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Selection of fast-growing willow (Salix spp.) clones for short-rotation forestry on mined peatlands in northern Finland

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TIIVISTELMÄ: NOPEAKASVUISTEN PAJUKLOONIEN VALINNASTA POHJOIS-SUOMEN TURVETUOTANNOSTA POISTUVILLA SOILLA

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Possibilities of developing suitable willow (*Salix* spp.) clones for short-rotation forestry on mined peatlands in the northwestern coastal area of Finland were studied in a field experiment in which 300 willow clones were tested during 1985-1987. Most of the tested clones started to grow from cuttings on limed and fertilized peat soil. *Salix viminalis* L. clones of southern origin had a higher leafless above ground biomass production than the well adapted control clone and the iocal Finnish willows, but their winter hardiness was not satisfactory. The growth habit of some southern willows was also better than that of the control clone. It was also possible to select clones with a good sprouting capacity. There were few *Salix myrsinifolia* Salisb. clones of Finnish origin, which had better cold tolerance than all other willows tested and higher biomass production than that of the control clone. The most critical factor to be selected for is the optimal combination of winter hardiness and biomass production. This is attempted by selecting clones on the basis of this experiment for a breeding program.

Tutkimus käsittelee pajukloonien valintaa lyhytkiertoviljelyä varten Pohjois-Pohjanmaalla turvetuotannosta poistuvilla suonpohjilla. Suonpohjalle perustetussa kenttäkokeessa tutkittiin n. 300 pajukloonin (*Salix* spp.) kasvua ja ominaisuuksia vuosina 1985-1987. Saatujen tulosten perusteella pajujen jalostuksella voitaneen kehittää näihin olosuhteisiin paremmin soveltuvia klooneja. Pistokkaiden kasvuunlähtö istutuksen jälkeen oli valtaosassa testattuja klooneja hyvä kalkitulla ja lannoitetulla suonpohjalla. Etelästä siirretyt *Salix viminalis* kloonit olivat nopeakasvuisia ja biomassantuotoltaan selvästi kontrollikloonia ja Suomesta valittuja klooneja parempia, mutta niiden talvenkestävyys oli heikko. Eräät eteläiset kloonit olivat sekä kasvutavaltaan että vesontaominaisuuksiltaan hyviä. Toisaalta osa kotimaisista *Salix myrsinifolia* klooneista osoittautui sekä talvenkestävyydeltään että biomassantuotoltaan kontrollikloonia paremmiksi.

Keywords: short-rotation forestry, clone selection, willows, *Salix,* mined peat areas
ODC 238+176.1 *Salix* +165.44+(480.9)

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1. Introduction

Following the energy crisis of 1973, research was begun in Finland into the cultivation of rapidly growing woody plants for energy purposes. Various willows (*Salix* spp.) are regarded as the most suitable species for these purposes in Finland. Short-rotation cultivation of these species has been studied intensively since 1977 (Hakkila 1985). The wide genetic variation found in willows, their polyploid cellular structure and their potential for almost unlimited hybridization allow rapid progress also in breeding work (Stott 1984).

The short-rotation willow experiments carried out in Finland have employed fast-growing species from southern regions, whose production capacity is greater than that of native Finnish willows. The most extensively studied species are the common osier, *Salix viminalis* L., *Salix* cv. *aquatica*, and the hydrid *Salix dasyclados* Wimm. The high biomass production capacity of these species is due to their efficiency in assimilating carbon dioxide and their good adaptation to growing sites with an abundance of light, warmth, water and nutrients (Kaunisto 1983, Pelkonen 1983, Siren 1983, Grip et al. 1984, Saarsalmi 1984). Since they are grown from cuttings, they are easy to clone and to propagate in numbers sufficient to fill large plantations. They can be coppiced at relatively frequent intervals, 2-6 years, and their rootstock lives for an estimated 20-40 years (Siren 1983, Stott 1984).

The area of mined peatland in Finland is increasing. It has been estimated that by the beginning of the next century it may amount to approx. 30 000-100 000 ha (Ahonen and Huusko 1986). Most of the mined peat soils are situated in the northwestern coastal region. The use of these areas for agriculture is not an attractive alternative in northern Finland, whereas forestry offers a most interesting way to cultivate them.

Successful short-rotation cultivation of willows under the conditions prevailing on mined peatlands in the northwestern coastal area of Finland would require the selection and development of new willow clones. It has been observed that willow clones tested earlier have not adapted well enough to local conditions, especially as far as resistance to cold is concerned. Climatic conditions at the latitude of Oulu are relatively favourable, the effective temperature sum being 1000 to 1100 dd°C and the thermal growing season lasting 150 to 155 days a year. One could thus expect a theoretical yield of 10 to 20 metric tonnes of dry matter/ha/yr (Linder & Lohammar 1982, Sievänen 1983, Perttu et al. 1984, Nilsson 1986). The mean February temperature is −9.9 °C and the low lying coastal area is one of the most prone to night frosts of any area in Finland, however. An optimal willow clone should possess the following properties: good rooting ability in a peat soil, high biomass production and dry matter content, good cold tolerance, adequate resistance to fungal infections and insect damage, an erect, "trunk-like" growth habit and good sprouting potential (Stott 1984).

This present work forms part of a joint project being conducted by the University of Oulu, the Research Institute of Northern Finland, the Research Council for Agriculture and Forestry within the Academy of Finland and Kemira Oy. The project deals with willow short-rotation cultivation methods, economics of suitable production chain and especially the selection of suitable plant species. The aim of this study was to select suitable willow clones for energy forestry on mined peatlands in the northwestern coastal area of Finland. The willow clone tests were planned and set up jointly by both authors, while the former was responsible for the field measurements and processing of the results.

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Mr. Timo Mattila, Director of Research and Technology at Kemira Oy, his predecessor, Prof. Niilo Lounamaa and Prof. Gustav Siren, who kindly supplied most of the clone material tested. Energy Department of Finnish Ministry of Trade and Industry has also financed this research work. We wish to record our appreciation and thanks to all these people and institutions.

2. Materials and methods

The willow clone selection experiments were set up in 1985 at Hirvineva in the parish of Liminka (64° 42'N, 25° 20'E, altitude 50 m above sea level), a mire where the mining of peat had come to an end in 1982 and which still contained 20−40 cm of well-humified sedge peat (H7). The subsoil is of sandy moraine.

The site was deep-ploughed and harrowed in autumn 1984, harrowed once again and spread with dolomite limestone at a dose of 6000 kg/ha in spring 1985. It was fertilized with a mixture of a compound fertilizer, superphosphate and potassium chloride, involving a dosage of 75 kg N/ha, 90 kg/P/ha and 150 kg K/ha. The same fertilizers were applied again in 1986 and 1987. The area was devided in half and rows of cuttings were planted parallel with its short side on either side of a 1 m buffer zone in the middle. Ten 20 cm cuttings of each willow clone were planted on 17.6.1985, each clone in a separate row with the cuttings and rows 70 cm apart. The total plot measured 250 m x 20 m.

The control clone selected was *Salix dasyclados* P6011, which in earlier trials on the same site was found to be the best in terms of biomass production, cold tolerance and resistance to insect and fungal damage. Its leafless, above-ground biomass production in 1982-1985, had been between 0.5 and 9.3 metric tonnes of dry matter/ha/a. Its two-year-old shoots had survived the exceptionally cold winter of 1984-1985 well (Fig. 1) (Lumme et al. 1984, Lumme and Kiukaanniemi 1987). Cuttings of this control clone were planted to form every tenth row in each half of the plot thus resulting in a total of 17 control rows in each half of the plot. A total of 310 clones were tested and their provenances and their hybridization parentages are shown in Table 1.

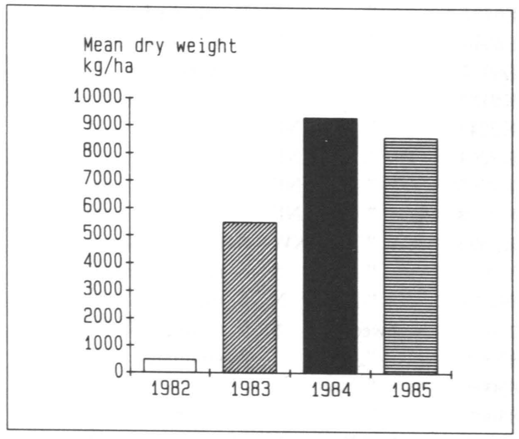

Fig. 1. Leafless, above-ground biomass production of the control clone *Salix dasyclados* P6011 at Hirvineva in 1982-1985.

Soil nutrient concentrations were determined in August 1985-1986 and in July 1987 according to Halonen et al. 1983. Variations in soil moisture levels were monitored using a tensiometer, along two transects across the length of the plot, one down the centre and one along one edge, each comprising of three units located at 60 m intervals with two tensiometers each, one at a depth of 5 cm and the other at 15 cm. The tensiometer readings were recorded twice a week between 28.6. and 15.9 in 1985 and 18.6. and 15.9. during 1986. In 1987 no measurements concerning soil moisture was performed. Soil temperature was measured with thermometers arranged in three rows of ten, placed at depths of 5 cm and 15 cm (Ericsson 1984) across the plot at the same points as the tensiometers and were read at the same intervals as the tensiometers. In 1987 thermometers were read three times a week.

