotations ;
- soil fertility may be reduced by a large number of harvests, in which nutrient exportation is high.

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ARE INCREASED YIELDS IN COPPICE SYSTEMS A MYTH?[1]

ABSTRACT

One advantage attributed to coppice systems is that wood production costs will be decreased because coppice yields are usually greater than seedling yields at the same age. Observed increases in coppice yields over seedling yields range up to 200%. These observed fast rates of coppice regrowth have generated the idea that coppicing will increase total yields.

Biomass-yield data from the Department of Energy's Short Rotation Woody Crops Program suggest that minirotations (2 years or less) at best equal but do not exceed the productivity rate of short-rotation (3-10 years) intensively cultured hardwoods on an average annual basis. In trials where rotation lengths of 2 and 4 years were imposed, the 2-year rotation treatment resulted in total yields equal to or lower than the 4-year rotation treatment in 40 of 48 comparisons. Coppice systems with rotation lengths greater than 2 years and single rotation systems followed by replanting of genetically improved stock need to be considered as options for short-rotation, intensively cultured (SRIC) systems. SRIC should be designed to maximize biomass production by using proper weed control, selected species or clones, and optimum fertilizer and water for the most appropriate rotation length and density strategy. When such practices are followed, increased yields will be obtained.

INTRODUCTION

It has been observed that coppice growth (regrowth following a harvest) often exceeds early establishment growth from cuttings or seedlings (Geyer 1981, McElroy and Dawson 1986, Steinbeck and Brown 1976, Zavitoski 1980, Ranney et al. 1985). Some of the increases have been quite phenomenal, with production rates of coppice stands ranging up to 200% over that of young establishment stands. It has been assumed or hoped that high coppice yields could offset the high establishment costs of planting a large number of seedlings of cuttings. Previous analyses of coppice data have often proceeded no further than demonstrating that coppice yields are considerably higher than establishment yields. However, an important question is whether the coppice production rates in stands harvested at an early age are high enough to equal or exceed the growth that would have occurred in stands

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[1] This paper is currently in press in Energy from Biomass and Wastes XI, Proceedings of the Institute of Gas Technology 11th Annual Meeting, March 1987.

established under the same conditions but that were allowed to grow somewhat longer before harvesting.

The question specifically addressed by data analysis in this paper is whether differences in total yields can be obtained by modifying the rotation length (or harvesting interval) of stands established at the same planning density. This is a limited analysis for two reasons. First, systematic evaluation of short-rotation, intensively cultured (SRIC) short-rotation coppice systems has been initiated so recently that most available coppice data represent only the "very short" (2-year) rotation systems. Evaluations on longer rotation coppice systems are continuing. Second, a fair evaluation between short-rotation and longer rotation systems should not be restricted to stands of the same density. Densely planted stands harvested frequently need to be compared with less dense stands harvested at a longer time interval. Well-designed experimental data of this type are not currently available, although experiments are in progress under funding from the Short Rotation Woody Crops Program. Thus, the topic of this paper is limited very narrowly to determining whether there is any biological advantage to "coppicing" a stand at a very early age instead of coppicing at a somewhat later age. This paper includes discussions of some of the parameters affecting coppicing success, including density, time of harvest, and species differences.

METHODS

To address the question posed by the title of this paper, experimental data were collected from past and present investigators in the Short Rotation Woody Crops Program (SRWCP) and from published literature. The most available data involved comparisons between 2- and 4-year rotations (as depicted in Fig. 1). Forty-eight paired data sets were located that allowed direct comparisons between yields from stands harvested at 2- and 4-year intervals. Within each of the paired data sets all other variables (e.g., species, site, spacing, and cultural conditions) remained the same. Data from Torreano and Frederick (1986 personal communication to Lynn Wright) provided 27 growth comparisons of either sycamore, sweetgum, or water/willow oak on three site types at three spacings, with treatments harvested at age 2, age 3, and age 4 of the first rotation and at age 2 of the second rotation. Eight comparisons of growth of black cottonwood in the Northeast with rotation length treatments of 1, 2, 3, and 4 years were available from Blankenhorn et al. (1986). Other direct comparisons between 2-year and 4-year rotations were found for hybrid poplar in the Pacific Northwest (Heilman and Peabody 1981) and Lake States (Hansen et al. 1986); eastern cotton in Kansas (Geyer 1986); willow in England (McElroy and Dawson 1986); sycamore in Georgia (Steinbeck and Brown 1976) and Mississippi (Kennedy 1980); silver maple in Kansas (Geyer 1986); and red alder in the Pacific Northwest (Debell 1986, personal communication). However the four comparisons from Steinbeck and Brown (1976) and Hansen et al. (1986) differ somewhat in that all data are from coppice stands; yields were not determined on the seedling stands harvested at age 2 or 3. The comparison of silver maple rotations in

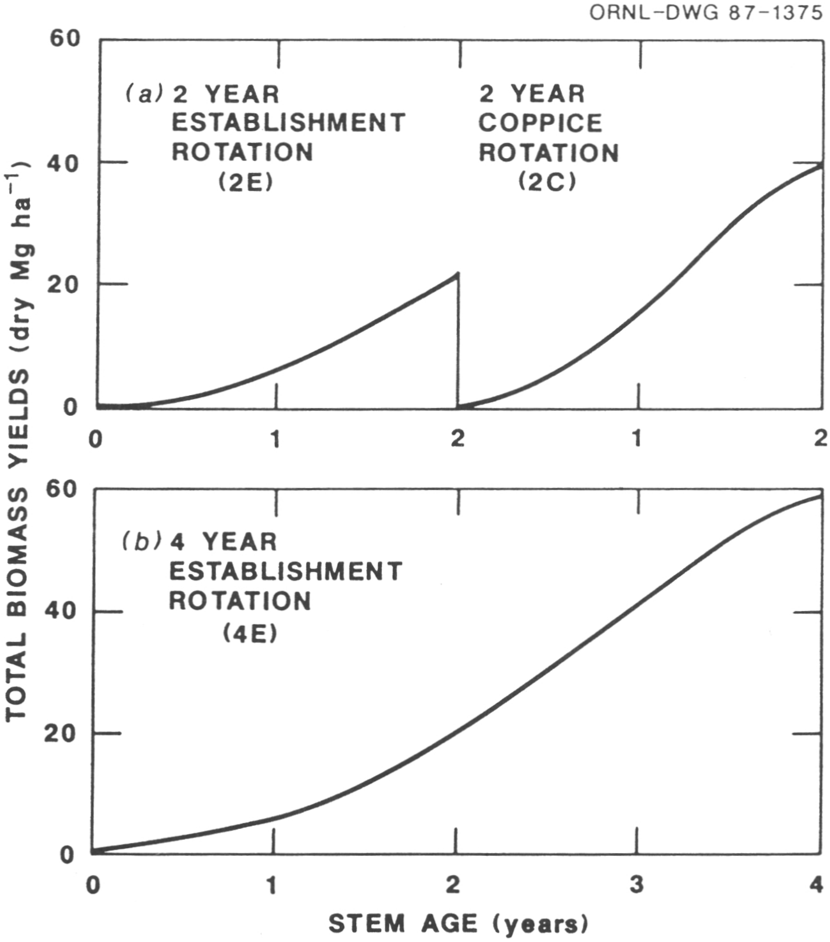

Fig. 1. Diagrammatic explanation for a given population density of "establishment rotation" and "coppice rotation" as used in this paper. The 2- and 4-year establishment rotation will be abbreviated in the paper as 2E and 4E, and the 2-year coppice rotation will be abbreviated as 2C. Comparisons between 2- and 4-year rotations are made by comparing the total yield produced in each system over 4 years.

Geyer (1986) was derived from two different plantings, established at different times.

Our approach to analyzing this information was to prepare computerized worksheets containing information on species, site location, site quality, density, current annual increment and mean annual increment (when available), rotation ages, and actual dry weight yields in megagrams per hectare for each paired data set. A "paired data set" is defined in this paper as two data points (means of replicates) derived from an experimental trial where all parameters but one are held constant. Percentage differences in yields were calculated for each paired data set, and then the complete worksheet was rearranged based on the rankings of the percentage differences. Once the percentage differences were ranked, along with all the descriptive information, we could search for possible correlates to percentage differences. Comparisons of averages of actual dry weight yields (e.g., megagrams per hectare of all 2-year rotation trials with all 4-year rotation trials) were not performed because yields varied considerably as a result of differences in species, site quality, cultural conditions, and spacing density. Original yield data are not being reported in this paper, in part because many of the results have not yet been published. However, this is probably advantageous, since it allows us to focus on examining trends that might otherwise be obscured.

The first analysis, a comparison between the relative increases (or decreases) of age 2 coppice yields over age 2 establishment yields, was performed on 42 data sets. Only data sets including age 2 establishment yields were analyzed. In performing this analysis, the total yield of the age 2 coppice growth was compared with the total yield of the age 2 establishment growth, and the difference was calculated as a percentage increase or decrease in yield. The percent differences were ranked in ascending order and sorted into evenly divided percentile groups.

The method of comparing total yields as a result of rotation length was similar to the method of comparing coppice and establishment yields. The total yield produced by two 2-year rotations (in most cases one establishment and one coppice rotation) was compared with the total yield obtained by a single 4-year "establishment" rotation at the same density. The frequency distribution of the percentage differences was examined using all 48 data sets.

RESULTS

The frequency distribution of the percentage differences in comparisons of age 2 coppice yields and age 2 establishment yields is shown in Fig. 2. In 62% of the data sets examined, coppice yields are higher than establishment yields, with the increases reaching more than 200%. However, in 21% of the trials, coppice yields are the same as establishment yields, and in 17% of the cases coppice yields are lower. None of the associated parameters (e.g., species, density) appeared to account solely for the distribution of percentage differences between establishment and coppice yields.

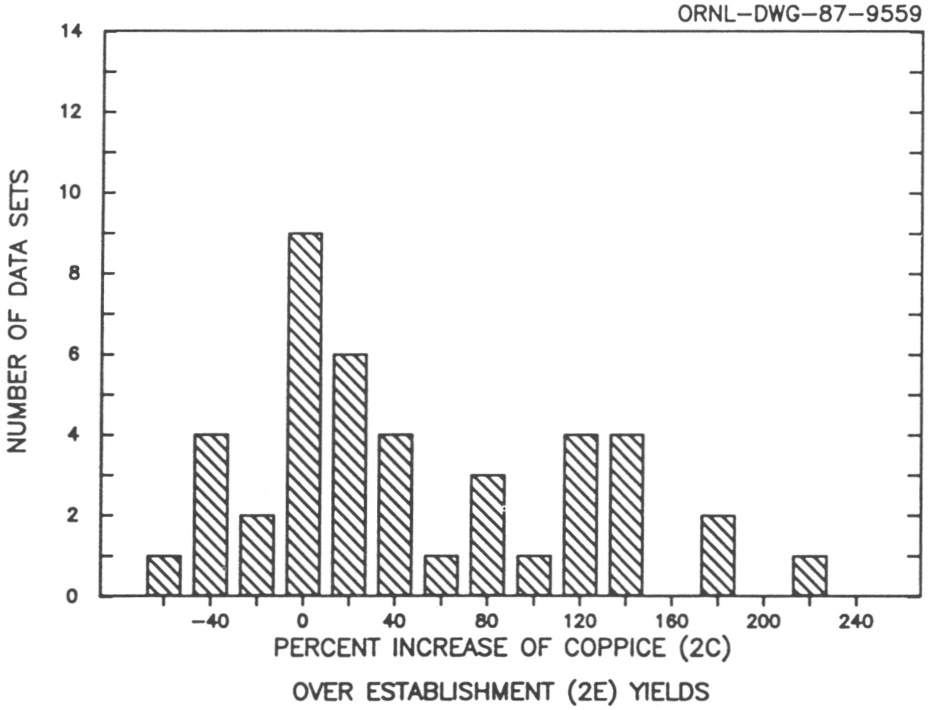

Fig. 2. Frequency distribution of 42 comparisons of age 2 coppice yields to age 2 establishment yields, with the results ranked and divided into percentile groups. The percent coppice yield increase was calculated as follows: (2C - 2E yields/2E yields) x 100.

Figure 3 shows the frequency distribution of the percentage differences that resulted from comparing the effect of rotation length on yields in stands at the same density and cultural treatment condition. In 40 of 48 paired comparisons (83%), total 4-year yields from the 2-year rotation length treatments are slightly less than or equal to yields obtained from 4-year rotation length treatments, given the same initial density and cultural treatments. Again, none of the associated parameters solely accounted for the distribution of percentage differences between 2- and 4-year rotations.

DISCUSSION

The results reported in this paper are not surprising, as indications that higher total yields could be obtained from somewhat longer rotations have been observed from the very first studies of high-density, short-rotation plantations. Heilman et al. (1972), Kormanik et al. (1973), Steinbeck and Brown (1976), Wittwer et. al (1978), Perala (1979), and Kennedy (1980) all concluded that rotations of 4 years or longer would be preferable to 2- or 1-year rotations for producing biomass with poplars or sycamores. These studies also concluded that the lowest spacing density tested (which, in each case, was approximately 1.2 x 1.2 m or about 7000 trees per hectare) was most desirable. Yields were often highest in establishment rotation at the most dense spacings, but during the coppice rotation there was usually very little difference in yields between spacing treatments. A major reason given for the lack of difference was that, at the higher spacing densities, high mortality of stumps and stem self-thinning during the coppice rotation resulted in similar stem densities at all spacings. In some cases, stump mortality during the coppice phase occurred even at the 7000 tree per hectare density, and Kennedy (1980) recommended that a spacing density of about 1.5 x 1.5 m (about 4444 trees per hectare) be considered.

Among the density studies currently being conducted by SRWCP investigators, one experiment provides new information on density relationships at somewhat lower densities (Torreano and Frederick, personal communication). In that experiment, sycamore, sweetgum, and water/willow oak are being evaluated on three site types at three spacings. The density effects observed thus far are not as strong as in the previous studies noted above because the densities being evaluated range from 1792 to only 5376 trees per hectare. For example, stump mortality did not occur in the coppice rotation at age 2 for any of the species. In the sycamore there was a significant reduction in the number of sprouts per stump with increased density, and age 2 coppice yields were similar for sycamore at all densities. The oak treatments showed no significant effect on the number of sprouts as a function of the densities tested, and the highest age 2 coppice yields were obtained at the highest density. These results demonstrate the importance of understanding species differences when determining the best density/rotation length strategies.

Results recently published by Geyer et al. (1985) provide further evidence for differences in species response to 2-year coppice

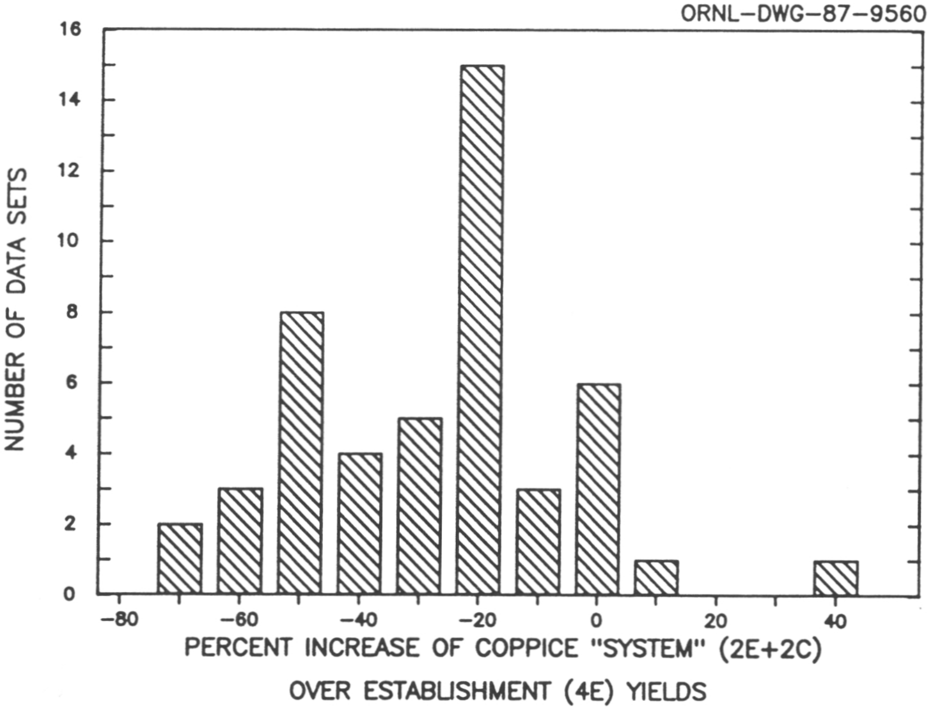

Fig. 3. Frequency distribution of 48 comparisons of total yields obtained by harvesting every 2 years against yields harvested at age 4, with the results ranked and divided into percentile groups. The percent coppice "system" yield increase was calculated as follows: (2E + 2C yields - 4E yields/4E yields) x 100.

rotations and density. His work evaluated the effect of several 2-year rotations on the coppice regrowth responses of 7 different species (boxelder, sycamore, black alder, sandbar willow, silver maple, catalpa, and eastern cottonwood (of which there were two sources). All trials were initially established at three spacings (0.3 by 1.2 m, 0.6 by 1.2 m, and 1.2 by 1.2 m or about 27,000, 13,500, and 7,000 trees per hectare, respectively). Results from this study expressed as the difference between coppice yields over several rotations and the establishment yield are shown graphically in Fig. 4. In this study, spacing differences did have a significant effect on yields in the first rotation; however, by the end of the first coppice rotation, yields were similar at all spacings for most species. Boxelder was an exception to that trend. It was the only species that continued to show increases in production in successive 2-year rotations. All other species showed significant decreases. Actual yields of boxelder were very low in the 2-year establishment rotation, whereas the establishment yields of sycamore, silver maple, and cottonwoods were relatively high. For most of the species evaluated the 2-year rotation cycle in high density stands was not a viable strategy for obtaining high yields.

The variation described above is most likely related to the degree of competition within the stand at the time of harvest. Competition may be for light, water, or nutrients, whichever is most limiting in the particular environment. Differences in competition responses exist not only between species but also between genotypes within a species. Graphs of current annual incremental growth (CAI) expressed as growth per hectare (Fig. 5) provide some indication of when competition was initiated in a stand of a given density and species. However such graphs can only be developed after the fact and, unlike the example shown in Fig. 5, the point of maximum CAI is often less discrete since year-to-year changes in environmental conditions can affect the pattern of CAI. Methods need to be found to index competition and to describe the relationship between such indices and sprouting vigor.

If competition is a major factor affecting sprouting vigor in the coppice rotations, then it follows that stands harvested in a dormant season prior to CAI_{max} should show good sprouting vigor and thus an increase in coppice growth over establishment growth at the same age. This statement assumes that the stands have been given sufficient time to establish a good root system, which, from most SRWCP studies, appears to take at least 2 years regardless of density. Following the same logic, the coppice growth of stands harvested after CAI_{max} should be equal to or less than establishment growth, depending on the amount of stress the root system may be experiencing because of competition. Unfortunately, in many of the data sets examined for this paper the age of CAI_{max} could not be accurately determined; therefore, this hypothesis could not be verified. However, the examples of differences in species response to coppicing provided in the above paragraphs provide some support for this concept. For example, both the boxelder and the water/willow oaks are examples of species that tend to allocate carbohydrates to root growth rather than top growth during the first year or two following establishment. In a 2-year rotation system, therefore, harvest occurs while the trees are just beginning to show

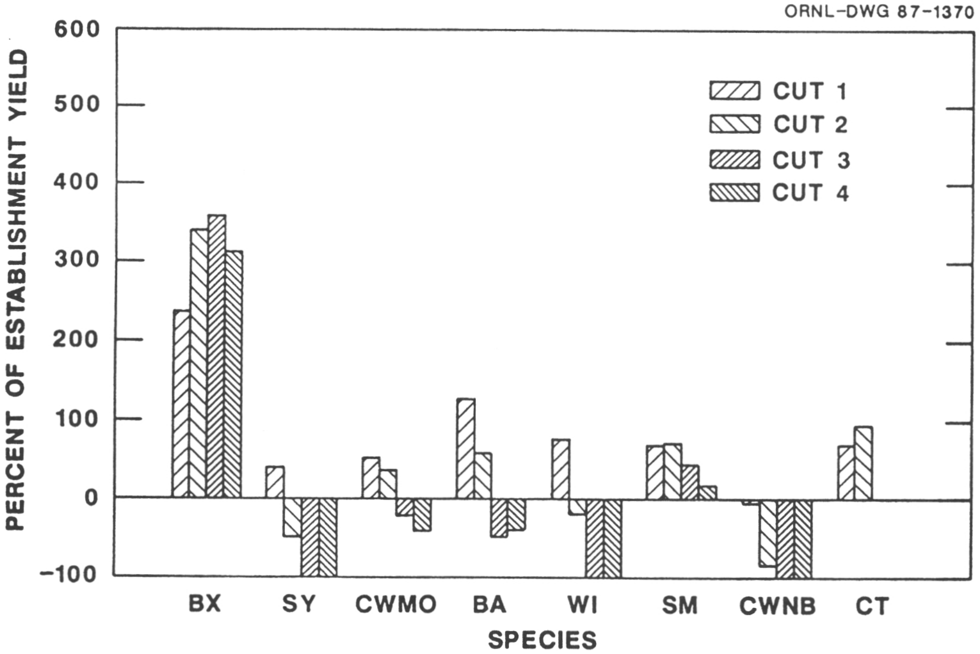

Fig. 4. Coppice yield expressed as a percentage of establishment yield in a 2-year coppice system with all spacings combined. The species abbreviations are as follows: BX = boxelder; SY = sycamore; CWMO = cottonwood, Missouri source; BA = black alder; SM = silver maple; CWNB = cottonwood, Nebraska source; and CT = catalpa. Source: Geyer 1986.

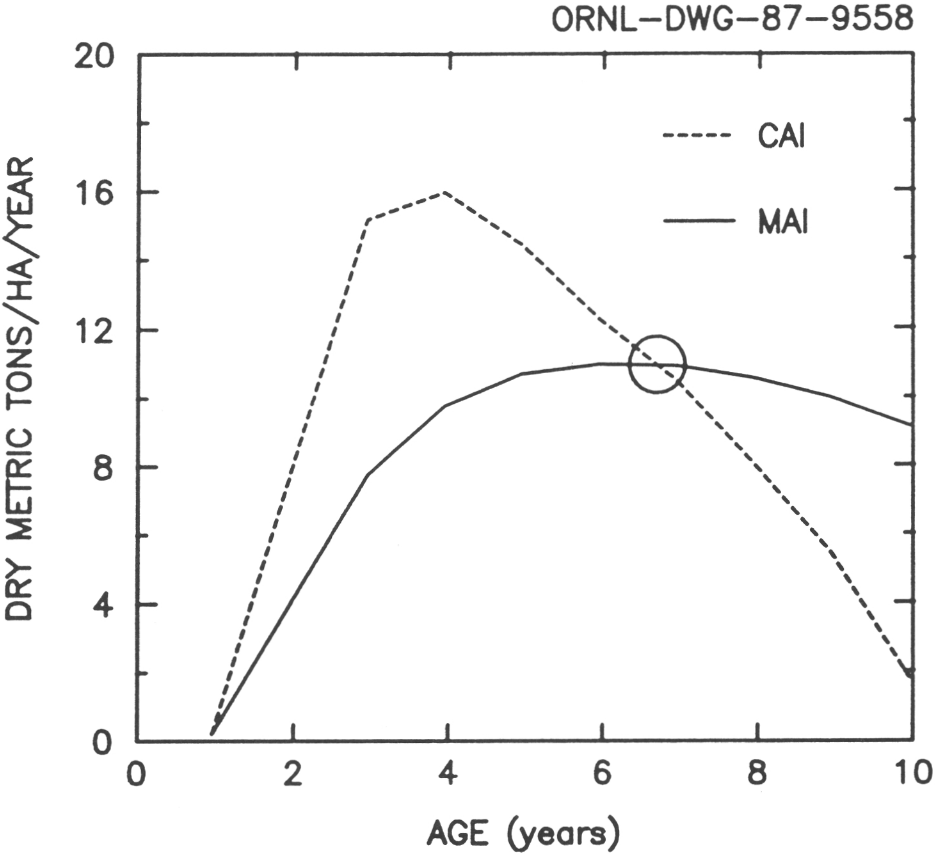

Fig. 5. The relationship of current and mean annual biomass increment (CAI and MAI, respectively) to age in a hypothetical SRIC plantation. Optimal rotation age for single rotation SRIC plantations occurs when the CAI and MAI curves cross at the peak of MAI; however, intertree competition, which slows the rate of incremental growth and potentially reduces sprouting vigor, begins to occur at the peak of CAI.

vigorous top growth (i.e., before CAI_{max}). However, because of the vigorous root systems, second-rotation coppice yields are many times higher than establishment yields.

The above hypothesis regarding the effect of competition on coppice regrowth needs further investigation under more varied site and species conditions. However, if true, it has several implications for energy plantations. First, it suggests that, if favorable economics depend on a coppice system, biomass yield of the establishment rotation may have to be penalized in order to ensure good sprouting vigor in successive coppice rotations. Second, the species and clones to be used in coppice systems must be selected based on coppice performance rather than seedling performance.

The results of the comparison between 2-year and 4-year rotation lengths addressed in this paper lead to the question of whether rotations of 6 to 10 years might not result in greater total production of biomass. Insufficient information is currently available to address this question adequately, but more results should soon be forthcoming from studies currently ongoing in the SRWCP. In the United States, Heilman and Peabody (1981) reported that a single 8-year rotation of black cottonwood in the Pacific Northwest resulted in about 33% greater productivity than two 4-year rotations. They speculated that even longer rotations and wider spacings might increase total productivity, but they made the important observation that control of competing vegetation is more critical at wider spacings. In Ireland, McElroy and Dawson (1986) found that 1-, 2-, 3-, 4-, 5-, and 6-year rotations of willow planted at 20,000 trees per hectare gave mean annual dry matter increments of 9.0, 12.0, 14.6., 16.0, 20.5, and 30.7 Mg ha^{-1} $year^{-1}$ respectively. Thus, a 6-year rotation with an MAI of 30.7 produced a total dry yield of 184 Mg in 6 years, while the 3-year rotations produced a combined total yield of only 87.6 Mg in 6 years. McElroy and Dawson caution that the 4-, 5-, and 6-year yield data were obtained on small plots and need to be verified in larger scale trials. Nonetheless, these data suggest that longer rotation should be evaluated.

CONCLUSION

Production systems need to be properly designed for maximum efficiency. Population densities (spacing), genetic material, and cultural practices need to be matched to the intended management strategy and desired end-use product. Given that optimal practices are utilized, very short rotation coppice systems may provide the best method for producing material that is suitable for methane production, for instance. Somewhat longer rotation (4- to 8-year) coppice systems may be the least costly method of producing the most wood chips for a variety of energy end-uses. In other cases, using single rotation systems (up to 10 years) and replanting with new genetic material may be the best method for obtaining both high yields and larger-sized material for such uses as whole-tree boiler systems. SRIC systems are designed to maximize biomass production by using proper weed control, selected species or clones, and optimum use of fertilizer and water for the most appropriate rotation length and density strategy. When such practices are followed, increased yields in SRIC systems are not myths.

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SECOND ROTATION GROWTH AND YIELD OF A POPULUS HYBRID

Short rotation intensive culture of hardwood species offers the promise of multiple rotations from one planting or establishment rota~~tion~~tion. Yields from coppice rotations are generally expected to be greater than the establishment rotations. However, there are few published reports of yields from multiple rotation studies conducted in the United States, and the available estimates are primarily from small plot databases. Wright's paper in this workshop ("Are increased yields in coppice systems a myth?") summarizes most of the current multiple rotation information from the United States.

At The Pennsylvania State University, we are evaluating the effects of four management strategies on first and second rotation growth and yield variables. Designed rotation length was four years. The purpose of the paper is to summarize the first rotation yield values and discuss the preliminary results from the second rotation.

PLANTATIONS AND TREATMENTS

The study location is in central Pennsylvania (latitude 41°N, longitude 78°W). Dormant cuttings of P. maximowiczii x trichocarpa were planted on two abandon fields in early May of 1980 and 1981. The Basher site was located on a nearly level floodplain derived from red shale and sandstone and the soil was a Basher silt loam. The Morrison site was an gently sloping upland area where sandstone and dolomite had weathered to a Morrison sandy loam. Cuttings were planted in rows 0.8 m apart and 0.6 m within row for 0.48 m^2 of growing space per tree. Each plantation (1.2 ha) consisted of six replications, three planted in 1980 and 1981, respectively. Each treatment unit was planted with 272 continuous inventory trees that were bordered with 2.4 m of similarly spaced trees. There were four treatment units per replication. The treatments were control, fertilization, irrigation and fertilization/irrigation. Control was native fertility and rainfall (about 10 cm per growing season month). Fertilization of individual replications was based on annual soil test recommendations to maintain non-limiting N-P-K-Ca-Mg soil fertility levels. Irrigation of individual replications was conducted by a trickle system to maintain non-limiting soil moisture conditions. Fertilization/irrigation treatment units were maintained in non-limiting conditions for both nutrients and water.