Table 1. Clone codes, place of origin, original species, and hybridization parentage of the willows tested at Hirvineva.

Clone	Location		Species/Parents
B1	Sweden	N	S.myrsinifolia Salisb.
B3	"	N	"
B5	"	N	"
B6	"	N	"
B8	"	N	"
B10	"	N	"
E6648	Finland	S	S. phylicifolia L.
E6727	"	S	S. cinerea L.
E6946	"	SE	S. myrsinifolia x phylicif.
E6977	"	S	S. cinerea
K2183	"	NW	S. myrsinifolia
K2242	"	NE	"
K2264	"	NE	"
K2266	"	NE	"
K2278	"	NE	"
K2306	"	NW	S. phylicifolia
V78	"	S	S. myrsinifolia
P6010	"	N	S. triandra L.
8101	Sweden	S	S. viminalis L. x caprea L.
83001	"		S. viminalis
83004	"		"
83089	"		"
Schwerinii	USSR	E	S. schwerinii Wolf
SU-8302	USSR		S. schwerinii
V8957	"	S	"
V8958	"	S	"
056	Denmark		S. dasyclados Wimm.
075	Finland		"
083	Sweden	S	S. trianda x viminalis
670	"	S	S. smithiana Doll.
681	"	S	S. viminalis L.
683	"	S	"
690	"	S	S. smithiana
699	"	S	S. viminalis
801	"	S	S. viminalis
803	"	S	S. alba L.
902	"	S	S. viminalis
908	Denmark		S. dasyclados
V761	"		" cv. aquatica
V777	Finland		S. dasyclados x S. triandra
V778	"		S. purlamb x S. cv. aquatica
V779	"		S. dasyclados x S.cv.aquatica
V780	"		S. viminalis x S. cv. aquatica
V783	"		S. viminalis x S. smithiana
V784	"		"
V785	"		"
E7894	"		"
E7899	"		"
E4856	"		S. cv. aquatica

Clone	Location		Species/Parents
S15111	Sweden	S	S. viminalis
Ignaberga 1	"	S	"
Ignaberga 2	"	S	"
Finja 1	"	S	"
Finja 2	"		S. dasyclados
GB-80-1	Great Britain		S. vimin. x aurita L. x cinerea
GB-80-2	"		S. viminalis
GB-80-3	"		"
GB-80-4	"		S. dasyclados
GB-80-6	"		"
GB-80-7	"		S. viminalis
GB-80-9	"		S. smithiana
CSA-C1	Canada		S. acutifolia Willd.
CSA-2	Hungary/Canada		S. alba, L.
CSA 9	Poland/Canada		S. "
CSA 13	Italy/Canada		S. "
CSA 15	"		S. "
CSA 18	Yugoslavia/Canada		S. alba
CSA 20	"		S. "
CSA 21	"		S. "
CSA 22	"		S. "
CSD 1	Canada		S. dasyclados
LSL 4	"		–
LSL 5	"		–
NL 420	Netherlands		S. viminalis
NL 733	"		–
DK-87	Denmark		S. viminalis
DK-69	"		–
DK 1903-47	Canada		S. rubra Huds.
A 82-35IT	Austria		S. viminalis
P 1968-1160	Denmark		S. daphnoides Vill.
L-78-B3	Sweden		S. caprea L.
L-78-AD4	"		"
SF-68801	Finland		–
SV 2	Denmark/Canada		S. viminalis
SN 2	USA/Canada		S. nigra Marsh
SH 2	Denmark/Canada		S. helix L.
S. stipularis	Great-Britain		
S. caprea x sericans	"		
S. calodendron	"		
CE 78-3	–		S. dasyclados
CE 78-22	USSR		S. schwerinii
L-78-003	Sweden	N	S. viminalis
L-78-021	"	S	"
L-78-044	"		S. dasyclados
L-78-90	"		S. viminalis

Table 1 contd.

Clone	Location		Species/Parents
L-78-91	Netherlands		"
L-78-101	Sweden	S	"
L-78-112	"	S	"
L-78-120	"	S	"
L-78-133	"	S	S. dasyclados
L-78-137	"	S	–
L-78-146	"		S. dasyclados
L-78-183	"	S	S. viminalis
L-78-195	Netherlands		"
L-78-196	"		S. dasyclados
L-79-4	Sweden		S. viminalis
L-79-8	"	S	"
L-79-12	"	N	"
L-79-22	Finland		S. dasyclados
L-79-25	France		–
L-79-26	"		S. viminalis
L-79-30	Sweden	S	"
L-79-35	–		–
L-79-36	Sweden	S	S. viminalis
L-80-10	"	N	S. viminalis
L-80-13	"	S	S. dasyclados
L-80-15	–		S. viminalis
L-80-19	–		S. viminalis
L-80-22	Sweden		"
L-80-29	"		"
L-80-32	"		"
L-80-35	–		"
L-80-40	"		"
L-80-45	Denmark		S. dasyclados
L-80-49	"		S. viminalis imperiales
L-80-51	"		S. viminalis
L-81-01	Sweden	N	–
L-81-03	"	S	S. viminalis
L-81-10	"	S	–
L-81-15	"	N	–
L-81-36	"	S	S. viminalis
L-81-41	"	S	"
L-81-903	"	S	S. viminalis
S-HK-81-1			
" 2			
" 3			
" 4			
" 5			
" 6			
" 7			
" 8			
" 9			
" 10			
" 11			

Clone	Location	Species/Parents
" 12		
" 13		
" 14		
" 15		
" 16		
" 17		
" 18		
" 19		
" 20		
" 21		
" 22		
" 23		
" 24		
" 25		
" 26		
" 27		
" 28		
" 29		
" 30		
" 31		
" 32		
" 33		
" 34		
" 35		
" 36		
" 37		
" 38		
" 39		
" 40		
" 41		
" 42		
" 43		
" 44		
" 45		
" 46		
" 47		
" 48		
S-HK-81-49		
" 50		
" 51		
" 52		
" 53		
S-HK-81-2x		
S-HK-81-12x		
S-HK-81-25x		
S-HK-81-32x		
S-HK-81-34x		
S-HK-81-38x		
S-81-28-3		

Table 1 contd.

Clone	Location	Species/Parents	
S-81-28-5			
S-81-28-9			
S-81-28-10			
S-81-29-1			
S-81-29-3			
S-81-29-4			
S-81-29-5			
S-81-29-6			
S-81-29-7			
S-81-29-9			
S-81-29-10			
S-81-29-11			
S-81-29-12			
S-81-29-13			
S-81-29-15			
S-81-29-16			
S-81-29-17			
S-81-29-19			
S-81-29-21			
S-81-29-25			
S-81-29-27			
S-81-29-29			
S-81-29-32			
S-81-30-1			
S-81-30-2			
S-81-31-1			
S-81-31-2			
S-81-31-3			
S-81-31-4			
S-81-31-6			
S-81-31-7			
S-82-32-2			
S-82-32-4			
S-81-34-2			
S-81-34-3			
S-81-34-4			
S-81-34-6			
S-81-34-8			
S-81-34-9			
S-81-35-5			
S-81-35-9			
S-81-36-3			
S-81-36-6			
S-81-38-1			
S-81-38-2			
S-81-38-3			
S-81-38-5			
S-81-38-6			
S-81-38-7			

Clone	Location	Species/Parents	
S-81-38-8			
S-81-39-5			
S-81-39-6			
S-81-39-7			
S-81-39-9			
S-81-30-10			
S-81-40-2			
S-81-40-3			
S-81-40-4			
S-81-40-6			
S-81-40-8			
S-81-40-9			
S-81-40-11			
S-81-40-21			
S-81-40-24			
S-81-42-2			
S-81-42-3			
S-81-42-10			
S-81-42-12			
S-81-42-14			
S-81-42-18			
S-81-42-20			
S-81-42-22			
S-81-42-23			
S-81-42-24			
S-81-44-1			
HK-82-3-14		S. viminalis x	S. viminalis
		L-78-198	L81-02
HK-82-3-39		"	"
HK-82-3-40		"	"
HK-82-3-44		"	"
HK-82-3-48		"	"
HK-82-3-61		"	"
HK-82-3-66		"	"
HK-82-3-67		"	"
HK-82-3-73		"	"
HK-82-3-81		"	"
HK-82-7-8		S. viminalis x	S. viminalis
		L-78-091	L81-02
HK-82-7-11		"	"
HK-82-7-13		"	"
HK-82-10-5		S. viminalis x	S. viminalis
		L-78-195	L81-02
HK-82-10-26		"	"
HK-82-10-31		"	"
HK-82-10-39		"	"
HK-82-10-42		"	"
HK-82-10-43		"	"
HK-82-16-23		S. viminalis x	S. viminalis

Table 1 contd.