Total height and stem diameter at 15 cm above ground were measured on all surviving trees at the end of each first rotation growing seasons. Total tree (wood, bark and branchwood above a 15 cm stump) four year yields were calculated from actual harvest (field weight) and overdry equations. Second rotation (first coppice) total height, stem diameter at 15 cm above ground and number of sprouts per stump were measured annually on 20 tree subsets of the surviving continuous inventory trees per plot. These sprout size variables were used in conjunction with age specific first rotation yield equations, adjusted for surviving root systems, to develop second rotation production estimates. Second four year rotation yield values will be determine as outline for the first rotation.

FIRST ROTATION SUMMARY

Site Preparation and Weed Control. The only weed control measures in establishing the 1980 plantations were plowing and disking prior to planting. Invading weeds reduced the establishment year growth of the 1980 plantings until the weeds were mechanically controlled late in the first growing season. An effective tillage plus chemical weed control program was implemented for 1981 plantings . Compared to the poor weed control for the 1980 planted trees, the effective weed control program for the 1981 planted trees increased the height and diameter of trees at both sites for every age and management strategy (except three year old Basher fertilized height). Weed control measures had the greatest effect on the control treatment and the least effect on the fertilization and fertilization/irrigation treatments.

Growth. First rotation growth demonstrated:

(1) Weed control in the establishment year had a significant effect on height and diameter of trees and on growth response to fertilization and irrigation amendments throughout the first rotation.

(2) Two year old trees grew faster in height and diameter than one year old trees, two year growth rates were sustained in the third year but slowed in the fourth year.

(3) More favorable sites (Basher) resulted in trees that were somewhat larger in height and diameter compared to less favorable sites (Morrison).

(4) Fertilization and fertilization/irrigation investments increased tree size variables over no amendments. Irrigation had mixed results.

Yield. Four year old total tree biomass yields from 1980 planted trees averaged 21.4, 26.9, 33.1 and 37.0 ODt/ha for control, irrigation, fertilization and fertilization/irrigation strategies (Figure 1), respectively. The irrigation, fertilization and fertilization/irrigation amendments resulted in additional yields of 26%, 55% and 73%, respectively, over control yields. Four year old total tree biomass yield from 1981 planted trees (good weed control) averaged 33.5, 33.3, 40.4 and 42.1 ODt/ha for control, irrigation, fertilization and fertilization/irrigation treatments (Figure 1), respectively.

Ovendry total tree yields revealed that:

(1) Proper weed control substantially increased biomass yields.

(2) Biomass productivity increased more in the second year compared to the first year, was greater in the third year than the second year and was similar in the third and fourth years.

(3) More favorable sites (Basher) yielded slightly more biomass, compared to less favorable (Morrison) sites.

(4) Irrigation, fertilization and fertilization/irrigation increased two, three and four year old biomass production.

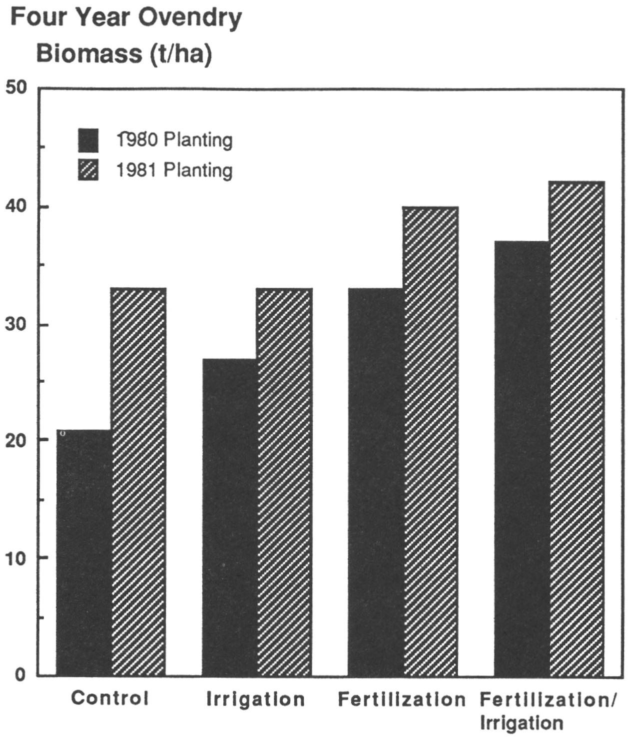

Figure 1. Average four year old ovendry biomass yields from the first rotation, by planting year.

SECOND ROTATION - 1980 PLANTATIONS ONLY

Tree Survival and Stem Density. Control and irrigation treatments consistently had higher survival values than the fertilization and fertilization/irrigation treatments in both the first and second rotations. End of first rotation survival values for the non-fertilized trees averaged 84% compared to an average of 75% for treatments receiving fertilizer. In the second rotation the tree survival differences between the fertilized and non-fertilized trees increased. After three growing seasons in the second rotation, 79% of the original non-fertilized cuttings had at least one living sprout whereas only 53% of the original fertilized plantings had at least one living sprout.

Reasons for the major decline in fertilization and fertilization/irrigation survival values between the first and second rotations were difficult to determine. One explanation for the differential survival rates between fertilization and non-fertilization may be selection pressure in the developing stands. The fertilization and fertilization/irrigation units may have had rapid segregation into dominating larger trees and suppressed smaller trees, with the suppressed trees eventually dying. For the fertilization and fertilization/irrigation treatments mortality rates increased after the third growing season of the first rotation and these higher mortality rates carried over into the second rotation. The control and irrigation treatments have resulted in slower tree growth rates and slower large-small tree segregation with more trees living longer than in the fertilization or fertilization/irrigation treatments.

The overall average number of living sprouts per stump was highest for the one year old coppice with 4.6 sprouts/stump. Sprout abundance declined to 2.3 and 1.8 sprouts/stump for ages 2 and 3 respectively. In the one year old coppice, there appeared to be a site effect (Basher having lower average number of sprouts per stump than Morrison) and a fertilization effect (fertilized trees having lower average values than non-fertilized trees) but these differences disappeared by age three.

Although there were no difference in number of sprouts/stump, the differential tree survival values between the fertilized and non-fertilized treatments produced differential stem densities. All three year old fertilized treatment units averaged about 19,000 stem/ha while the non-fertilized treatment units averaged about 30,000 stem/ha.

Total Height and Stem Diameter. The average height and diameter values for the largest sprout/stump of the one year old coppice were essentially the same for all treatments at both sites (Figure 2). In the second and third growing seasons, the largest sprout/stump average size variables were slightly greater at the Basher site than at the Morrison site, and the fertilized trees were larger than the non-fertilized trees (Figure 2). Averaged over both sites, the control and irrigation treatments were 6.2 and 6.4 m in total height and 4.0 and 4.1 cm in diameter, respectively. The combined Basher and Morrison site fertilization and fertilization/irrigation total heights were 7.6 and 7.4 m and the diameters were 5.3 and 5.1 cm, respectively.

Our preliminary analyses of the second rotation tree size variables suggests:

(1) Total height and diameter values were slightly dependent on site.

(2) Total height and diameter values were dependent fertilization. Irrigation had a slight effect on tree size variables.

(3) Age specific tree size variables in the second rotation were greater than in the first rotation.

Yields. Site-replication-treatment yield estimates for 20 randomly selected stumps with at least one living sprout were used in combination with the number of surviving stumps to estimate biomass production per land area. Overall, the sprout growth in the first growing season of the second rotation was estimate to produce 5.55 ODt/ha of total tree biomass. This value was much higher than the one year old production in the establishment rotation (.25 t/ha) and also higher than accumulated two year old yield of 4.15 ODt/ha for the first rotation. Differences in one year coppice yields between the two plantation sites were less than .20 t/ha. Irrigation was the only treatment to have one year old yields that were markedly different than the other treatments (Figure 3).

In the second coppice growing season, all trees produced 16.12 ODt/ha of total tree biomass to accumulate 21.66 ODt/ha of biomass at the end of the second coppice year. The annual plantation wide biomass production of about

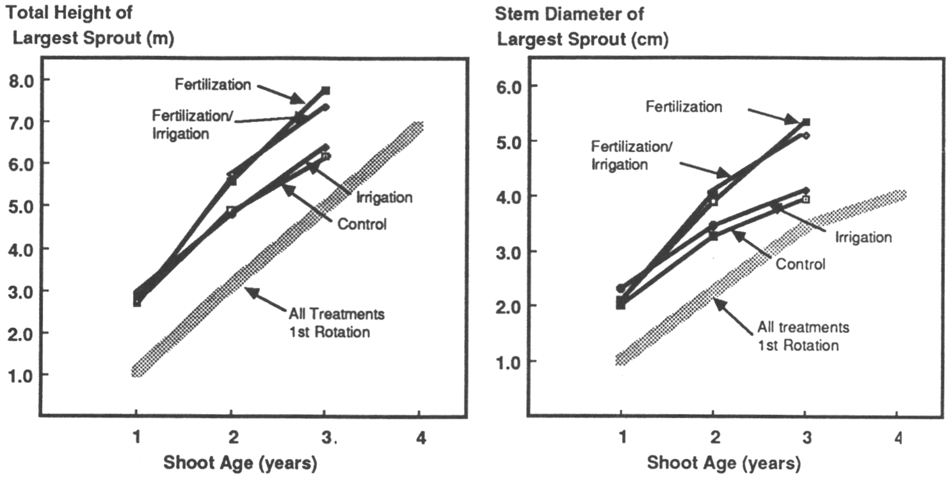

Figure 2. Average total height and stem diameter for second rotation , by management strategy and averaged over the two plantaion sites.

16 ODt/ha in the second coppice year was higher than the 12 ODt/ha of biomass produced in years three and four of the first rotation. Averaged overall treatments, the accumulated two year old total tree biomass was slightly lower at the Basher site than at the Morrison site. Fertilization/irrigation was the only treatment to have two year old biomass yields than were substantially different from the yields of the other treatments (Figure 3). Averaged over both plantation sites, the two year old accumulated total tree yields were 20.74, 18.06, 20.42 and 25.45 ODt/ha for control, irrigation, fertilization and fertilization/irrigation, respectively. Although, there were consistent and substantial yield advantages from the investments of water and/or fertilizers at age two in first rotation, these same advantages were not evident in the two year old coppice yields.

The overall coppice yield of about 22 ODt/ha after two growing seasons was similar to the first rotation yields obtained at:

a. Four years of age for the control and irrigation treatments (24 ODt/ha).

b. Three years of age for fertilization and fertilization/irrigation treatments (21 ODt/ha).

In the third coppice growing season, all trees produced 18.02 ODt/ha of total tree biomass to accumulate 37.93 ODt/ha of biomass at end of the third coppice year. The annual plantation wide third year biomass production of about 18 ODt/ha in the coppice rotation exceeded the maximum first rotation annual production of 13 ODt/ha measured in the fourth growing season. Averaged over treatments, the accumulated three year old total tree biomass

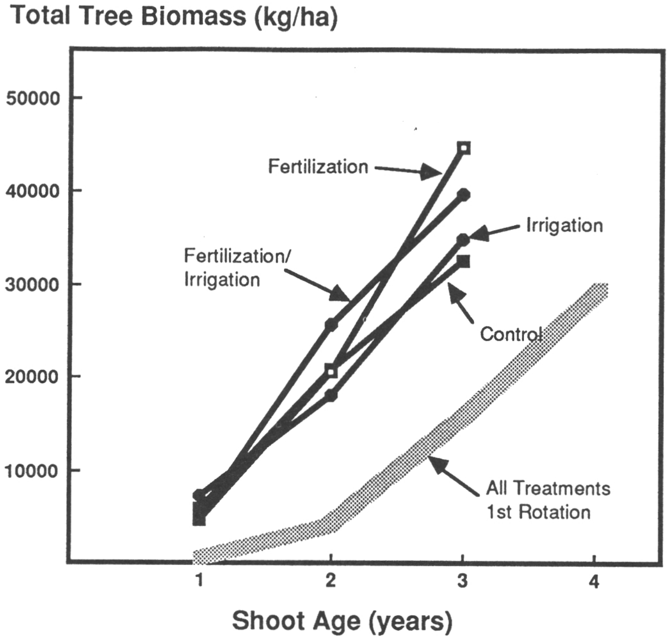

Figure 3. Average total tree biomass for second rotation, by management stratagy and averaged over plantation sites.

at the Basher site (37.62 ODt/ha) was slightly lower than the biomass at the Morrison site (38.25 ODt/ha). Fertilization and fertilization/irrigation three year old biomass yields were substantially higher than the control and irrigation treatment yields (Figure 3). Averaged over plantation site, the three year old accumulated total tree yields were 32.52, 34.80, 44.74 and 38.68 ODt/ha for control, irrigation, fertilization and fertilization/ irrigation, respectively. In the first rotation, there were consistent and substantial yield advantages from the investment of water and/or fertilizers. These advantages were not evident in the one and two year old coppice yields. In the third coppice growing season, the differential yields among the treatments displayed in the first rotation were beginning to reappear with one notable exception -- the relatively low yield values for the fertilization/ irrigation treatment. The overall coppice yield of about 38 ODt/ha at the end of three growing seasons exceeded the amount produced in the four years of the first rotation for all sites and treatments.

Amount of biomass accumulated in the second rotation after three growing seasons was substantially greater than after three growing seasons in the first rotation (Table 1). The relative second to first rotation yield gains were largest for the control and irrigation treatments and lower for the fertilization and fertilization/irrigation treatments. Overall the second rotation had accumulated about 22.5 ODt/ha more biomass by age three than was accumulated in the same time period of the first rotation.

Table 1. Biomass yields for first and second rotations, by management strategy.

Management Strategy	Ovendry Biomass: Three Years Rotation 1st	Three Years Rotation 2nd	Four Years Rotation 1st	Four Years Rotation 2nd[1]	1st and 2nd Four Year Rotations Combined Total	1st and 2nd Four Year Rotations Combined Ave. Annual
	(- - - - - - - -	-	tonne/hectare	- - - -	- - - - -	- - - -)
Control	9	32	21	41	62	7.8
Irrigation	12	35	27	47	74	9.3
Fertilization	20	45	33	53	86	10.8
Fertilization/ Irrigation	22	40	37	57	94	11.8

[1] Assumes the second rotation will yield 20 ODt/ha more biomass at age four than was measured for first rotation harvest. A conservative assumption was based on second rotation to first rotation gain at age three (overall average gain was 22.2 ODt/ha).

The plantations were designed to achieve maximum productivity when harvested every four years. To compare second rotation yields with first rotation yields at harvest, we assumed that the second rotation would maintain the third year accumulated yield advantage into the fourth growing season. On average, the advantage was 22.5 ODt/ha. However, the rate of height and diameter growth in the coppice growth appeared to be slowing down faster in the later stages of the second rotation than in the later stages of the first rotation (Figure 2). Therefore, a more conservative second rotation yield advantage of 20 ODt/ha was used to project second rotation harvest.

Projected second rotation four year biomass yields were 41,47,53 and 57 ODt/ha for control, irrigation, fertilization and fertilization/ irrigation respectively. Combined first and second rotation biomass yields and average annual production values suggest that the investments of water and nutrients increased the site productivity potential. Greater growth and yield advantages were achieved from the investment of fertilization than by the investment of irrigation. In contrast, greater mortality has been measured on the fertilized treatment units, particularly in the second rotation. If this trend continues, the four year old second rotation yields for the fertilized units maybe too high.

SUMMARY

Dense Populus plantations for evaluating multiple four year rotation growth and yield from four management strategies have been established on two sites in central Pennsylvania. The establishment rotation has been harvested and the second rotation is nearing harvest. The results to date suggest that fertilization more than irrigation will increase both first and second rotation growth rates and biomass yields. Sprout total height and diameter growth rates were greater in the first and second growing seasons of the coppice rotation than same age growth rates in the establishment rotation. Increased growth rates and multiple stems/stump resulted in higher age specific accumulated biomass values in the second rotation than in the first rotation. Tree mortality, either due to stumps not sprouting following harvest or from inter tree competition, may become a more dominating factor of stand productivity than site selection or cultural investments.

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BIOMASS PRODUCTION OF *SALIX* 'AQUATICA' ON AN ABANDONED FIELD IN SOUTH FINLAND

ABSTRACT

The biomass production of *Salix* 'Aquatica' fertilized with sludge and planted on abandoned farmland in South Finland was studied during two, three-year rotation periods. The number of sprouts and the stand density were considerably greater during the second rotation than during the first. The dominant height and dominant diameter of the sprouts were slightly greater at the end of the second rotation, but the mean height and mean diameter slightly smaller. The mean annual production of leafless dry mass by this *Salix* species during the first rotation period was 3.0 - 6.1 t/ha/a, and during the second 6.5 - 7.6 t/ha/a. The leaf area index of the one to three-year-old sprouts varied from 4.5 to 6.5. Sludge fertilization increased production during the first rotation period. However, the effect of a second application of sludge was not significant owing to the fact that the amount of nutrients added was only small.

INTRODUCTION

The mass production of small-sized, hardwood stands was first studied in Finland at the beginning of the 1970's as part of a project on the cultivation and utilization of short-rotation timber (Hakkila et al. 1979). Research on short-rotation cultivation was continued in the PERA Project (Wood as an energy source) at the Finnish Forest Research Institute (Hakkila 1985), at the universities of Oulu and Joensuu and by a number of industrial enterprises. The purpose of these projects was to study intensive methods for producing biomass, based on short rotation periods, coppicing tree species and high growing densities. The initial aim was to produce wood raw-material for industry, but this was changed, following the oil crisis, to the production of energy wood.

The production of cultivation material for short-rotation plantations, and the establishment, management, nutrient status and economic viability of the plantations have been studied rather extensively in Finland (Harstela & Tervo 1981, 1983, Hytönen 1983, 1984, 1985, 1986, 1987, Kaunisto 1983, Kossi 1983, Sievänen 1983, 1984, Hytönen & Ferm 1984, Lumme et al. 1984, Saarsalmi 1984, Siira et al. 1984, Ferm 1985, Hakkila 1985, Lehtonen & Tikkanen 1986, Lumme & Kiukaanniemi 1987, Lumme & Törmälä 1988). *Salix* species of foreign origin have mainly been used in the short-rotation experiments carried out in Finland (Pohjonen 1987). The cultivation of birch, alder and poplar species has also been investigated.

There is not very much information available at the present time about the development of short-rotation plantations over longer periods, as well as about the effects on production of different planting densities and rotation periods. There is also a lack of information about the effect of coppicing of the plantation on production, especially when using longer rotation periods. This paper presents results for the development of a *Salix* 'Aquatica' plantation, fertilized with sludge, during two, three-year rotation periods. The results for the first rotation period have already been published earlier (Hytönen 1985).

The manuscript has been read by Lic.For. Ari Ferm and Prof. Eero Paavilainen. The measurements made in the field experiments, as well as the different work stages, have been carried out by Seppo Vihanta, Esa Heino, Viktoria Palonen, Keijo Polet and Maire Ala-Pöntiö from the Kannus Research Station, the experimental farm of the Foundation of Work Efficiency, and Rajamäki Forest Foreman College. The translation from Finnish to English was done by Mr. John Derome. Erkki Anttila and Asko Henttonen from Oy Alko Ab have influenced the progress of the work in many ways. I would like to extend my warmest thanks to all those mentioned above, as well as to those who have helped in other ways.

MATERIAL AND METHODS

Experimental design

The experiment was established in 1982 on a sandy mull field situated close to Alko Oy's Rajamäki factory ($60^{o}32'$ N, $24^{o}37'$ E). The field, which had been left fallow, was ploughed and 6,000 kg dolomite limestone/ha mixed into the topsoil at the same time. Twelve sample plots (300 m^2 in size) were marked out on the ploughed area and sludge spread on the plots at three levels, with three replications (Table 1). Application was done in 1982 before the willows were planted, and sludge again applied at half dosages in 1985 between the rows of willows. The control plots were fertilized each year with a multinutrient fertilizer during the first three years of the experiment. The control plots were no longer fertilized during the second rotation period.

Table 1. The fertilizer treatments

Treatment	First rotation	Second rotation
1. Control	Multinutrient fertilizer	-
2. Sludge 30	30 m^3/ha sludge	15 m^3/ha sludge
3. Sludge 60	60 m^3/ha sludge	30 m^3/ha sludge
4. Sludge 120	120 m^3/ha sludge	60 m^3/ha sludge

The sludge was obtained from Alko Oy's Rajamäki factory. The nitrogen content of the sludge was relatively high (Table 2) but that of phosphorus and potassium much lower. The heavy metal contents of the sludge were low. The dry-matter content of the sludge was 11.9 % at the first application, and only 1.6 % at the second. Owing to the lower dry-matter content, lower nutrient content and 50 % lower application level, the amount of nutrients given to the willows in the second sludge application was very small. In the case of nitrogen, for instance, 22 times less than the amount given in the first application (Table 2).

Table 2. Amount of nutrients (out of dry mass) in the form of sludge and multinutrient fertilizer.

Nutrient	Nutrient content of the sludge		Treatment[1]							
			Sludge 30		Sludge 60		Sludge 120		Control[2]	
			Dosage, kg/ha							
	1982	1985	1982	1985	1982	1985	1982	1985	1982	1985
N, %	9.60	7.30	389	18	778	35	1555	70	226	-
P, %	1.25	0.60	51	1	101	3	203	6	99	-
K, %	0.37	0.78	15	2	30	4	60	8	188	-
Ca, %	0.63	0.81	26	2	51	4	102	8	34	-
Mg, %	0.15	0.28	6	1	12	1	24	3	1	-
S, %	2.27	1.83	92	4	184	9	368	18	28	-
Fe, %	2.56	2.25	104	5	207	11	415	22	3	-
B, ppm	10	29	0.04	0.01	0.08	0.01	0.16	0.03	0.71	-
Cu, ppm	1040	1240	4.00	0.30	8.00	0.60	17.00	1.19		
Mn, ppm	189	105	0.80	0.03	1.50	0.05	3.10	0.10		
Zn, ppm	294	190	1.20	0.05	2.40	0.10	4.80	0.19		
Co, ppm	13	7	0.05	0.00	0.11	0.00	0.21	0.01		
Cr, ppm	14	25	0.06	0.01	0.11	0.01	0.23	0.03		
Pb, ppm	34	24	0.14	0.01	0.28	0.01	0.56	0.02		
Cd, ppm	9	1	0.04	0.00	0.07	0.00	0.15	0.00		
Ni, ppm	43	26	0.18	0.01	0.35	0.01	0.71	0.03		
Hg, ppm	0.7	0.002	0.00	0.00	0.00	0.00	0.01	0.00		

1) See Table 1.

2) Administered in three annual amounts.

The willows (*Salix* 'Aquatica', clone V769) were planted at a density of 80 cm (distance between rows) x 35 cm (distance between transplants in the rows) to give a density of 36,000 plants/ha. One-year-old rooted cuttings, whose shoots had been cut back to the stem, were used. Weeds were controlled mechanically using a tractor-pulled harrow only during the first summer. The three-year-old willow sprouts were harvested three years after planting. The productivity of manual harvesting in this experiment has been presented by Siekkinen (1986).

Measurements

The height and diameter distributions of the willows on the different plots were measured each year using a systematic sample. In order to avoid any possible edge effects, the rows along the edges of the plots were not measured (Zavitkovski 1981). The height of the sprouts from ground level up to the tip of the shoot were measured to an accuracy of 1 cm, and the diameter at a height of 10 cm above the ground to an accuracy of 1 mm. Sprouts under 20 cm long were not measured. Only the diameter was measured in 1986 and 1987. Information about the stand density (sprouts/m^2), sprouting capacity (sprouts/stump), mortality and possible animal damage was recorded at the same time.

Sample sprouts, cut at a height of 10 cm above the ground, were taken each year. After measuring the length and diameter, the sprouts were dried (1-2 days at 105 ^{o}C) and the leafless dry mass determined. The leaf dry mass was also measured and the leaf area of the plants was determined using a Li-Cor leaf-area meter.

The dry mass equations, which had the form $Y = aX^{b}\mathcal{E}$, were solved using the procedure reported earlier (Hytönen 1985, Hytönen et al. 1987). The dry-mass equations for the first rotation period have also been presented earlier (Hytönen 1985). Since the dry-mass equations calculated for the different fertilizer treatments for the period 1982-1984 did not differ from each other, the samples taken from the different fertilizer treatments were combined to form the same material. The dry-mass equations for 1985-1987 are presented in Table 3. Butt diameter and the product of the square of the butt diameter and the height (d^2h) were used as the independent variables. The butt diameter proved to be a better explainer than height, and almost as good a one as d^2h (Table 3).

Table 3. Dry mass equations for *Salix* 'Aquatica' sprouts. Equations have the form $Y = aX^b\varepsilon$, which after logarithmic transformation have been corrected with $s_e^2/2$. Y = dry mass (g), d = diameter at the base (mm), h = height (cm), a and b = constants, R^2 = degree of determination, V = coefficient of variation.

Compartment	Age of sprouts, a	N	$x = d^2h$ a	b	R^2 %	V %	$x = d$ a	b	R^2 %	V %	$x = h$ a	b	R^2 %	V %
Stem and branch mass	1	27	0.00254	0.93145	99	13	0.04894	2.66544	98	17	$0.4 \cdot 10^{-5}$	3.00553	98	19
	2	23	0.00221	0.96292	99	7	0.04076	2.84179	99	9	$0.6 \cdot 10^{-5}$	2.94294	98	17
	3	24	0.00202	0.97487	99	14	0.04845	2.76780	99	14	$0.3 \cdot 10^{-5}$	3.14469	94	34
Leaf mass	1	27	0.01253	0.70118	97	17	0.11595	2.00704	96	19	$1.0 \cdot 10^{-5}$	2.26113	96	21
	2	23	0.00232	0.82533	94	28	0.02763	2.44256	95	27	$1.7 \cdot 10^{-5}$	2.50760	92	34
	3	24	0.00020	1.02644	96	23	0.00698	2.84825	94	30	$0.01 \cdot 10^{-5}$	3.39428	95	26
Leaf-area	1	27	8.90343	0.57551	97	15	55.48100	1.64596	96	17	0.16877	1.85931	96	17
	2	23	1.44415	0.700608	94	25	11.81464	2.07406	94	24	0.02187	2.12733	91	30
	3	24	0.25133	0.85458	97	17	4.79900	2.37701	95	22	0.00053	2.81007	95	22

The growing season in summer 1987 was exceptionally cold (Fig. 1). The early part of the growing seasons in 1982 and 1985 were also cooler than the other years. The summer in 1983 was the warmest.

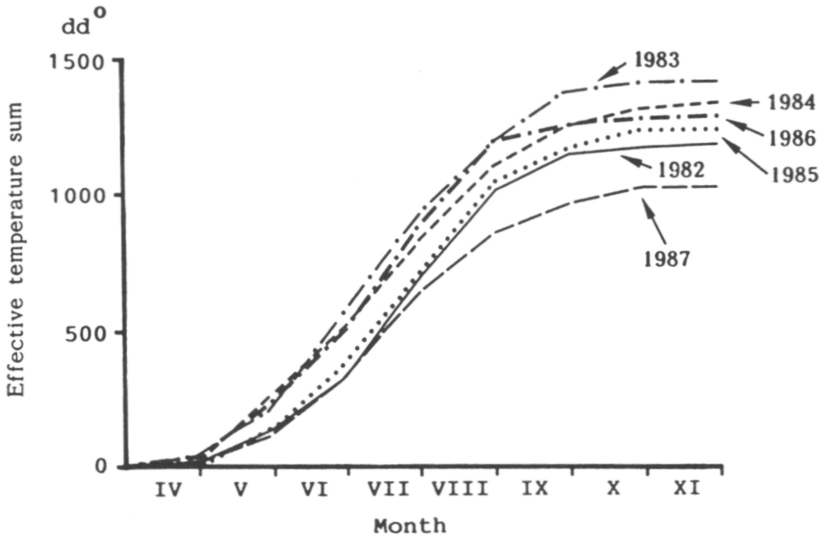

Fig. 1. Development of the effective temperature sum at Hyvinkää's Mutila weather station during 1982-87.