Clone	Location	Species/Parents	
		L-78-021	CE78-8
HK-82-16-24		"	"
HK-82-16-26		"	"
HK-82-16-29		"	"
HK-82-16-32		"	"
HK-82-16-59		"	"
HK-82-16-61		"	"
HK-82-16-63		"	"
HK-82-16-64		"	"
HK-82-16-65		"	"
HK-82-16-66		"	"
HK-82-16-67		"	"
HK-82-17-36		S. viminalis x	S. viminalis

Clone	Location	Species/Parents	
		L-78-021	L78-013
HK-82-17-76		"	"
HK-82-17-77		"	"
HK-82-19-23		S. viminalis x	S. viminalis
		L-78-090	L81-02
HK-82-19-41		"	"
HK-82-19-46		"	"
HK-82-19-52		"	"
HK-82-19-53		"	"
HK-82-19-57		"	"
HK-82-19-58		"	"
HK-82-19-69		"	"
HK-82-19-86		"	"

Stem biomass production was measured in 1985 by stripping off the leaves and cutting all the shoots at the base. The combined fresh weight of the shoots on each cutting was then determined in the field to an accuracy of 0.5 g. The dry matter content of each clone was determined in the laboratory by drying a separate fresh sample from each at 105° C for 2 days. The dry matter content figures for 1986 and 1987 may be regarded as indicative, since only 2–5 shoots per clone were available. In 1986 and 1987 the biomass production was calculated by regression based on measurements of the lengths and basal diameters of the shoots on all the stools of each clone and determination of the correlation of shoot length and diameter with shoot dry weight from sample shoots (Table 2) (Nilsson 1982, Hytönen 1985). Height growth increment was determined by measuring the length of every sprout on each cutting from the base to the lower edge of the apical leaf whorl to an accuracy of 1.0 cm.

Survival of the planted willows was calculated by counting the numbers of live cuttings representing each clone, in addition to which the number of shoots per cutting was counted and the growth habit assessed on two relative scales (see below). Relative ratings were also

Table 2. Dry mass equations of uneven-aged *Salix* sprouts, $Y = aX^be$, (Y = dry mass, a and b = standards), ($X = d^2h$, h = shoot height, cm, d = shoot diameter at 10 cm height, mm).

Species/ Age of sprouts	N	a	b	R^2 %
Salix viminalis				
1 yr	25	0.00395	0.9014	96
S. dasycl.				
1 yr	25	0.00331	0.9143	97
2 yr	25	0.00224	0.9838	98
S. myrsinif.				
1 yr	25	0.00244	0.9245	96
1 yr	25	0.00141	0.9501	98

used to estimate the extent of insect and fungal damage (see below). Frost damage was assessed in terms of the damage caused to the growing tips and lower leaves of the shoots, again using a relative scale (see below). There was an opportunity to assess frost damage during the growing season in 1986 and in 1987 when night frosts occurred in July and August. The relative scales employed for the assessment of growth habit, branching and insect and frost damage were the following:

1. Growth habit:
1 = upright, with straight shoots
2 = slightly trailing growth, with shoots somewhat bent
3 = markedly trailing growth, with shoots highly bent
4 = excessively trailing growth, with some of the shoot growing along the ground
2. Branching:
0 = shoot not branched at all
1 = shoot possessing a few poorly developed branches
2 = large numbers of poorly developed branches or a small number of strong branches
3 = large numbers of strong branches, poor apical dominance
4 = entirely bush-like growth habit
3. Frost damage:
0 = no visible damage
1 = drooping crown
2 = crown drooping and black, middle and lower leaves dark in colour
3 = crown black or severed, middle and lower leaves much blacker than normal
4 = all leaves black, some darkening of the stem
4. Insect damage:
0 = no visible damage
1 = slight feeding at the crown
2 = 50 % destruction of the crown, slight feeding on lower leaves
3 = crown destroyed, marked feeding on lower leaves
4 = almost 100 % defoliation

The biomass and height growth increment results were tested statistically using a one-way analysis of variance and correlation analysis, the clones to be examined being tested against the nearest two control rows on the same side of the plot.

The principal properties of the clones tested, as recorded in 1985 and 1986, are set out in Tables 6 to 10. The figures in the last column of each table are the growth habit and branching assessments, amounts of frost damage and numbers of shoots per stool in 1986. The symbols (*) used in the Tables 6 to 10 refer to statistical significance compared to the control clone P6011 in terms of biomass production and height increment: * = $p<0.01$ and ** = $p<0.001$.

3. Meteorological conditions at Hirvineva in 1985–1987

Mean June, July, August and September temperatures in 1985 were close to the long-term means, only the colder weather in July departing markedly from the average values (Table 3). The effective temperature sum for the growing season was the same as the long-term mean. In 1986 May and June were warmer than normal but August and September were exceptionally cold. The effective temperature sum was somewhat lower than the long-term mean. The whole growing season in 1987 was exceptionally cold. The effective temperature sum was clearly lower than the long-term mean (Table 3).

Table 3. Mean temperatures (°C) and effective temperature sums (dd°C) at Hirvineva for June, July, August and September 1985–1987 and corresponding long-terms means for 1931–1980.

	Mean temp.°C			Long-term	Temp. sum dd°C			Long-term
	1985	1986	1987	mean °C	1985	1986	1987	mean dd°C
May	5.6	8.8	6.9	7.3	51	123	75	95
June	13.0	15.5	12.2	12.8	241	315	216	240
July	15.2	15.8	14.2	16.2	316	336	284	340
August	14.3	10.9	10.4	14.0	287	183	160	270
Sept.	8.5	5.2	7.1	8.4	110	44	65	105
					1051	1001	800	1050

Precipitation was well below average in June and July 1985 and above average in August and Septemper, while in 1986 it was well below average in June, average in July and well above it in August and September. In 1987 precipitation was higher than the average most of the growing season (Table 4).

Table 4. Precipitation (mm) at Hirvineva in June, July, August and September 1985–1987 and corresponding long-term means for 1931–1980.

	Precipitation mm			Long-term
	1985	1986	1987	mean mm
June	24	25	85	57
July	25	71	87	71
August	103	180	104	71
September	66	97	56	57

4. Results

4.1. Physical and chemical properties of the soil

In 1985 soil temperatures were below normal throughout the growing season (Fig. 2). The normal maximum soil temperature at depth 15 cm in summer is 14 to 18 °C. Soil temperatures were much higher in 1986 from June to the beginning of August, but fell below those for the previous year later on account of the exceptionally cold August weather. In 1987 soil temperatures were below normal throughout the growing season (Fig. 2). A temperature differential of 1 to 2°C existed throughout between the centre and edges of the plot in 1985 to 1986.

The two soil moisture measurement transects gave similar results, although transect located in the centre of the plot showed a greater variation than did the transect at the edge in 1985 (Fig. 3a). Soil water tension levels would rise higher during dry periods in the centres than at the edge. The maximum in soil water tension was reached in mid-July, with 119.5 cm H_2O, or pF 2.08, recorded at the depth of 5 cm in the centre. Soil moisture was higher for the first half of the growing season in 1986 than in 1985, but fell to an exceptionally low level in response to the rainy weather experienced in August (Fig. 3b). Again the maximum tension values were recorded in mid-July, 180 cm H_2O, or pF 2.26 at the 5 cm depth in the centre of the plot.

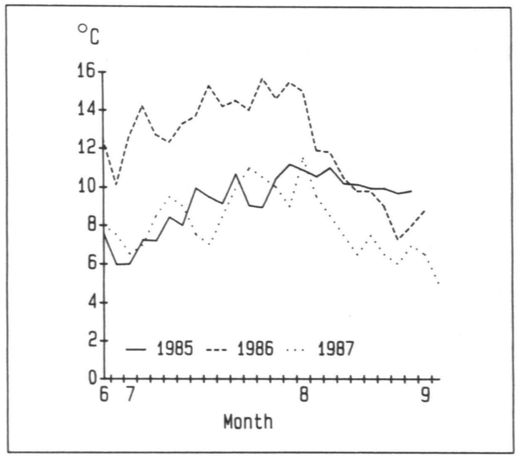

Fig. 2. Soil temperatures (°C) at depth 15 cm in 1985–1987.

The pH of the peat was low before liming, as were nutrient levels, except for ammonium nitrogen and exchangeable magnesium prior to fertilization (Table 5).

4.2. Properties of the willow clones

4.2.1. Survival

The survival of the planted cuttings in 1985 varied from one clone to another in the range

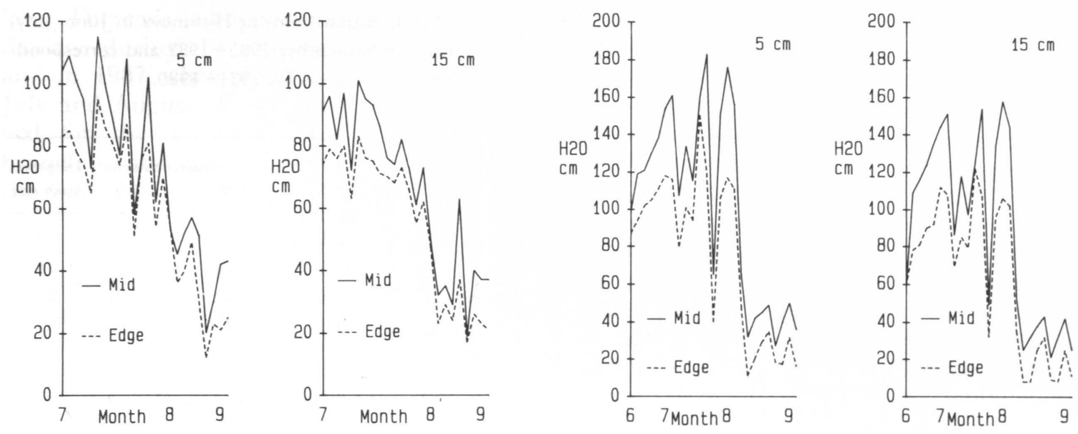

Fig. 3. Soil water tension (cm H_2O) at depths 5 cm and 15 cm along the centre and edge transects in 1985 (a) and in 1986 (b).

Table 5. Soil pH and nutrient status at the depth of 0–20 cm before and after liming in 1985 and fertilization in 1985–1987.

Soil parameter			Before fertilization	After fertilization 1985–1987
pH			4.80	6.2-6.4
Tot N		%	1.98	2.0-2.1
NH_4-N		mg/l	21	45-53
NO_3-N		-"-	00.0	23-30
soluble	P	-"-	00	34-38
exch.	K	-"-	9	273-285
exch.	Mg	-"-	87	254-268
exch.	Ca	-"-	520	1879-1900

30-100 %, the best rates being recorded for the hybrid series SHK81 (mean 99.8 %) S81 (mean 98.9 %) HK82 (mean 98.6 %) and GB (mean 98.3 %) (Tables 6,7,8,9). The *Salix schwerinii* Wolf clones also established themselves well (mean 97.5 %) as did the series L (mean 96.4 %) (Tables 6 and 9). All these fared somewhat better than the control clone P6011 (96.1 %). Survival was satisfactory in the series V777 and V780 (mean rate 88.8 %) and in the *Salix myrsinifolia* Salisb., *S. phylicifolia* L. and *S. triandra* L. clones (mean 89.0 %) (Tables 6 and 10).

4.2.2. Biomass production

Mean leafless, above-ground biomass production for the control clone *Salix dasyclados* P6011 was 6.57 g dry matter per cutting on one half of the plot in 1985 (Figs. 4 and 5, p.81). The respective figure for the other half of the plot a mean biomass production of 6.13 g dry matter per cutting.

The mean leafless, above-ground biomass production of the clones tested varied in the range 0.39–53.5 g dry matter per cutting in 1985. The most productive were the hybrid series SHK81 (range 7.0–53.50 g) and S81 (range 3.0–45.6 g), while substantially lower figures ($p<0.01$) were obtained for the series HK82 (range 0.27–24.3 g), L (range 0.63–22.9 g) and GB (range 6.9–20.4 g). The lowest production rates of all were recorded in the *Salix myrsinifolia*, *S. phylicifolia* and *S. triandra* clones (range 0.78–10.9 g). The corresponding figures for the Finnish hybrids V777 and V780 was range 2.1–15.3 g, and that for the *Salix schwerinii* clones selected in the USSR 2.3–10.1 g (Tables 6-10).

Altogether in the first growing season there were 86 clones which had a greater leafless, above-ground biomass production than that of the control P6011 clone ($p<0.001$ for 63 clones, $p<0.01$ for 22 clones) (Fig. 6, p. 82).

The mean, leafless above-ground biomass production of the P6011 clone in 1986 was 84.3 g dry matter per stool on one side of the plot and a mean biomass production of 85.0 g dry matter per stool on the other side (Figs. 4 and 5). The willows tested did not grow well in 1986 on account of the exceptionally cold weather in August (Table 3). There were only five clones with a leafless, above-ground biomass production greater than that of the P6011 clone ($p<0.01$) (Tables 6-10, Fig. 7).

In 1987 biomass production of the two year old shoots of the control clone P6011 was measured only from control rows, which were close to those tested willows having survived the winter 1986 to 1987. The mean leafless, above-ground biomass in the control rows was 148.3 g dry matter per stool (sum of years

Table 6. Properties of the *Salix* clones, series L, GB and V.

Clone	Survival % 1985	Survival % 1986	Biomass prod. g/cutting (d.w.) 1985	Biomass prod. g/cutting (d.w.) 1986	Dry matter content % 1985	Dry matter content % 1986	Height growth cm 1985	Height growth cm 1986	Growth habit/ frost damage/ shoots · stool^{-1}
L76–44	100	90	5.6	60.7	27.1	38.7	50.5	102.5	2/1/2/3.0
L78–21	100	70	7.8	26.5	25.3	36.8	71.6	88.2	2/1/1/2.1
–90	100	0	22.8**		28.5		106.5**		2/2/
–91	100	0	22.7**		26.8		114.2**		2/1/
–112	100	90	17.9	54.8	27.4	39.0	99.7**	116.9	2/0/1/3.6
–133	80	60	4.8	64.2	27.7	38.6	48.4	108.3	2/1/2/2.6
–183	90	90	29.2**	34.2	29.9	39.7	92.0**	98.6	2/2/1/2.6
L79–12	100	80	11.3	5.4	27.4	38.6	67.5	73.9	2/1/1/1.3
–22	90	80	4.2	66.8	28.9	39.6	49.7	106.8	2/1/1/3.5
–25	100	100	11.6	44.9	27.5	39.2	56.9	111.1	3/2/1/2.7
–35	100	100	7.7	80.9	26.0	37.4	74.5	118.3	2/2/1/3.2
L80–22	100	60	13.8	29.5	26.7	37.9	76.9*	96.0	2/1/1/2.6
–29	100	70	13.3	25.0	24.8	35.7	75.4	97.2	2/1/1/3.6
–45	100	100	3.8	70.7	30.7	39.9	48.6	101.9	2/0/1/4.2
L78–B3	100	100	1.6	55.3	43.1	48.6	23.0	93.3	2/0/0/4.6
L78–AD4	90	90	4.5	42.0	37.5	43.5	17.1	109.3	2/0/0/5.1
075	90	80	12.3	58.8	32.8	41.2	63.4	90.0	2/2/1/3.9
GB–80–03	100	0	20.4*		27.1		89.4**		2/2/
CE–78–03	100	70	10.4	30.9	23.5	34.6	60.3	99.2	2/2/2/2.0
–22	100	60	10.4	65.4	28.5	39.7	66.3	128.8*	2/2/1/2.5
CSD–01	100	80	11.3	64.8	23.4	34.7	64.3	112.4	2/1/2/2.4
LSL–05	100	90	9.0	95.4	28.7	39.7	63.6	118.2	2/2/0/5.0
V761	80	80	2.1	97.8	25.6	36.4	37.2	109.2	2/0/1/3.6
V777	70	90	15.3	77.1	25.4	37.1	65.1	116.3	2/1/2/3.2
V778	100	70	3.8	62.6	25.7	36.9	43.4	128.1*	1/0/1/2.1
V779	90	100	8.0	92.8	25.1	35.9	66.2	125.7	2/1/1/2.7
780	100	90	8.2	47.8	27.8	38.6	53.9	108.0	2/2/1/2.0
SH2	100	50	12.5	14.2	25.6	36.3	93.3**	92.2	3/1/1/2.8
Finja 2	100	90	7.7	65.4	27.3	39.1	62.4	121.2	2/1/1/3.0
Tofta 2	80	60	13.3	43.6	30.2	40.8	32.8	80.1	2/0/0/4.2
S.stipularis	100	90	13.2	33.3	26.7	37.9	87.0**	96.6	2/1/1/3.1

Table 7. Properties of the *Salix* clones, crossing series S81.