RESULTS

Distribution of sprout number into height and diameter classes

The distribution of the number of one-year-old willows into different height and diameter classes clearly followed a bimodal distribution (Fig. 2). The number of extremely short and thin sprouts was greatest in the one-year-old plantation. The death of short and thin sprouts, i.e. the first peak in the distribution, starts already during the first growing season. The frequency distributions of living sprouts approached the normal distribution during the second and third year.

The significance of the second smaller peak in the height and diameter distribution is more important, however, from the point of view of the total dry mass of the sprouts. The distribution of the above-ground leafless total biomass in different height classes has been drawn to illustrate this point in the figure showing the height distribution of the sprouts in 1985 (Fig. 2j). The number of short willows in the plantation is many times greater than the proportion of their biomass.

The distribution of the number of sprouts, dry mass of the stems and leaves and leaf area into different height classes in the one-year-old plantation are presented in Fig. 3. The proportion of short sprouts out of the total number of sprouts was considerably large, but out of the biomass small. For instance, the proportion of sprouts shorter than 110 cm out of the total dry mass of the willow plantation was only 4.6 %, but their proportion out of the number of sprouts 53 %. The corresponding values for the total leaf mass and total leaf area are 9.7 % and 13.9 %. The ratio between stem mass and leaf mass was different in the short sprouts. Measurement of short sprouts can be omitted without bringing about any appreciable increase in the error associated with the stem mass determinations. The amount of work can be considerably reduced and the measurements concentrated on selected sprouts.

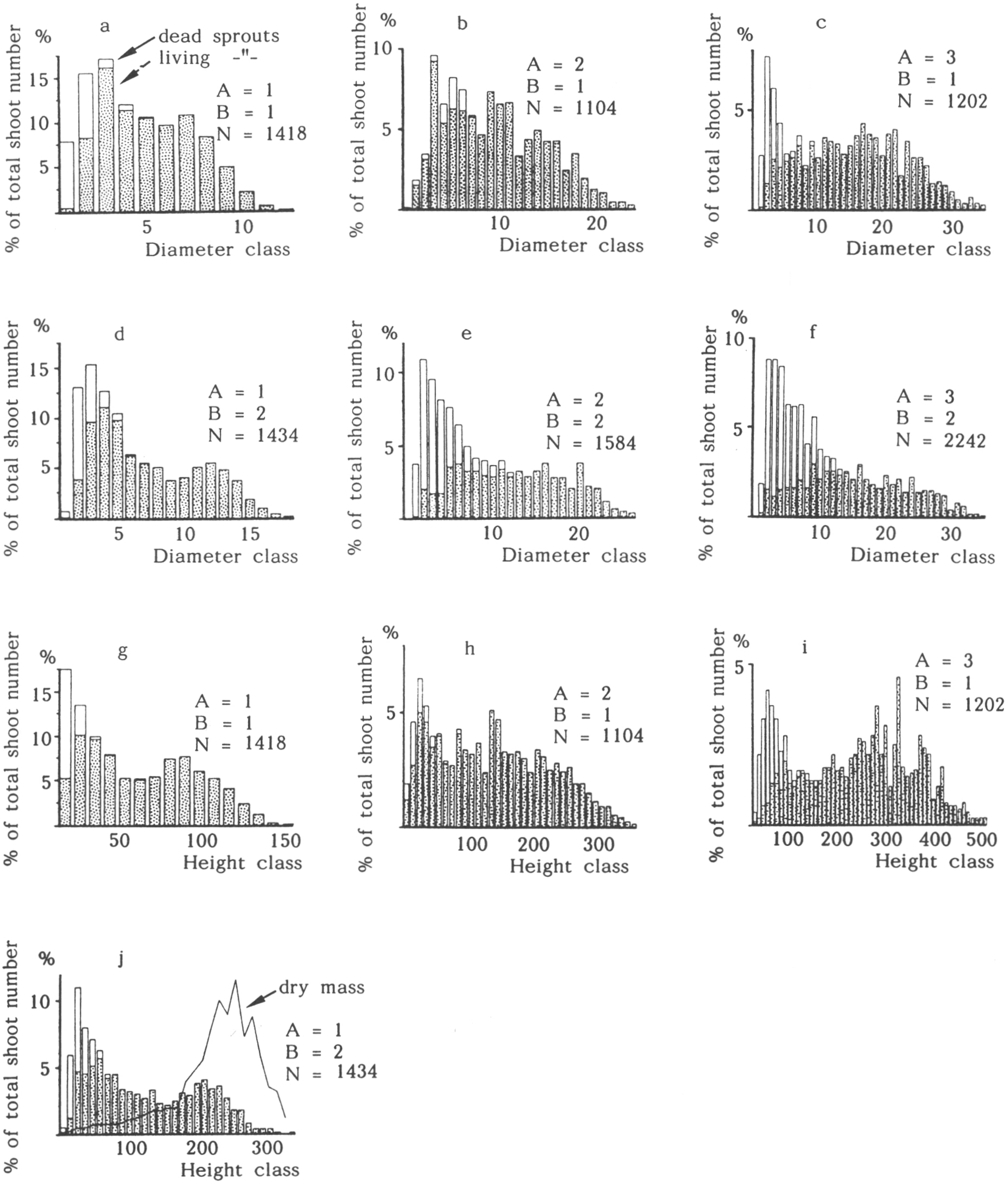

Fig. 2. Frequency distribution of stem diametre (a to f) and shoot height (g to j) and total above-ground dry mass in height classes (j). Diameters are in 1 mm classes and heights in 10 cm classes. A = age of sprouts (a), B = number of rotation period, N = total number of sprouts.

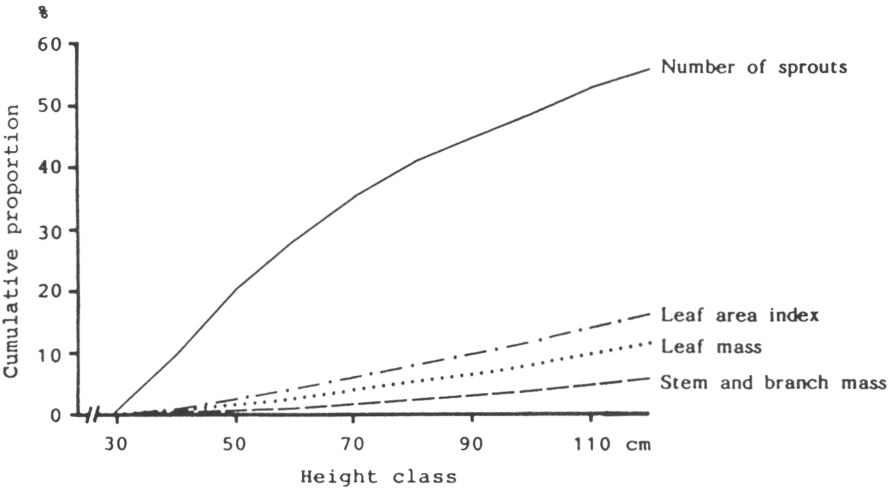

Fig. 3. Cumulative frequency distribution of the number of sprouts, leafless above-ground mass, leaf mass and leaf area index in height classes with 10 cm class interval. One-year-old sprouts in 1985.

Development of the number of sprouts

The plants cut back to the stump produced an average of 4.5 sprouts/stump during the first growing season (Fig. 4). By the following year the number of sprouts had fallen to 2.5 sprouts/stump. The reduction in the number of sprouts by the third year was only small. The willows coppiced well following harvesting, levels of 12 sprouts/stump even being reached. The fall in the number of sprouts started the next year, but levelled off at a fairly high level.

The original planting density was 36,000 transplants/ha. The mean number of sprouts during the first year after planting was 150,000/ha, and later fell to 75,000 - 90,000 sprouts/ha (Fig. 4). The maximum number of sprouts following harvesting came close to 400,000/ha. Despite this, the number of sprouts fell, owing to the death of small sprouts, to 150,000 - 250,000 sprouts/ha by the end of the third year.

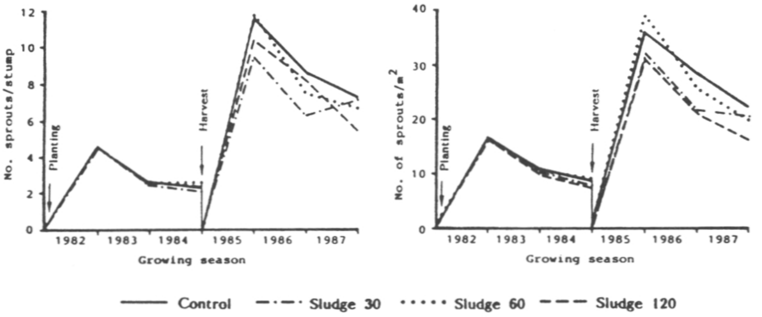

Fig. 4. Number of sprouts per stump and stand density

Height and diameter

The dominant diameter and height (thickest and longest sprout from each group of sprouts) increased linearily during the first rotation period (Fig. 5). The development of height and diameter was faster at the beginning of the second rotation period than at the beginning of the first rotation period. Following harvesting the height of the one-year-old sprouts was as great as that of the two-year-old sprouts during the first rotation period. The exceptional weather conditions during summer 1987 have clearly had an effect on the inferior growth during the year in question. Although the dominant height and diameter of the sprouts increased during the second rotation period, the mean diameter and mean height were lower, presumably due to the higher density (Fig. 5).

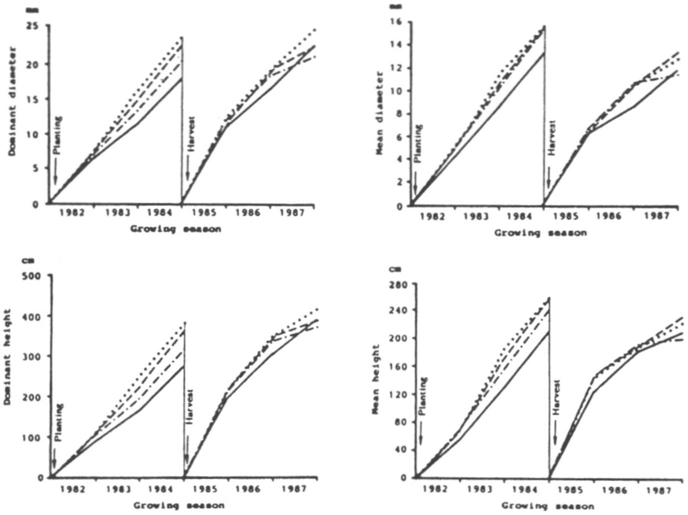

Fig. 5. Dominant and mean diameter, dominant and mean height of willow sprouts. See Fig. 4 for legends

Dry mass production and leaf area

The biomass production was low during the growing season following planting, only 0.5 - 0.9 t/ha dry matter (Table 4, Fig. 6). The dry mass production during the second year was six times greater and during the third year as much as 9...15 times greater than that during the first year. The willows fertilized with the commercial fertilizer grew rather poorly, and those given the medium sludge dosage (60 m^3/ha) grew the best. The differences in production were statistically almost significant in 1983 ($p < 0.062$) and in 1984 ($p < 0.056$).

Table 4. Above-ground leafless mass, leaf mass and total dry mass of willows.

Characteristic	Age of sprouts, a	Rotation, no.	Treatment 1) Sludge 30	Sludge 60	Sludge 120	Control
Above-ground leafless mass, t/ha	1	1	0.47	0.66	0.77	0.92
	1	2	4.07	5.42	5.24	5.00
	2	1	3.09	4.80	6.89	5.74
	2	2	14.76	14.50	17.10	14.33
	3	1	9.08	13.38	18.41	14.26
	3	2	19.50	20.37	22.88	21.84
Leaf mass, t/ha	1	2	2.14	2.62	2.57	2.39
	2	2	3.39	3.12	3.64	3.09
	3	2	3.59	3.77	4.24	4.06
Total above-ground mass, t/ha	1	2	6.21	8.04	9.48	7.39
	2	2	18.15	17.62	20.74	17.42
	3	2	23.09	24.12	27.12	25.90

1) See Table 1.

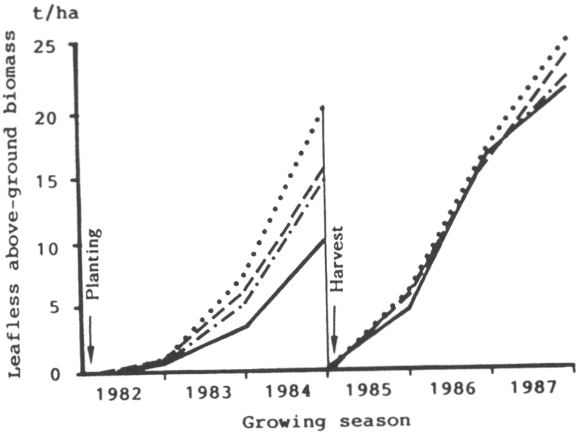

Fig. 6. Leafless above-ground dry mass of willow. See Fig. 4 for legends.

The mass of the one-year-old sprouts after harvesting was, on the average, 4.9 t/ha, i.e. about seven times greater than that of the same-aged sprouts during the first rotation period (Table 4, Fig. 6). During the second year the mass was as large as that measured at the end of the first rotation period. The annual production during the third year was lower than that during the previous year, presumably due to the exceptionally cool growing season. Reapplication of sludge had no statistically significant effect on the growth of the willows.

The total, leafless, above-ground mean annual increment of dry mass during the first rotation period was 3.0 - 6.1 t/ha/a. The corresponding mean annual increment during the second rotation period was 6.5 - 7.6 t/ha/a. The annual mean increment of the one-year-old willows was smaller in both rotation periods than that of the two or three-year-old willows.

The amount of willow leaf mass increased along with age, although to a considerably smaller extent than the amount of stem mass (Fig. 7). The leaf area index changed only slightly along with the age of the plants or increase in stem mass. The leaf area indices varied between 4.5 and 6.5 (Fig. 7). Although the leaf mass of the two-year-old willows was considerably greater than that of the one-year-old plants, there was no clear difference as regards the leaf area index. The reason for this may be the slightly different shape of the leaves of the two-year-old willows compared to that of the one-year-old willows.

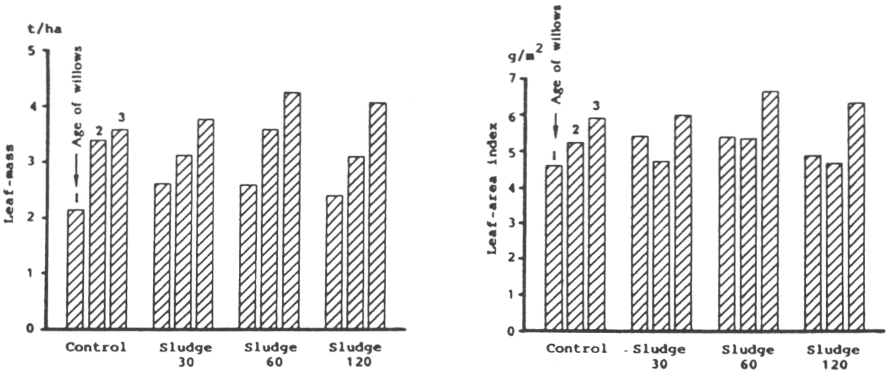

Fig. 7. Leaf mass and leaf area of willow during the second rotation period.

DISCUSSION

The distribution of the number of one-year-old sprouts into height and diameter classes clearly followed a bimodal distribution. The majority of the sprouts were short and thin. The second, smaller peak, represented the group of dominant sprouts. According to Mohler et al. (1978), the positive skewness reaches a maximum immediately before the suppressed plants start to die off. This phenomenon has started in the willow plantation already before the end of the first growing season. When a dense stand starts to thin out the most suppressed plants die out first. This results in a reduction in the skewness and even attainment of a normal distribution until thinnig starts again (Mohler et al. 1978). According to the diameter distributions, the willows in this experiment would most likely have gone through a second thinning-out stage when they reached the age of four of five years. According to Ford (1975) and Ford & Newbould (1971), bimodality of the distribution indicates a disjunct distribution of growth rates. This hierarchy is considered to have a distinct breakpoint. The increase in the relative growth rate from small plants to large is not uniform throughout the range of plant size. This type of distribution of relative growth rate has been described as the outcome of competition (Ford 1975).

The biomass of underdeveloped, declining sprouts which die off at a later stage is very small compared to the mass of the larger sprouts, even though their number is high. It would have been possible, when measuring the stem number series in the one-year-old plantation, to omit over 50 % of the sprouts without underestimating the stem mass by more than 5 %. If we are only interested in the amount of stem biomass, then the very smallest sprouts can be ignored.

The reduction in the number of sprouts as a result of mortality was a sign of internal competition within the stand. The reduction was at its greatest between the first and second years, which was the stage where the smallest sprouts died off. Harvesting of the three-year-old willow stand, and subsequent coppicing, increased three to fourfold the density of the stand calculated according to the number of sprouts. These new stump sprouts were also fully viable during the first growing season. The dominant diameter and height at the end of the second rotation period were slightly greater than those at the end of the first rotation period. In contrast, the mean diameter and height of the sprouts was, owing to the greater number of sprouts, smaller at the end of the second rotation period than at the end of the first.

The mean value for the leaf area index in the one and two-year-old stands was 5.1. The leaf area index reached 6.2 in 1987 when the willows were three years old. The maximum leaf area index was 6.7. The changes in the leaf area index were small, especially in the case of the one and two-year-old willows. The leaf area index values obtained here were slightly underestimated owing to the fact that the leaves were sampled at a time when the maximum leaf area had passed. Maximum leaf index values of 6.5 (Nilsson & Eckersten 1983) and 4.5 (Cannell et al. 1987) have earlier been obtained for short-rotation willow plantations.

Fertilization with sludge increased the production of the willows during the first rotation period. Although sludge was again applied at the beginning of the second rotation, the amount of nutrients given to the willows was very small compared to the amounts which they utilize (see Saarsalmi 1984, Ferm 1985, Hytönen 1985). The effect of the second application of sludge was thus small. Application of the sludge may also have had a detrimental effect on the stumps and roots of the willows. Crushing of the stumps has been found to have a harmful effect on the growth of *Salix* 'Aquatica' (Hytönen 1985). The growing conditions during the two rotation periods should also be taken into account when comparing the production results. The effective temperature sum during the 1987 growing season, especially, was exceptionally low. Early summer in 1982 and 1985 was also cool.

The development of the dry mass during the growing season when the willows were planted was rather modest, below 1 t/ha. The production during the first growing season following harvesting was many time higher. The overall production obtained during the second rotation period was greater than that during the first. The mean annual increment of the stem mass during the first rotation period was 3.0 - 6.1 t/ha/a. The corresponding figure for the second rotation period was clearly higher, 6.5 - 7.6 t/ha/a. The amount of leaf mass was also higher during the second rotation period. The higher production level obtained during the second rotation period is undoubtedly more a result of the greater number of sprouts per unit surface area than their greater size.

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PRODUCTION OF BIOMASS FROM SHORT-ROTATION COPPICE WILLOW IN NORTHERN IRELAND 1974-1987

Summary

In many developed countries the oil crisis of 1973/1974 prompted the investigation of alternative and renewable energy supplies. In Northern Ireland, because of a range of local circumstances, these investigations had additional relevance. These circumstances included:-

1. The absence of worthwhile reserves of traditional fossil fuels.

2. The extensive area of disadvantaged marginal land particularly in the west (196,000 hectares).

3. The viability of current farming practices - traditional milk beef enterprises - depends on financial support from public funds thereby increasing the problem of agricultural surpluses.

4. Low population densities in much of Northern Ireland - 27.5/ sq km in Fermanagh - and a relatively low *per capita* energy demand (2.5 toe per year) indicated that biomass could make a significant contribution as an alternative energy source.

Thus trials initiated in 1973 had the dual objective of determining the role of biomass as an alternative crop in the development of some 200,000 hectares of marginal agricultural land and investigating its potential as an alternative and renewable energy resource to meet local demands.

Initial trials identified *Salix* as the most suitable genera for the surface water mineral gley soils potentially available for biomass production. Yields of 12 - 15 tonnes per hectare per year dry matter have been achieved from *Salix burjatica* (Syn. *Salix* Aquatica Gigantea) in triennial harvesting cycles and at a planting density of 20,000 per hectare.

Wood chips made from willow have been used successfully over a 5 year period as a fuel for glasshouses showing substantial savings on oil fired systems. They have also been used to produce fuel briquettes which compare favourably in energy value and cost with briquettes from other resources. New biotechnological developments in fractionation and hydrolysis of wood offer opportunities for the production of fuel ethanol and other chemicals used as industrial raw materials.

Currently the harvesting of willow is being studied in association with the Engineering Division of Loughry Agricultural College, who have a joint Department of Agriculture/ETSU contract to design and build a harvester.

The impact of the rust disease *Melampsora epitea* on coppiced willow plantations is being assessed and variation which exists

in clonal susceptibilities is being exploited in new plantings being undertaken in sub-contract work for the University of Aberdeen.

In view of the emergence of rust as a serious disease problem on *S. burjatica* one of the most important areas for future investigation is clonal evaluation and selection to establish as wide a base of material as possible.

In early trials investigating spacing the annual harvesting cycles used did not allow the lower density plantings fully to exploit the site and resulting weed competition reduced yields. Difficulties in experimental design particularly in plot size experienced in harvest cycle trials pointed to the necessity for a re-examination of the interaction of harvesting cycles and planting densities.

Because of changing economic circumstances better types of land may become available for biomass production in Northern Ireland. This, together with the indications that higher nutrient levels may help to reduce the effects of disease make the reappraisal of fertiliser usage a priority.

Species/Spacing/Density

Following screening trials at Long Ashton Research Station (Stott 1971) and The Horticultural Centre Loughgall, (Anon. 1983) *S.* burjatica was selected as the most promising subject. Trials investigating the performance of *S. burjatica* at eight spacings were planted as unrooted cuttings in March 1975. From establishment nine annual harvests have been taken and the yields are given in Table 1.

Table 1

Yields (t/ha) of *S. burjatica* planted at eight spacings and harvested annually.

Spacing (m)	Fresh wt. 1984	Dry wt. 1984	Mean Fresh wt. 1976-84	Mean Dry wt.* 1976-84
1.0 x 0.25	44.0	19.4	38.7	17.0
1.5 x 0.25	37.1	16.3	30.6	13.5
2.0 x 0.25	35.9	15.8	26.5	11.7
3.0 x 0.25	24.2	10.6	20.6	9.1
1.0 x 0.50	33.2	14.6	30.7	13.5
1.5 x 0.50	32.5	14.3	27.9	12.3
2.0 x 0.50	33.1	14.6	24.1	10.6
3.0 x 0.50	25.7	11.3	20.1	8.8

* calculated using 1984 dry weight figures.

At the closer spacings, maximum yields were usually achieved within two years of establishment and have been maintained, there being no trend towards decreasing yields. The widest spacings showed a significant reduction in yield, indicating that complete ground capture had not been obtained to date, with annual harvesting.

Higher density increased competition and reduced cane numbers per stool. The 1.0 x 0.5 m spacing gave 16.6 canes per stool whilst the 3.0 x 0.5 m gave 29.9. Trials evaluating longer harvesting cycles have shown a reduction in cane numbers per stool from a mean of 16 for annual harvesting cycles to four for three year cycles. Based on these results and management considerations, it was decided that a spacing of 1.0 x 0.5 m (20,000/ha) had the best potential for optimising yield. Subsequent trials have indicated that square spacing (0.7 x 0.7 m) may be more productive than rectangular spacing at the same density.

The risks inherent in restricting the work to a single species were recognised at the outset and ongoing trials have evaluated newer clones and selections of *Salix*. Included were selections of *S. viminalis* shown to be more productive in trials elsewhere (Stott et al 1981), *S. viminalis* 'Bowles hybrid', *S. viminalis* 'Mullatin' and *S. Dasyclados* have given 14.0, 13.4 and 22.0 t/ha respectively. More recent clonal evalutions carried out on plantings made in 1982 showed that the Swedish selections SQ83, SQ69 and SQ683 also had potential as replacements for *S. burjatica* under Northern Ireland conditions yielding 18.3, 12.4 and 11.8 t/ha DM respectively.

Diseases

Since 1985 the rust disease *Melampsora epitea* has emerged as a serious disease on *Salix burjatica* Korso ♂ (Clone 056). First symptoms were recorded in early July in 1985 and 1986 but in 1987 it was already causing serious foliar symptoms by mid June. Development of the disease was rapid and caused premature defoliation in all three years. Yields from three year-old plots of *Salix burjatica* harvested in 1986 and showing severe rust symptoms in 1985 and 1986 indicated significant yield reductions. Infected *Salix burjatica* Korso ♂ plots gave a mean annual yield of 8.4 t/ha D.M. whilst Germany the female clone of *S. burjatica* which to date has shown a high level of resistance gave 13.4 t/ha DM.

In the current season rust has been recorded for the first time on *S. burjatica* Germany ♀ though at a very low level. By mid August 1987 *S burjatica* Korso ♂ had reached the point of defoliation and growth had virtually stopped at many sites.

Melampsora rusts have also been recorded in 1987 on all *S. burjatica* clones in our collection - 056, 075, 78146, 78196, 81090 from Sweden and P6001 from Finland. In addition *S. x Dasyclados*, *S. viminalis* Reifenweide and *S. calodendron* have also shown rust infection in 1987 though at much lower levels than on *S. burjatica* Korso o. The *Melampsora* in these instances has not been positively identified as *M. epitea* and indeed, particularly on *S x Dasyclados* and *S. viminalis* Reifenweide, the infections are of a different colour and are in larger more discrete spots rather than widely dispersed colonies.

Potentially even more damaging are the die-back organisms which have appeared as secondary infections in the stems after the rust induced defoliation has occurred. These have formed two distinct types of symptoms (a) pale ellipsoidal necrotic spots often associated with a node and having black, regularly arranged, perithecia embedded in the lesion. This organism was identified as *Glomerella miyabeana* (b) a general area of die-back usually occurring at the tip. The diseased tissue was often black and on occasions had pink structures associated with them. *Fusarium sambucinum* was identified as the causal organism, though in 1985 similar symptoms had been identified as being caused by *Cryptodiaporthe salicella*. The combined effect of these organisms has produced a high level of stool death in stands which have been freshly coppiced and where the current year's regrowth has been heavily infected with rust. Increased disease tolerance has been observed on physiologically older wood and where competition for light water and nutrients is reduced at the margins of the plantation. Certain experimental areas of *S. burjatica* have been kept rust free using fungicides: the most effective of these being benodanil (applied as 200 g/ha Calirus) and myclobutanil (applied as 300 g/ha Systhane). The latter appears to have significant eradicant action.

Pre-planting treatments

In 1976 trials were extended to two sites in Co Fermanagh to provide information on the economic performance of *S. burjatica* in the soils and climate where, commercial development might first take place. These trials are designed to study the effects of pre-planting treatments and harvesting cycles on yield. Soils at these sites are typical of much of the infertile disadvantaged mineral gley soils of the area containing a high proportion of silt and fine sand. Natural drainage is very limited and artificial drainage is both very expensive and of limited practical value. These conditions together with a high rainfall make conventional farming difficult (O'Neill 1981) and the successful production and utilisation of grass dependent on high levels of management.

Yields from annual harvests for four pre-planting treatments are recorded in Table 2.

Ploughing before planting has given consistently higher yields over the six-year harvesting period. Ploughing costs estimated at £40/ha were off-set by improved planting rates - it has been estimated that where ploughing has been carried out planting rate per man hour can be doubled. From these early trials it was apparent that the successful establishment of willow coppice was dependent on maintaining a pH of around 6.5. The maintenance of a weed-free environment to eliminate competition was also highlighted as a basic requirement. *S. burjatica*, although vigorous, is a poor competitor particularly in the establishment year.

Table 2

Yields (t/ha) of *S. burjatica* planted at 20,000/ha for 4 pre-planting treatments. 1977 - 82.

Pre-planting treatments	1977	1978	1979	1980	1981	1982	Mean fresh wt 1977-82	Mean dry wt* 1977-82
Paraquat only	4.9	11.6	13.8	21.1	15.5	18.1	14.1	6.6
Glyphosate	6.4	16.2	14.6	22.6	15.9	17.5	15.5	7.3
Paraquat+ Ploughing	11.9	21.2	24.7	23.5	19.8	21.6	20.4	9.6
Ploughing only	11.5	19.2	18.0	23.2	15.5	15.8	17.2	8.2

*Calculated using 1982 dry weight figures.

Harvesting cycles

Existing knowledge has shown that increased annual yield increments result from increasing harvesting interval. (Hamilton and Christie 1971). A trial was planted in 1976 to determine the optimum balance to achieve maximum yield with minimum harvesting cycle in order to overcome cash flow problems associated with the longer cycles employed in traditional afforestation. The results for annual, biennial and triennial harvesting cycles are given in Table 3.