Clone	Survival %		Biomass prod. g/cutting (d.w.)		Dry matter content %		Height growth cm		Growth habit/ frost damage/ shoots · stool^{-1}
	1985	1986	1985	1986	1985	1986	1985	1986	
S81−28−10	100	10	36.5**	13.6	26.5	37.8	112.8**	117.0	3/1/1/1.0
S81−29−01	100	10	20.0*	18.7	25.1	36.9	85.1*	111.0	3/2/2/2.0
−03	100	10	24.2**	27.4	25.6	36.9	105.3**	93.5	2/1/2/2.0
−04	100	10	31.0**	6.9	29.2	40.6	105.8**	78.0	2/2/1/1.0
−05	100	10	22.1**	9.5	27.0	39.7	97.2**	62.5	2/2/1/2.0
−06	100	0	38.1**		28.7		103.4*		2/3/
−07	100	40	25.1**	19.6	27.7	38.9	96.9**	102.6	2/2/2/2.3
−10	100	10	34.6**	20.7	27.5	39.9	113.6**	116.0	2/2/2/1.0
−11	100	0	29.1**		27.8		112.6**		2/1/
−12	80	0	29.6**		27.3		108.0**		2/2/
−13	100	0	45.6**		26.5		133.2**		2/2/
−15	100	30	26.3**	36.1	25.7	36.7	104.2**	(137)	2/1/2/1.7
−16	100	30	27.5**	17.6	27.1	39.3	113.4**	94.2	2/1/1/1.7
−17	100	10	22.6**	14.0	27.0	39.2	88.9**	96.0	2/2/2/1.0
−19	100	0	30.6**		26.2		122.7**		2/2/
−25	100	0	22.0*		27.2		111.1**		2/2/
−27	100	10	28.0**	19.3	25.9	36.7	113.8**	121.0	2/2/1/1.0
−29	100	50	24.8**	24.3	29.1	39.5	100.6**	113.4	2/2/1/2.2
−32	90	0	23.2**		30.0		81.7*		3/2/
S81−30−01	100	10	32.9**	18.7	26.7	37.1	104.3**	104.0	2/1/1/1.0
−02	100	50	35.7**	68.0	30.6	40.0	100.6**	105.1	2/2/1/2.4
S81−31−01	100	45	20.7*	25.0	25.7	37.0	85.1	88.7	2/2/1/2.8
−02	100	80	23.1**	19.9	27.8	38.9	93.8**	87.6	2/2/1/2.3
−03	100	20	20.9*	32.0	26.9	37.8	86.9	92.8	2/2/1/3.0
−04	100	80	17.7	53.2	26.9	37.5	85.1*	101.5	2/3/1/2.5
−06	100	20	22.1*	10.4	28.0	39.2	106.5**	64.0	2/1/1/1.5
S81−34−02	100	0	20.2*		24.9		95.2**		2/1/
−03	100	80	13.4	42.0	23.1	34.4	84.3	101.2	2/1/1/3.1
−06	100	100	13.1	42.3	25.6	36.8	91.3*	102.9	2/1/2/2.4
−08	100	90	11.5	45.3	28.1	39.5	71.0	104.4	2/2/1/3.8
−09	100	70	24.3**	45.9	27.2	38.6	99.2**	106.7	2/1/1/3.3
S81−38−01	100	0	24.9**		25.9		117.1**		2/1/
−02	90	0	21.5*		27.5		93.6**		2/2/
−05	100	0	20.6*		24.7		105.5**		2/1/
−06	100	30	26.6**	3.9	28.3	39.7	104.3**	57.7	2/2/1/1.0
−07	90	20	33.8**	44.9	28.3	39.9	103.3**	114.7	2/2/2/3.5
−08	100	0	31.0**		29.9		108.2**		2/2/
S81−39−05	100	0	31.4**		26.4		103.2**		2/1/
−06	100	20	29.2**	34.6	27.2	38.7	106.0**	116.8	3/2/1/2.0
−10	100	80	20.5*	57.7	30.7	39.8	90.7*	104.3	2/2/1/3.4
S81−40−02	100	0	41.4**		23.5		131.7**		2/1/
−03	90	0	28.3**		24.2		102.6**		2/1/
−09	100	0	27.1**		26.2		112.2**		2/1/
−11	100	20	23.4**	36.3	25.6	37.1	118.2**	127.0*	2/1/1/1.5
−21	100	30	24.4**	9.4	22.2	33.7	107.6**	92.5	2/1/1/1.0
−24	100	0	34.2**		23.7		120.3**		2/2/

Table 7 contd.

Clone	Survival %		Biomass prod. g/cutting (d.w.)		Dry matter content %		Height growth cm		Growth habit/ frost damage/ shoots · stool^{-1}
	1985	1986	1985	1986	1985	1986	1985	1986	
S81−42−02	100	20	27.6**	30.1	24.9	35.8	106.7**	110.8	2/1/2/2.0
−03	100	30	20.1*	72.5	25.7	36.3	94.1*	88.0	2/1/1/5.0
−12	100	0	20.9*		23.4		93.5*		2/2/
−18	100	55	20.9*	33.8	25.1	37.0	87.2	116.9	2/2/1/2.0
−20	100	10	27.6**	12.9	24.4	35.8	114.4**	102.0	2/1/1/1.0
−23	100	0	22.8**		23.4		100.6**		2/2/
S81−44−01	100	60	32.8**	44.3	27.1	39.0	108.5**	125.1	2/0/1/2.2

Table 8. Properties of the *Salix* clones, crossing series SHK−81.

Clone	Survival %		Biomass prod. g/cutting (d.w.)		Dry matter content %		Height growth cm		Growth habit/ frost damage/ shoots · stool^{-1}
	1985	1986	1985	1986	1985	1986	1985	1986	
SHK81−02	100	30	11.6	14.8	26.8	37.9	67.8	92.3	2/2/1/2.0
−05	100	0	24.7**		25.4		95.5**		2/1/
−06	100	0	32.7**		26.0		114.5**		2/2/
−08	100	30	17.1	15.1	25.3	36.2	90.9*	95.3	2/1/1/1.5
−11	100	10	21.0*	20.3	24.1	35.3	99.3**	100.7	2/2/1/1.5
−13	100	80	20.6*	57.5	27.0	38.9	97.8**	106.9	2/1/1/2.6
−14	100	40	22.4**	35.3	25.5	36.4	83.8	88.5	2/2/1/2.5
−15	100	0	22.5**		25.4		101.8**		1/1/
−16	100	0	20.7*		24.9		93.9*		2/1/
−20	100	10	20.9*	8.6	23.4	34.8	92.4*	64.0	2/2/1/1.0
−21	100	50	21.4*	76.3	24.6	35.1	94.2**	124.6	2/1/1/3.2
−22	100	40	24.3**	46.9	26.8	37.5	85.5	122.3	2/1/1/2.0
−23	100	10	22.1*	22.0	23.8	35.0	99.7**	(159)	2/2/1/1.0
−24	100	0	26.4**		18.7		106.8		2/2/
−25	100	10	26.2**	(126.2)	26.5	37.8	95.3**	(154)	2/1/1/5.0
−37	100	30	31.0**	23.1	23.9	35.1	112.0**	109.3	2/1/2/1.3
−38	100	90	23.4**	65.7	27.9	39.4	98.2**	98.7	2/1/1/2.8
−39	100	0	29.9**		25.7		99.9**		2/2/
−40	100	30	28.0**	42.5	25.7	36.8	103.8**	113.5	2/1/1/2.7
−41	100	0	45.5**		29.8		121.1**		2/1/
−42	100	30	22.7**	11.2	23.6	35.2	92.0*	69.4	2/2/0/1.5
−44	100	0	29.6**		24.9		108.9**		2/2/
−45	100	60	19.1	36.8	26.5	37.6	93.4**	89.4	2/1/1/1.0
−46	100	10	21.4*	6.6	25.9	37.3	95.1**	50.0	2/1/1/3.0
−47	100	10	24.9**	62.3	25.3	36.2	97.6**	115.5	2/1/1/4.0
−49	100	20	27.8**	5.0	26.7	37.8	110.7**	66.0	2/1/1/1.0
−52	100	40	25.8**	26.2	22.0	33.5	99.1**	105.9	2/1/1/2.0
SHK81−2x	100	10	53.5**	(142.2)	25.8	37.1	103.6	(162)	2/2/2/3.0

Table 8 contd.

Clone	Survival %		Biomass prod. g/cutting (d.w.)		Dry matter content %		Height growth cm		Growth habit/ frost damage/ shoots · stool^{-1}
	1985	1986	1985	1986	1985	1986	1985	1986	
SHK81−12x	100	10	25.3**	71.4	25.4	37.3	92.9	115.0	2/2/1/4.0
SHK81−25x	100	10	28.4**	12.8	25.2	36.9	102.2	90.5	2/2/1/2.0
SHK81−32x	100	70	10.8	74.0	25.3	37.2	77.5	106.7	2/1/1/3.8
SHK81−34x	100	80	23.4**	196.3**	27.0	38.1	92.0	132.1*	2/1/2/4.4
SHK81−38x	100	10	40.7**	64.5	30.8	41.3	104.2**	(130)	3/3/1/2.0

Table 9. Properties of the *Salix clones*, crossing serie Hk82 and *Salix Schweriini* clones.

Clone	Survival %		Biomass prod. g/cutting (d.w.)		Dry matter content %		Height growth cm		Growth habit/ frost damage/ shoots · stool^{-1}
	1985	1986	1985	1986	1985	1986	1985	1986	
HK82−3−61	100	60	5.7	16.0	25.5	36.3	55.5	92.9	2/1/2/1.8
−73	100	50	5.5	5.0	24.2	35.9	57.2	62.0	2/1/0/1.4
HK8210−05	100	10	24.3**	14.8	25.9	37.0	91.5*	98.0	2/2/1/1.0
−39	100	50	9.6	18.7	25.3	36.7	62.9	85.1	2/1/1/1.4
−43	90	75	5.3	30.1	25.7	36.6	52.0	128.0*	2/0/1/2.0
HK8216−24	100	75	8.4	2.3	27.1	39.3	60.4	93.9	2/1/1/2.2
−26	100	60	14.7	51.6	25.4	36.9	91.4*	128.0	2/1/1/2.0
−29	100	10	19.7	28.4	26.1	37.1	102.0**	81.5	2/1/1/2.0
−64	100	100	11.1	30.7	23.5	34.0	72.3	112.0	2/1/1/2.3
−67	100	70	14.7	26.8	27.1	38.9	86.9	98.0	2/1/1/3.0
HK8217−36	100	65	13.3	64.7	25.4	36.8	80.9	125.8	2/1/1/2.6
−76	100	50	16.8	74.6	26.4	37.8	93.6*	112.7	2/1/1/3.6
HK8219−53	100	50	0.3	16.5	26.6	38.1	64.0	98.0	2/1/1/1.8
E7899	100	100	4.2	111.3*	28.9	38.3	50.8	133.5*	3/1/1/4.7
Schwerinii	90	100	2.3	57.4	23.5	35.4	41.5	120.7	2/1/1/2.7
SU8302	100	80	10.1	50.8	26.0	37.1	86.1*	121.5	2/1/2/3.1
V8957	100	100	2.3	99.4	26.9	38.7	32.4	153.9*	1/0/1/1.6
V8958	100	100	3.8	172.6*	27.5	39.1	43.2	161.9*	1/0/1/1.4

1986 and 1987). Consequently biomass production in the two year old shoots in 1987 was only 60 to 70 g dry weight per stool.

The leafless, above-ground biomass production of the two year old shoots of the winter-tolerant willow clones was low in 1987 due to the low temperatures of the growing season. There were two *S. myrsinifolia* clones, K2183 (234.4 g per stool, dry weight, $p<0.001$) and K2242 (105.1 g per stool, dry weight, $p<0.05$), which had higher biomass production than the control clone P6011 during the cold summer (Fig. 8).

Table 10. Properties of the *Salix myrsinifolia*, *S. phylicifolia* and *S. triandra* clones.

Clone	Survival %		Biomass prod. g/cutting (d.w.)		Dry matter content %		Height growth cm		Growth habit/ frost damage/ shoots · stool^{-1}
	1985	1986	1985	1986	1985	1986	1985	1986	
B1	90	80	10.9	36.8	45.3	51.2	19.2	77.9	2/0/0/4.9
E6946	90	100	1.0	50.3	39.1	46.7	8.0	112.2	2/2/0/3.9
K2183	100	100	4.5	112.8*	39.8	47.1	56.2	147.9*	2/2/0/4.4
K2242	100	90	1.6	87.3	39.1	46.9	33.4	133.2*	2/2/0/4.4
K2264	80	80	1.4	86.0	40.3	48.3	24.5	136.9*	2/1/1/3.1
K2266	80	80	0.9	46.6	39.5	47.4	15.4	115.9	2/1/0/3.6
K2278	80	90	0.8	57.0	39.8	46.3	16.3	122.0	2/1/0/3.5
K2306	90	90	2.7	70.3	42.3	49.8	32.9	133.4*	2/1/0/4.1
V78	80	100	3.5	101.1	45.5	48.5	40.6	121.9	2/3/1/4.8
6010	100	80	1.0	43.3	41.6	48.8	22.1	79.1	2/3/1/4.8

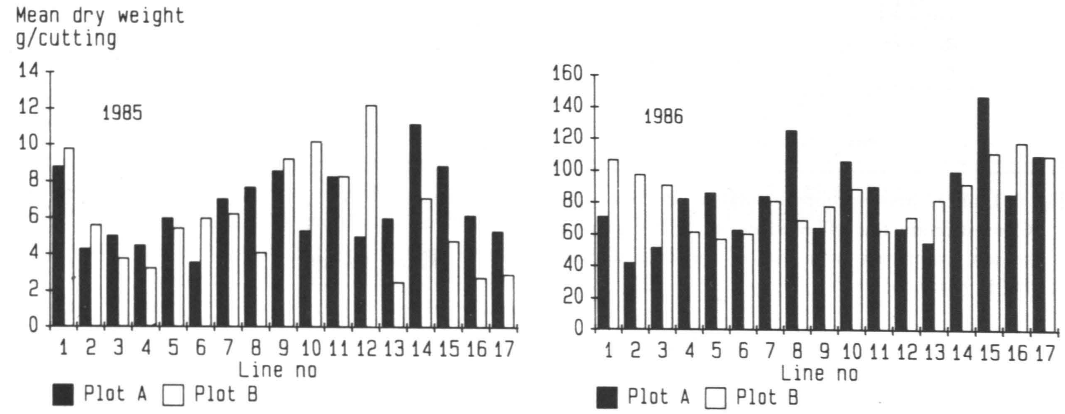

Fig. 4. Leafless, above-ground biomass production of the control clone *Salix dasyclados* P6011 in 1985 and 1986.

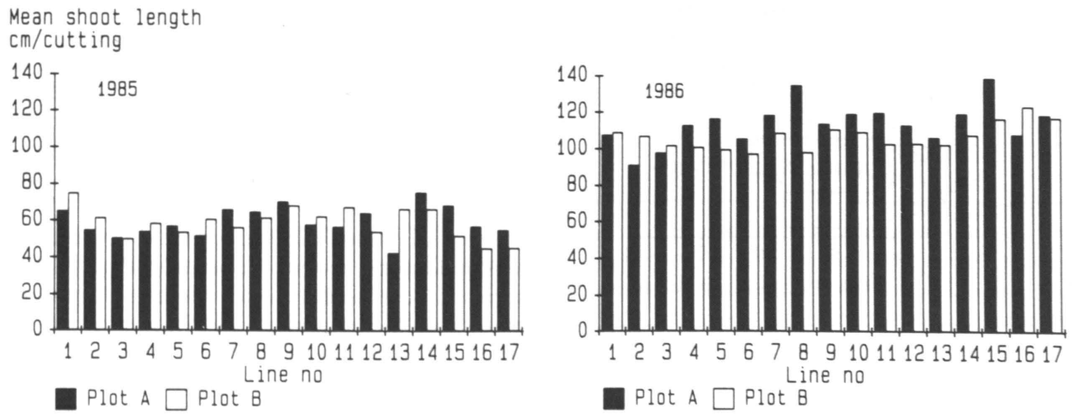

Fig. 5. Height growth increment of the control clone *Salix dasyclados* P6011 in 1985 and 1986.

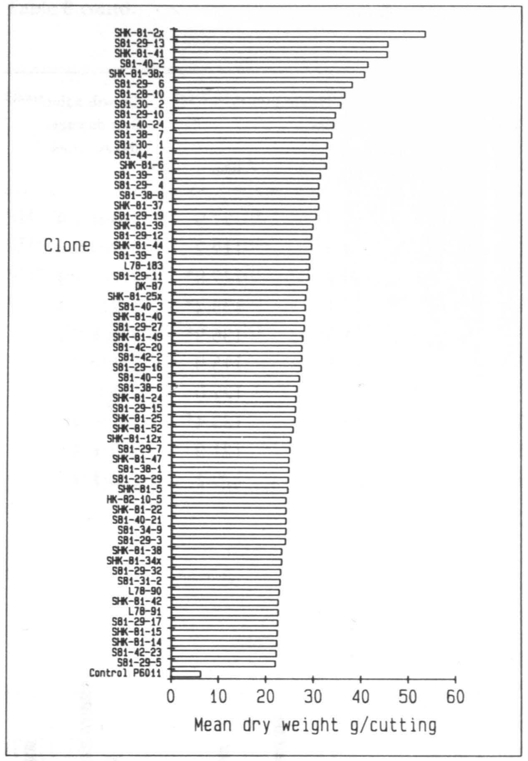

Fig. 6. Leafless, above-ground biomass production of the 63 most productive willow clones in the first growing season, compared with that of the control clone P6011 (p<0.001).

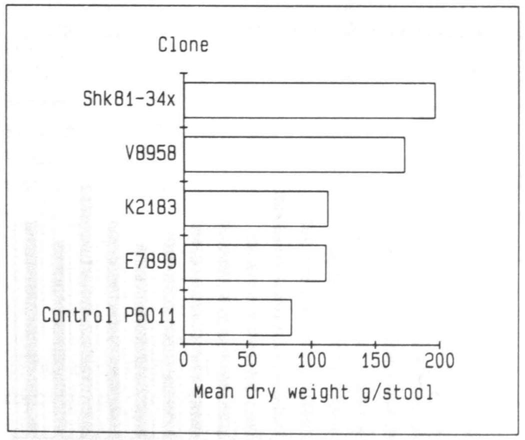

Fig. 7. Leafless, above-ground biomass production of the most productive willow clones in the second growing season, compared with that of the control clone P6011 (p<0.01).