Table 3

Yields (t/ha DM) of *S. burjatica* planted at 20,000/ha for three harvesting cycles. 1977 - 1982.

Harvesting cycle	1977	1978	1979	1980	1981	1982	Annual yield increment
Annual	4.1	7.8	8.0	10.6	7.8	8.8	7.8
Biennial		17.1		31.2		24.0	12.0
Triennial			40.2			47.5	14.6

These results confirm that the annual dry matter yield increment increases with longer harvest intervals. Growth in the year following establishment is consistently less than in subsequent years and this is reflected in the mean yields from the first harvest for all cycles.

The increasing annual yield increments recorded from biennial and triennial harvesting cycles - 12.0 and 14.6 t/ha dry matter respectively, led to observation plots being established at Loughgall in 1979 to investigate yields from four, five and six - year cycles. These plots gave their first harvest in winter 1985 and the pattern of increasing annual dry matter yield increments has been maintained. The four-year cycle gave a mean dry matter increment of 16 t/ha/yr, the five-year cycle 20.5 t/ha/yr, and the six-year cycle 30.7 t/ha/yr. These yields were obtained from small experimental plots and in order to estalish reliable commercial yields larger scale trials will be required.

Harvesting: At Loughry College a harvester has been developed under a joint Department of Agriculture/ETSU project. which continuously cuts and bundles (30-40 kg) 3 year-old *S. burjatica*. This machine is mounted on the three point linkage of a tractor which has modified controls to enable it to operate in reverse. While demonstrating the feasibility of mechanical harvesting this machine has several defects which cannot be overcome on this model. The two main problems are connected with achieving reliable tying of the twines and producing a tightly tied bundle. The first problem is partly due to the continuous operation of the machine and the second is due to there being insufficient expansion, of the bundle after ejection, to take up the slack in the twines.

A new design, based on the principles developed in the present machine, has been produced to overcome these defects. The new machine should be ready for testing in 1987 and fully developed for commercial use in 1988.

Specification for new harvester:-

Trailed machine on low ground-pressure tyres.

Cutting mechanism : 915 mm diameter circular saw

Intake system : Contra-rotating augers

Conveying and packing system: 1st and 2nd stage packing arms

Tying cycle time : <30 sec. (machine stops during tying)

Forward speed : 1 m/sec.

Output : 0.22 - 0.25 ha/hour

Bale diameter : 750 mm

Bale weight : 300 kg

Machine weight : 1800 - 2000 kg

Utilisation

In order to realise the full potential of biomass production in the marginal areas of Northern Ireland, the utilisation of the end product must be fully researched. This is particularly so in an area which does not have any tradition in using wood chip as an energy source. A number of end uses has been investigated and the identification of further uses for the products of a willow coppicing system is seen an essential pre-requisite to the establishment of larger areas of willow coppice for any future industrial uses which may develop.

Direct Burning: In view of the high costs of fossil fuels and their serious economic effects on the glasshouse industry in Northern Ireland, trials to investigate the use of willow biomass as an alternative fuel began in January 1983. A heating system incorporating an automatic stoker, gasifier and high efficiency boiler was installed. This was fed with willow chip at 50 - 75% DM and was used to heat a glasshouse measuring 30 m x 7 m.

Using the formula for total estimated heat loss quoted in the Ministry of Agriculture Fisheries and Food Bulletin 115 - Commercial Glasshouses - the energy requirement of an early tomato crop in this house was calculated as 311 GJ. Performance was monitored over the three year period 1983 - 1985 for a tomato crop planted at a density of 3.5 plants/m^2 planted in mid-February and cleared in early October. A minimum day temperature of 20°C was maintained until mid-May and 18°C subsequently. A temperature of 16°C by night was maintained throughout the heating period. Annual data are recorded in Table 4.

Table 4

Annual data for an early tomato crop using willow chip as the heat source

	Mean daily minimum air temp. (°C)	Mean boiler efficiency (%)	Mean daily fuel consumption (kg)
1983	2.7	85	225
1984	2.2	84	359
1985	3.0	87	254

The mean daily consumption of the boiler was 280 kg of chips at 70 per cent dry matter and residual ash percentage was 0.5%. The crop produced a mean yield of 24.8 kg/m^2, averaged over the 1983-1985 cropping seasons. Each tonne of tomatoes produced, required the energy input of 9.5 tonnes of chips at 70% dry matter, costing £125. Using 35 sec oil at £0.18/litre the energy costs per tonne of tomatoes would be £360. Comparative data for willow chip, coal and oil are shown in Table 5.

Table 5

Comparative data for alternative energy sources supplying 1.0 TJ

Fuel	Energy value (MJ/kg)	Total reqd (t)	Cost/t (£)	Cost/MJ (p)
Willow chip (70% DM)	14.2	88.1	17.6	0.12
Coal	32.6	43.7	90.0	0.28
Oil (35 sec)	44.2	30.2	135.9	0.31

Willow briquettes have been successfully manufactured by a commercial briquetting system using hydraulic screw presses. Density and energy value determinations have shown them to be fully competitive with briquettes manufactured from other resources. The briquettes manufactured from willow chip had a density of 1.16 g/cm^3 and an energy value of 19.5 MJ/kg.

Ethanol and animal feedstock: New biotechnological developments in biomass conversion in Canada and elsewhere have created opportunities for the economic production of ethanol as an octane enhancer to replace lead in petrol and the production of animal feed supplements. Fractionation is achieved using a steam explosion technique (Iotech Process - Murphy 1985).

Future work

Clonal evaluation and selection in *Salix*

Salix offers the best potential for biomass production on mineral gley soils but because of recent disease problems a much more detailed methodical and co-ordinated approach needs to be adopted towards clonal evaluation and selection in order to establish as wide a clonal base of material as possible. Limited data exists on the performance of approximately ten clones of *Salix* some of which, under Northern Ireland conditions, are as productive as *S. burjatica* Korso ♂. Five of these (*S. burjatica* Korso ♂, *S. burjatica* Germany ♀, *S. viminalis* Bowles Hybrid, *S. viminalis* 683, and *S. x Dasyclados*) have been selected for planting in the work being undertaken under a sub-contract with the University of Aberdeen. A total of 3.3 ha was planted in 1987. Propagation material has been difficult to obtain in quantity and a nursery area of 0.4 ha was planted at Loughgall in 1987 to provide planting material for future needs. It has been laid out in such a way as to enable early comparisons of the clones to be made albeit under an annual harvesting regime. In addition an area of mixed clones has been planted to assess the role such plantings would have in reducing disease pressure.

Spacing: Densities of 20,000 ha^{-1} are commonly used whenever coppicing systems with willow are being investigated but throughout the literature a wide variation of densities from 10,000 to 60,000/ ha is evident. The spacing of 1.0 x 0.5 m (20,000/ha) was adopted in Northern Ireland as the result of spacing trials laid down in 1973 which combined densities from 6,000 - 40,000/ha with annual harvesting. The main difficulty with the lower densities was that they did not achieve complete site capture with annual harvesting and competition from weeds reduced yields. This would not necessarily be the case with longer harvesting cycles. The interaction of planting densities and harvesting cycles will be further investigated in order to determine the shortest harvesting cycles likely to give the most advantageous cash flow to the farmer.

Experience has shown that plot sizes were too small in early trials. In future. individual plots will be sufficiently large to permit mechanical harvesting whilst at the same time allowing a reasonable number of comparisons to be be made - the minimum plot size will be 250 m ,giving a recorded area of 100 m2.

Nutrition: At the beginning of the work a decision was made that the production of biomass from short rotation coppice willow was to be a low input system on marginal agricultural land and that no fertilisers were to be used. Recycling leaf litter supplies approximately 130 kg N/ha/yr. Conditions have changed since those early decisions were made and the possibility of using higher grade land may justify the application of fertilisers. in addition, observations made when rust infections were at their height in August 1985 and 1986 showed that those stools which were nutritionally strongest avoided the worst effects of the disease and were least damaged by the subsequent ingress of secondary pathogens. Consequently work needs to be undertaken to develop fertiliser recommendations for local conditions and this work will be undertaken on the soil types and under those climatic conditions where it is considered that energy forestry has its greatest potential.

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VARIATION IN COPPICING CHARACTERISTICS AND BIOMASS PRODUCTION OF WILLOW CLONES AND HYBRIDS FROM THE BREEDERS POINT OF VIEW

ABSTRACT

The coppicing characteristics and biomass production of willow clones and their hybrids were studied. The material consisted of a clone test with 60 clones. The experimental material was selected on the basis of height growth out of 14 hybrid progenies of different willow species, hybrids and cultivars. The height, the diameter, the number of sprouts/ stool and the fresh weight/stool were measured. In all characteristics considerable variation was discovered both between families and clones. Broad sense heritabilities of the characteristics measured varied 0.71 - 0.81. The correlations between all the traits were positive. The ideotype of a short rotation energy willow with special interest in the growth form, was discussed.

INTRODUCTION

The genus *Salix* is very variable. It consists of more than 300 species with a very wide natural distribution. There is considerable variation in size, growth form and architecture of the crown both between and within the different species. The growth form of willows varies from small dwarf shrubs of the subgenus *Chamaetia* to middle-sized bushes of the subgenus *Vetrix* and small trees of the subgenus *Salix* (Skvortsov 1968). Frequent natural hybridization brings more variation to the willow populations, which provide the breeder with a huge and almost unutilized gene pool. More variation can be created artificially by inter- and intraspecific hybridization, which is easy in the genus Salix.

In willow breeding it is important to know what kind of willow we want to develop, i.e. what kind of combination of morphological and physiological characteristics are to be synthetized in order to give the highest biomass production per hectare and unit of time.

All the desirable characteristics are combined in a model plant - an ideotype, the concept of which was first introduced in agricultural plant breeding and later applied to forest trees (Donald 1968, Dickman 1975, 1985). The desirable components of an ideotype of a tree for short rotation energy forestry have been suggested by several authors (Siren, Lestander & Sennerby 1979, Fege 1981, Siren 1985, Koski & Viherä-Aarnio 1986).

The growth form and the coppicing characteristics of a short rotation energy willow can be regarded as important components of the ideotype. For example, the affinity for coppicing has an effect on the ease of reproduction and plantation establishment. On the other hand, the growth form of willows has an effect on harvesting efficiency.

One important characteristic of the ideotype is a high harvest index. The concept of harvest index (HI) has been used in agriculture for more than 20 years. Donald (1962) proposed the term for the ratio of grain yield to total biological yield. More commonly, the harvest index is defined as the proportion of harvested dry matter out of the total dry matter. In agriculture, the success of plant breeding has resulted more from the improvement in harvest indices than from an improvement in the production of total phytomass per unit land area (Kertesz 1984). In willows, too, we should increase the allocation of biomass to larger sprouts, instead of the smaller lateral branches and leaves. Thicker sprouts are more suitable for energy production purposes (Hytönen & Ferm 1984).

In willow breeding we should first know what combination of coppicing characteristics is the best for high biomass production. We should then know how high a proportion of the total phenotypic variation in these traits is genetically determined, and how these characteristics are inherited, separately and together. We are then in a position to decide whether these characteristics can be affected through breeding or by controlling the environment, or through a combination of both. In this connection we should also determine whether the different traits are interconnected due to genotypic or phenotypic correlations. If we carry out selection for one character, how do we affect the other one. Breeders often have to face the fact that improving an economically important trait simultaneously lowers another one (Velling & Tigerstedt 1984).

In order to speed up the breeding work selection for a specific trait often has to be made already at a very early age. However, it is necessary to have a high juvenile-mature correlation in order to be able to make early selection. Even willow breeding can be speeded up considerably by early selection.

Some of the questions presented above in this paper will be illustrated using a small material obtained from a willow clone test.

MATERIAL AND MEASUREMENTS

The material consists of 14 hybrid progenies of different willow species, hybrids and cultivars. Crossings between 13 willow clones were made in spring 1981. In the progenies obtained, within-family selection was made on the basis of height growth. The selected clones were planted in experiment 1036/1. In addition to the hybrid clones, the parent clones and one standard clone were also included in the experiment. The experiment is a clone test with 60 clones, 4 replications and 20 stools/clone. The experiment was established on sandy mull in spring 1984 at Vantaa, southern Finland, where it has since grown without fertilization and irrigation. The cutting sprouts were cut at the end of the first growing season, and the height and the number of sprouts were measured. The stools were then allowed to coppice. Two years later the height, diameter and number of 2-year-old stump sprouts and the leafless fresh-weight/stool were measured.

RESULTS AND DISCUSSION

Variation in different coppicing characteristics and biomass yield

Figures 1-4 illustrate the variation between clones in biomass production, number, average height and average diameter of two-year-old stool sprouts. In two-way analyses of variance there were highly significant differences between the clones as well as the replications in all the characteristics.

The average biomass yield of the experiment is 955 g/stool (Fig. 1). The most productive clones are hybrids of the families H 3159 S. x dasyclados x E 6761 S. caprea, H 3159 S. x dasyclados x E 4856 S. cv. Aquatica, H 3157 S. viminalis x E 4856 S. cv. Aquatica and H 3157 S. viminalis x E 6761 S. caprea. In some families the production of the best hybrids is as high as 3000 g/stool, which is 2-3 times better than the production of the parent clones. The production/ha of these superior clones cannot, however, be estimated owing to the small size of the sample plots.

The number of sprouts/stool varies from 3-15, the average for the experiment being 7.1 sprouts/stool (Fig. 2). Clones with the highest coppicing affinity are the hybrids H 3159 S. x dasyclados x E 6761 S. caprea, H 3159 S. x dasyclados x

E 4856 *S*. cv. Aquatica, H 3157 *S*. *viminalis* x E 4856 *S*. cv. Aquatica, H 3157 *S*. *viminalis* x H 3163 *S*. x *smithiana* and the mother clone H 3157 *S*. *viminalis*.

The average sprout height of the clones varies from 50 cm to 270 cm, the average for the experiment being 194 cm (Fig. 3). The variation in this characteristic resembles the pattern of variation in biomass production, but the differences are not so big. The hybrids H 3157 *S*. *viminalis* x E 6761 *S*. *caprea*, H 3157 *S*. *viminalis* x H 3163 *S*. x *smithiana*, H 3159 *S*. x *dasyclados* x E 6761 *S*. *caprea* and H 3159 *S*. x *dasyclados* x E 4856 *S*. cv. Aquatica have the longest sprouts on the average.