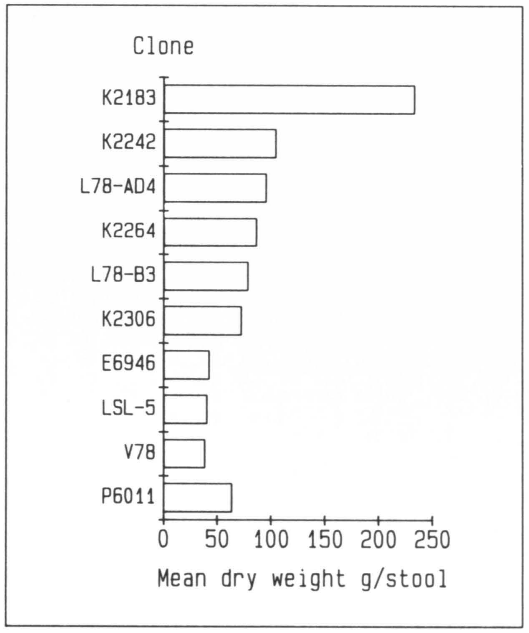

Fig. 8. Leafless, above-ground biomass production of the most productive willow clones in the third growing season, compared with that of the control clone P6011.

4.2.3. *Winter tolerance*

The root systems of most clones tested showed poor winter tolerance during the winter of 1985-1986, only 52 clones (17 %) out of a total of 301 had a survival rate (i.e. good winter tolerance of the root system) equal to or exceeding 70 % in 1986, and only 5 of the 63 most productive clones in 1985 remained alive through the winter 1985-86. Sprouting occurred on 89 % of the stumps of the control clone P6011. The highest rates of survival in 1986 were found in the *Salix schwerinii*, *S. myrsinifolia*, and *S. phylicifolia*. All four clones of the former series and 10 of the 15 clones of the latter showed a survival rate of >70 %. Five out of the eight clones of the series V777 and V780 survived the winter to a satisfactory extent. Correspondingly the series L possessed 10 cold tolerant clones out of 44 tested, the series HK82 four out of 43, SHK81 four out of 59 and S81 seven out of 76 (Tables 6-10). There was a negative correlation (r = -0.702**) between biomass production in the first growing season and winter

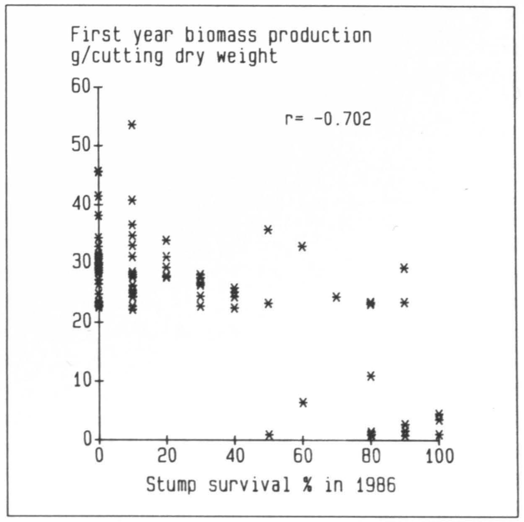

Fig. 9. Correlation between leafless, above-ground biomass production in the first growing season and stump winter tolerance in 1985–1986.

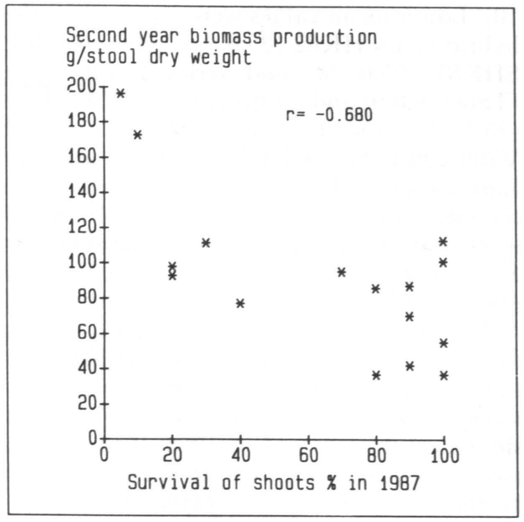

Fig. 10. Correlation between leafless, above-ground biomass production in the second growing season and shoot winter tolerance in 1986–1987.

tolerance of the roots (Fig. 9). Accordingly a negative correlation (r = -0.680*) was obtained between biomass production during the second growing season and winter tolerance of the shoots (Fig. 10). However, the correlation between biomass production between the first two growing seasons in the case of the most productive clones and those most winter tolerant was r = 0.473* (Fig. 11).

Winter tolerance of the one year old shoots in the clones with proper root winter hardiness was acceptable only in the control clone P6011 (100 % survival), in *S. myrsinifolia* clones, K2183 (100 %), K2242 (90 %), K2264 (80 %), E6946 (100 %), V78 (100 %), B1 (80 %) and in *S. phylicifolia* clone K2306 (90 %), in *S. alba* clone LSL-5 (70 %) and in *S. caprea* clones L78-AD4 (90 %) and L78-B3 (100 % survival) during winter 1986-1987 (Fig. 8).

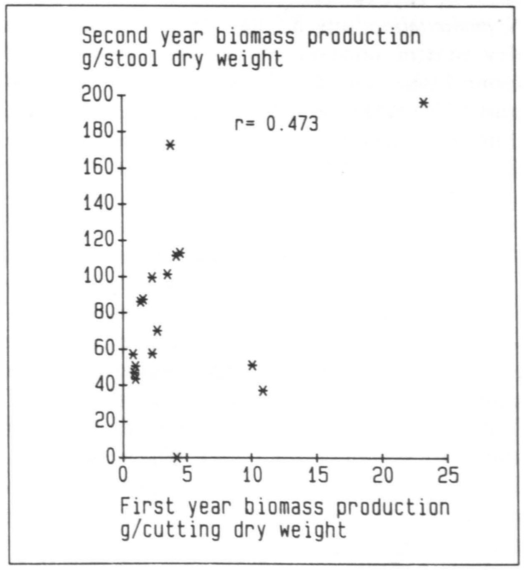

Fig. 11. Correlation between leafless, above-ground biomass production in the first and second growing seasons in the willow clones with satisfactory root winter tolerance and the highest biomass production in 1986.

4.2.4. *Dry matter content*

Dry matter content in the willow clones tested in 1985 was in the range 18.7 to 46.0 %. The highest figures being recorded in the slow-growing *Salix myrsinifolia*, *S. phylicifolia* and *S. triandra* clones (mean 41.6 %) (Table

10). Lower mean values were obtained for the hybrid series HK82 (25.6 %), S81 (26.2 %), SHK81 (25.0 %) and series L (26.4 %) (Tables 6,8,9) and for the control P6011 clone (25.1 %) ($p<0.01$). The series V777 and V780 (26.1 %) and GB (25.8 %) and the *Salix schwerinii* clones (25.9 %) had dry matter content values close to the P6011 control level, and thus markedly lower than those for *S. myrsinifolia, S. phylicifolia* and *S. triandra* *($p<0.01$) (Tables 6 and 9)*.

The stump sprouts in 1986 had a higher dry matter content than those arising from the cuttings in 1985, but the differences between the species and clone series remained similar to those noted in 1985. The highest mean dry matter ratios were again recorded in the *S. myrsinifolia, S. phylicifolia* and *S. triandra* clones (48.1 %). The dry matter content of the control clone P6011 was 39.1 % (Table 10).

The dry matter content of the two year old shoots of the winter tolerant willows varied between 43.2-53.1 % in 1987 the highest values recorded in *S. myrsinifolia* clones K2183, K2242, K2264, E6946, V78, B1 and *S. phylicifolia* clone K2306 (49.7-53.1 %). The dry matter content of the shoots in *S. alba* clone LSL−5 and in *S. caprea* clones L78−B3 and L78−AD4 varied between 43.2−49.6 %. The dry matter content of the control clone P6011 was 41.3 %.

4.2.5. Growth habit and sprouting capacity

Only minor differences in growth habit were seen between the tested clones, the majority of which were slightly trailing and with slightly bent shoots (grade 2 on the scale). There were only a few clones of a higher standard (grade 1) or lower standard (grade 3 or 4). Thus a considerable proportion of the new clones had a better growth habit than the control P6011, which was classified as grade 3. Much greater variability was observed in the degree of branching (depicting the degree to which the plant assumes a bush-like form). The best in this respect were the clones of the HK82 series (grades 0-2) and the *Salix schwerinii* clones from the USSR (grade 0). The hydrid series SHK81, L, GB, V777 and V780 were also fairly good in this respect (grades 0-3), but the series S81, *S. myrsinifolia, S. phylicifolia* and *S. triandra* were somewhat poorer. Only 25 clones represented a clear improvement over the control clone P6011 with respect to branching habits (grade 0 as opposed to grade 2) (Tables 6−10).

The mean number of shoots per cutting in 1985 varied from clone to clone in the range 1.0−3.7. The lowest numbers were recorded for the clones of *Salix schwerinii* (1.3) and *Salix myrsinifolia, S. phylicifolia* and *S. triandra* (1.4). A mean of 1.7 shoots was obtained for the series HK82 1.6 for the series GB, V777 and V780, 1.8 for the series L and for the series SHK81. The greatest number of shoots was found on the S81 hybrid clones (2.2). The control clone P6011 had a mean of 1.4 shoots per cutting.

Sprouting increased in all the clones in the 1986 growing season after coppicing in autumn 1985. The number of strong sprouts was in 1986 1.6 to 5.0 shoots per stool, with least on the *S. schwerinii* clones (mean 2.2) and most on the *S. myrsinifolia* and *S. phylicifolia* clones (mean 4.2) (Tables 6−10). The corresponding value for the control clone P6011 was 3.8.

4.2.6. Resistance to frost, insect pests and diseases

Evaluation of damage after two consecutive frosty nights (−1.5 °C and −2.0 °C) in autumn 1986 showed the *S. myrsinifolia* and *S. phylicifolia* clones to be the hardiest of all, only two out of ten showing slight frost damage in the crowns. Since the other clones that had survived the previous winter had frost damage of grade 1 or 2, it may be said that no severe frost damage was noted. (Tables 6−10).

No severe fungal infection was observed on any of the clones in 1985−1987, but slight damage was caused by insects, chiefly by the leaf beetle *Galerucella lineola* F., *(Chrysomelidae)* and to some extent by certain *Phyllodecta* species. No marked differences in the extent of attack by *Galerucella lineola* were observed between the clones studied, most being assigned the grade 1, i.e. some feeding on the crown. The new clones did not differ from the control in the extent of insect damage, the control also being classified as grade 1 in this respect.

5. Discussion

The survival of most of the willow clones tested was high in this peat soil in the first growing season. Most foreign willow species and their clones grow naturally in mineral soils, but according to these results it is possible to change the chemical conditions of peat to make it more suitable for willows by liming and fertilization.

Many of the 310 tested willow clones produced more biomass in their first growing season than did the control clone *Salix dasyclados* P6011, which had previously been found to be best adapted to conditions at Hirvineva. These first growing season results suggest that the temperature, precipitation and illumination conditions prevailing in the northwestern coastal area of Finland during the growing season may not be the only reason for the low biomass production found in willow clones tested earlier, but that the reason may lie in their own physiology.

The clones, which produced the greatest biomass during the first growing season were those of the hybrid series SHK81, S81, HK82 and series L. The highest figure of all, recorded for clone SHK81−2x, was in fact 3−9 times those recorded for the control clone P6011. All the most productive clones were either *Salix viminalis* hybrids or pure *S. viminalis* clones originating from southern regions. The *Salix dasyclados* clones collected from the same areas, for instance, had a lower biomass production. The most productive clones in short-rotation experiments conducted in southern Sweden have been of *S. viminalis* or *S. dasyclados* (Sennerby-Forsse et al. 1983, Nilsson 1986).

Such results obtained in 1985 with southern willows is interesting, if one takes in account that the winter of 1984−1985 exceptionally cold one in the northwestern coastal area of Finland consequently the ground was frozen to an unusual depth the frost, soil temperatures in the layer 0−15 cm were consistently 3−4°C below normal throughout the growing season. Even the normal soil temperatures prevailing at Hirvineva are much lower than those at the latitudes in which the southern willows originate. In 1986 the biomass production of some of the winter-tolerant clones exceeded significantly that of P6011, but the differences were not as dramatic, presumably due to cool weather in 1986.

The fast-growing *Salix viminalis* clones imported from further south, and thus accustomed to warmer climates, are able to benefit from the illumination conditions of the growing season over a long period of time. Their rate of photosynthesis remains high for a considerable part of the season and usually declining only at the end of Septemper, whereas the Finnish clones *Salix myrsinifolia, S. phylicifolia* and *S. triandra*, become dormant by beginning of September (Sievänen 1983). Due to this characteristic the most productive willow clones of southern origin, however, showed a poor winter tolerance in the winters of 1985−1986 and 1986−1987. A significant negative correlation was obtained between the measures of first year biomass production and winter tolerance of the root system. Winter hardiness of the one year old shoots was low in the southern clones, which had satisfactory cold tolerance in the root system and none of those survived through the winter 1986−1987.

According to the results obtained in 1986−1987 it seems possible to select cold tolerant and relatively productive local Finnish clones as *Salix myrsinifolia* clone K2183. The behaviour of this clone, when biomass production is concerned, was quite different from that found in the southern willows. In 1985 the aerial, leafless, biomass production was only 5 g per cutting, dry weight, in the second growing season it was 113 g per stool, dry weight (one year old shoots after coppicing), and in the third 234 g per stool, dry weight (two year old shoots). Obviously this clone insures sufficient root growth during the first growing season and therefore the first year shoot growth is weak. Even though the growing seasons 1986 and 1987 were colder than usual the level of biomass production obtained with the clone 2183 was quite low, but willows of this type can be used for breeding.

The clones tested differed considerably in dry matter content. No correlation was observable between biomass production and dry matter content in either the most productive clones or those of southern provenance in general. By contrast, the slower growing *Salix myrsinifolia*, *S. phylicifolia* and *S. triandra* clones had a much higher dry matter content than the southern willows. Comparison of the slower-growing Finnish willows with the fast-growing clones of southerly provenance would suggest that rate of growth was inversely proportional to dry matter content during the first growing season. This higher dry matter content in the northern willow species may reflect adaptation to low winter temperatures, since a low water content facilitates resistance to cold.

A reasonable proportion of the clones tested were more upright in their growth habit than the control clone, *Salix dasyclados* P6011, which tends to adopt a trailing habit, especially at low planting densities. The most upright of all were all hybrid clones of *Salix schwerinii* or *Salix viminalis*. These two species are very similar morphologically. With only four exceptions, the best clones with respect to biomass production and winter tolerance in the second growing season also possessed a good growth habit. Willows that differ only in growth habit, the orientation of the shoots would affect the position of the leaves relative to the sun, all the leaves being horizontal on a willow of trailing habit, whereas those on one of upright aspect would be in a vertical position with respect to the sun. It is also easier to harvest willows, which grow upright than the trailing ones.

Major differences emerged between the clones in the degree of branching (i.e. adoption of a "bushy" form) although only 25 clones branched clearly less than did the P6011 control. The least branching in both years was found in the hybrid *Salix schwerinii* and *Salix viminalis* clones. The best clones in terms of biomass production and winter hardiness the first three growing seasons featured average or better than average branching. A shoot with pronounced branching (i.e. large numbers of non-woody side branches with low dry matter content) is obviously less able to withstand the cold in winter, for instance, than one with few branches and would also tend to exhibit poorer height growth.

Marked differences were noted between the present clones in the number of shoots developing per stool during the first and second growing season. The lowest numbers being recorded for the *Salix schwerinii* clones, which had a lower number of shoots than the control clone P6011. The highest number of shoots was found in *S. myrsinifolia*, *S. phylicifolia* and *S. triandra* clones. The number of shoots developing per cutting during the first and second growing seasons is a detail of particular importance under the conditions prevailing in the northwestern coastal area of Finland. Presumably it is essential for successful overwintering that there should be only a small number of shoots per cutting, so that each will be stronger to withstand the cold (i.e. will have a higher proportion of woody material and a lower water content than weak shoots existing in large numbers).

No severe fungal infections were noted in the willows, although rust fungi *Melampsora spp.* occurred in abundance in birch forests (*Betula pubescens* Ehrh.) around Hirvineva area. The research continued, however, only for three years. Extensive damage has been caused in willow experiments in other parts of Finland by this rust (Hakkila 1985).

A certain amount of insect damage was recorded in the first three growing seasons, the most common pest being the leaf beetle *Galeruqella lineola*. The differences between the clones were not considerable, but it seems that *Salix schwerinii* and *S. viminalis* clones were preferred by this beetle. Damage was usually concentrated in the crowns or upper leaves of the willows, where the nitrogen content in particular is high (Anttonen 1985). According to Wiren et al. (1984) and Tahvanainen et al. (1985) phenol-free willow species as *Salix viminalis* are among the preferred sources of food for *G. lineola*. In 1985 despite a peak in *G. lineola* population there was no significant damage at Hirvineva. However, particular attention should be paid to this pest in the future. It is evident that the short-rotation cultivation of willows will require the development of a number of clones differing slightly in their allelochemistry in order to avoid the risks of pest damage entailed in a monoculture.

The results showed that the experimental design used was succesfull in early selection of clonal material even with small number of specimens per clone in an environment where

the selection is rigid due to distinct differences in the clones to the circumstances. However, the different annual growth patterns due to climatical or clone specific factors makes it necessary to continue early selection tests at least three years before the selection for further trials can be safely made.

The results obtained during the three growing seasons suggest that it would be possible to increase the biomass production of fast-growing willows in the northwestern coastal area of Finland, but that the crucial problem is whether it is possible to find out the satisfactory ratio between winter tolerance and biomass production. It is now possible to select the best clones in terms of biomass production and the best in terms of cold tolerance and attempt by hybridization to generate the optimal clone for the conditions prevailing in this region.

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