The average diameter of the sprouts varies from 3 mm to 17 mm, the average for the experiment being 10.8 mm (Fig. 4). The hybrids H 3157 *S*. *viminalis* x E 6761 *S*. *caprea*, H 3159 *S*. x *dasyclados* x E 6761 *S*. *caprea* and H 3159 *S*. x *dasyclados* x E 4856 *S*. cv. Aquatica have the thickest sprouts on the average.

There are also hybrids that are intermediate to or even worse than their parents in all the characteristics studied. In addition, there is still some considerable variation remaining within the families, despite the fact that selection was done on the basis of sprout height.

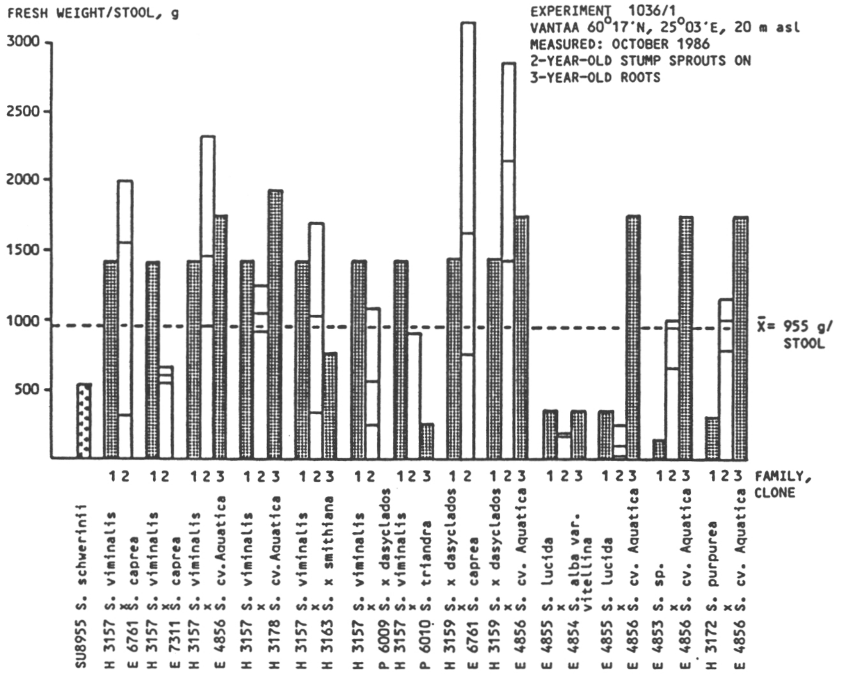

Figure 1. Biomass yield of willow clones and their selected hybrids in experiment 1036/1 at Vantaa. 1 = mother clone, 2 = hybrid clones (the best clone, the average of the family and the worst clone), 3 = father clone.

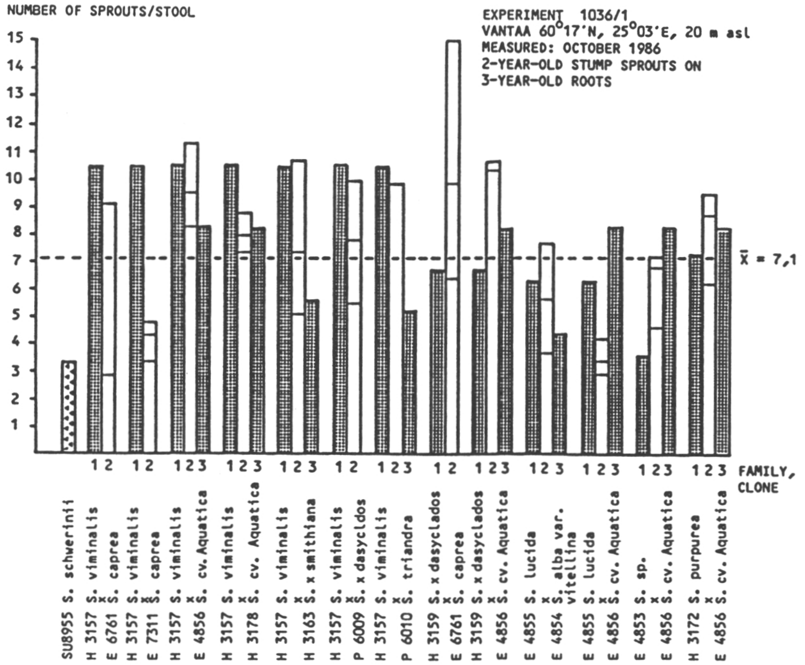

Figure 2. Number of sprouts/stool of willow clones and their selected hybrids in experiment 1036/1 at Vantaa. 1 = mother clone, 2 = hybrid clones (the best clone, the average of the family and the worst clone), 3 = father clone.

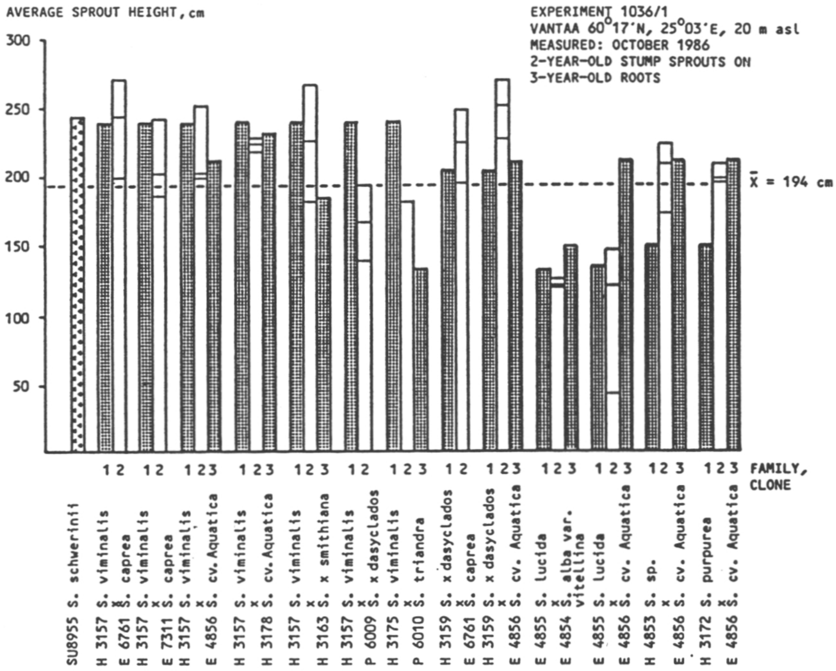

Figure 3. Average sprout height of, willow clones and their selected hybrids in experiment 1036/1 at Vantaa. 1 = mother clone, 2 = hybrid clones (the best clone, the average of the family and the worst clone) 3 = father clone.

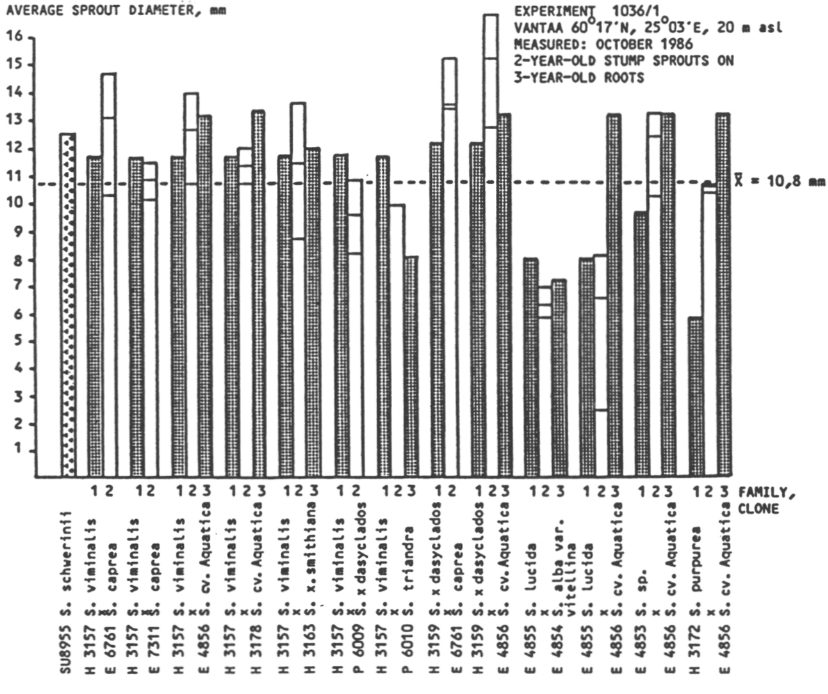

Figure 4. Average sprout diameter of willow clones and their selected hybrids in experiment 1036/1 at Vantaa. 1 = mother clone, 2 = hybrid clones (the best clone, the average of the family and the worst clone), 3 = father clone.

Correlations between sprouts of different type and age

Correlations between different coppicing characteristics measured on one-year-old cutting sprouts and two-year-old stool sprouts are presented in Table 1. Some selection for height growth and biomass yield can already be made in the first year after planting the cuttings. On the other hand, the real affinity of different clones for coppicing cannot be determined until after the first harvesting of the experiment, and very little can be deduced about the future biomass yield of a willow clone on the basis of the number of sprouts in the first year.

Table 1. Correlations between one-year-old cutting sprouts and two-year-old stool sprouts after harvesting.

1986 \ 1984	One-year-old cutting sprouts	
Two-year-old stump sprouts	Average sprout height	Number of sprouts/stool
Average sprout height	0.700 $p<0.001$	
Number of sprouts/stool		0.421 $p<0.001$
Fresh weight/ stool	0.591 $p<0.001$	0.144 $p=0.030$

Inheritance of coppicing characteristics and biomass production

The total phenotypic variation observed in the traits of interest to a breeder can be divided into different causal components of variance according to the following, well-known formulae (Falconer 1983):

$$V_P = V_G + V_E$$

$$V_P = V_A + V_D + V_I + V_E,$$

where V_P = phenotypic variance
V_G = genotypic variance component
V_A = additive " "
V_D = dominance " "
V_I = interaction " "
V_E = environmental " "

$\frac{V_G}{V_P}$ = degree of genetic determination, heritability in the broad sense, $h^2_{b.s.}$

$\frac{V_A}{V_P}$ = heritability in the narrow sense, $h^2_{n.s.}$

The ratio V_G/V_P expresses the extent to which individuals' phenotypes are determined by their genotypes, i.e. how high a proportion of the total phenotypic variation is due to genotypic differences. The ratio V_A/V_P expresses the extent to which phenotypes are determined by the genes transmitted from the parents. The heritability V_A/V_P determines the degree of resemblance between relatives, and is therefore of greatest importance in breeding programmes. When working with willows that can be easily propagated vegetatively, we can master the whole genotypic component of variance, V_G.

In this material the ratio V_G/V_P was calculated for average sprout height and diameter, number of sprouts/stool and fresh weight/stool according to Becker (1968). The values obtained are presented in Table 2. The broad-sense heritabilities of all characteristics are high. The estimates of the proportion of V_G include both the proportion of genotypic variation and genotype-environment interaction. Thus to some degree they over-estimate the proportion of the genotype. The genotype-environment interaction must be seriously taken into consideration in the case of willows that are cultivated as large monoclonal plantations. If the interaction variance component, V_I, is high, different clones for different sites should be selected carefully.

Table 2. Broad-sense heritabilities of coppicing characteristics and biomass yield.

Trait	$h^2_{b.s.} = V_G/V_P$
Average sprout height	0.77 (±0.03)
Average sprout diameter	0.81 (±0.03)
Number of sprouts/stool	0.73 (±0.12)
Fresh-weight/ stool	0.71 (±0.04)

Interdependence of coppicing characteristics and biomass production

Correlations between the traits of two-year-old stool sprouts are shown in Table 3. The length, diameter and number of sprouts are, of course, positively correlated with the fresh-weight/stool. The correlation between the average sprout height and average sprout diameter is naturally positive and highly significant. The positive correlation between the number of sprouts and their size probably indicates the general vitality of the stumps.

Table 3. Phenotypic correlations between traits of 2-year-old stool sprouts.

	Average sprout height	Average sprout diameter	Number of sprouts/ stool	Fresh-weight/ stool
Average sprout height	1			
Average sprout diameter	0.914 ($p<0.001$)	1		
Number of sprouts/ stool	0.442 ($p<0.001$)	0.442 ($p<0.001$)	1	
Fresh-weight/ stool	0.789 ($p<0.001$)	0.831 ($p<0.001$)	0.727 ($p<0.001$)	1

These correlations are phenotypic. They can be used to determine which trait should be measured instead of biomass yield if the biomass itself cannot be measured directly. The phenotypic correlation consists of the genotypic correlation and the environmental correlation (Falconer 1983). In order to be able to determine, how selection for one trait affects another, we should also know what proportion of the correlation is genotypic.

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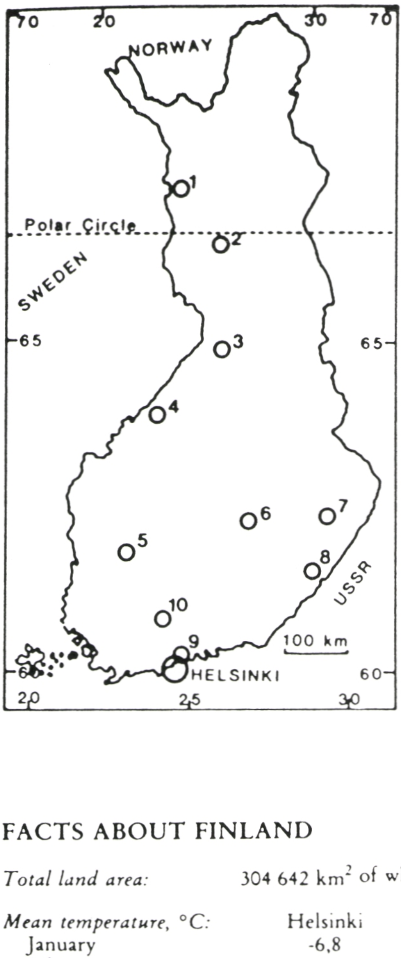

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FACTS ABOUT FINLAND

Total land area: 304 642 km^2 of which 60—70 per cent is forest land.

Mean temperature, °C:	Helsinki	Joensuu	Rovaniemi
January	-6,8	-10,2	-11,0
July	17,1	17,1	15,3
annual	4,4	2,9	0,8
Thermal winter (mean temp. < 0°C):	20.11.—4.4.	5.11.—10.4.	18.10.—21.4.

Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens

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