Growth and Nutrition of Willow Clones

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Growth and nutrition of 20 clones representing different species and interspecific hybrids of willows growing on an abandoned field were studied. There were highly significant differences between the clones as regards the survival, number of sprouts/stool, sprout mean height and diameter and stem biomass production/stool. The differences between the clones in the concentrations of all nutrients in both the leaves and stems were highly significant.

Keywords *Salix*, clones, hybridization, biomass, nutrients, forests, fuelwood.
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1 Introduction

Willow species have played an important role in research on the production and utilization of wood energy in Finland because their fast rate of growth and strong sprouting ability satisfy the requirements for short-rotation tree species (Hakkila 1985). There are considerable differences in the biomass production and winter hardiness of willow species and clones grown in experimental cultivations (Pohjonen 1977, Lepistö 1978, Lumme and Törmälä 1988). There are also corresponding differences in the rooting capacity of the cuttings and sprouting ability of the stools (Lumme et al. 1984, Lumme and Törmälä 1988), in the dry matter content of the stems (Sennerby-Forsse 1985, Lumme and Törmälä 1988, Mosseler et al. 1988) and in the density of the wood (Flower-Ellis and Olsson 1981, Sennerby-Forsse 1985, 1989). The relative proportion of bark out of stem dry mass also varies between clones (Sennerby-Forsse 1985). Hybridization has also been applied in the development of vigorously sprouting and productive hybrids and in attempts to combine the good winter hardiness of domestic species with the high productivity of exotic clones (Viherä-Aarnio 1988, 1989, 1991).

Exotic willow species grown using a short rotation period have high nutrient requirements (Kaunisto 1983, Saarsalmi 1984, Hytönen 1986), and large amounts of nutrients are often removed from the soil in repeated whole-tree harvesting. Site factors, such as the nutrient content, moisture and pH of the soil, obviously have a strong influence on the growth and productivity of willows (Ericsson and Lindsjö 1981, Hytönen 1986, 1987). On the other hand, differences have been found with respect to nutrient consumption between the species and clones of willow (Komlenovic and Kristinic 1982, Ericsson 1984, Nilsson 1985, Simon et al. 1990). Clear interactions have also been found between the genotype and growing site both at the species level and at the clonal level within species (Rönnberg-Wästljung and Thorsen 1988). These factors can be taken into account when breeding clones or varieties which are suitable for different types of site. In addition to being winter hardy and productive, the clones should also have effective nutrient consumption.

Peat cut-away areas are considered to be suitable sites for the short-rotation cultivation of willow (Hakkila 1985). Due to recent changes in Finnish agricultural policy a considerable amount of fertile agricultural land is becoming available for other use. Much of this land would be well suited for tree cultivation (Ferm and Polet 1991). However, rather little is known about the productivity and nutrient consumption of willows on mineral soils.

The aim of this study is to determine growth and foliar and stem nutrient concentrations of clones representing different species and interspecific hybrids of willows growing on an abandoned field.

2 Material and Methods

2.1 Plant Material and Experimental Design

The plant material used in the experiment originated from interspecific crossings of willow produced at the Finnish Forest Research Institute in 1981. The parents used in the crossings were domestic and central European species and hybrids (Viherä-Aarnio 1988, 1989, 1991).

The crossing parents and the best growing individuals of each progeny were propagated vegetatively. A field trial was established with the rooted cuttings on a ploughed and harrowed field in Vantaa, southern Finland (60°17'N, 25°03'E, 20 m asl), in May 1984. The experiment was arranged as a row trial using a randomized block design. Each clone was represented in the trial by 20 cuttings, 5 cuttings/plot in each block. The planting density was 0.8 × 0.8 m. A border of *S.* × *mollissima* was planted around the trial. After establishment the trial was weeded mechanically. In order to promote sprouting the willows were cut back to leave a stool about 5 cm high in April 1985. The willows were subsequently harvested on two occasions: November 1986, April 1990.

For this study 20 clones were selected from the trial in August 1986. Nine of them were the clones used as parents, 10 clones represented the hybrids between them, and *S. schwerinii* was included as a comparison (Table 1). The best growing clone in each family was selected from the crossing progeny. Most of the clones investigated in this study belong systematically to the subgenus *Vetrix* of the genus *Salix*. Only *S. triandra*, *S. alba* and *S. lucida* are included in the subgenus *Salix*, which is considered to be an older group than *Vetrix*, and occurs primarily in the subtropical and temperate zones (Skvortsov 1968, Dorn 1976). The subgenus *Vetrix* is, in turn, a later developed group adapted to the cool climatic zone and with a more northerly distribution (Skvortsov 1968, Dorn 1976).

2.2 Measurements and Sampling

Soil Sampling

Soil samples were taken in autumn 1986 in order to determine the fertility of the substrate. Eight subsamples were taken with a soil auger (∅ = 2.3 cm) from the 0–20 cm thick layer on each plot. The sampling points were located at a distance of about 15–20 cm from the plants. The subsamples from each plot were combined to give bulked samples for the chemical analyses. The pH was measured in a slurry of soil and distilled water, and ammonium acetate (pH 4.65 1 M) extractable nutrients (Halonen et al. 1983) by inductively coupled plasma atomic emission spectrometry (ICP/AES) (ARL 3580). Total N and C were determined on a CHN analyser (Leco CHN 600).

Table 1. Willow clones included in the study. Arrows indicate, from where the clones were introduced to Finland.

Parent clones

Clone	Species	Provenance
E 4854	*Salix alba* var. *vitellina* (L.) Stokes	Hungary → Sweden → Finland, Tuusula
E 4855	*Salix lucida* Muhl.	USA, Illinois → Sweden → Finland, Tuusula
E 4856	*Salix* 'Aquatica'	Denmark → Finland, Tuusula
E 6761	*Salix caprea* L.*	Finland, Tuusula
E 7311	*Salix caprea* L.*	Finland, Mäntsälä
H 3157	*Salix viminalis* L.	Germany, Graupa → Hungary → Finland
H 3159	*Salix dasyclados* Wimm.	Netherlands, Wageningen → Hungary → Finland
H 3163	*Salix* × *smithiana* Willd.	Poland, Poznan → Hungary → Finland
H 3172	*Salix purpurea* L.	Russia, Petrograd → Hungary → Finland
H 3178	*Salix* 'Aquatica'	Yugoslavia, Novi Sad → Hungary → Finland
P 6010	*Salix triandra* L.	Finland, Liminka
SU 8955	*Salix schwerinii* E Wolf**	Russia, Amur → Finland

Hybrid clones

Clone	Seedlot of the hybrid progeny	Female parent	Male parent
V 781	G01-81-016	H 3157 *Salix viminalis*	E 6761 *Salix caprea*
V 782	G01-81-015	H 3157 *Salix viminalis*	E 4856 *Salix* 'Aquatica'
V 783	G01-81-010	H 3157 *Salix viminalis*	H 3163 *Salix* × *smithiana*
V 793	G01-81-014	H 3159 *Salix dasyclados*	E 6761 *Salix caprea*
V 7507	G01-81-017	E 4855 *Salix lucida*	E 4854 *Salix alba* var. *vitellina*
V 7510	G01-81-008	H 3157 *Salix viminalis*	H 3178 *Salix* 'Aquatica'
V 7511	G01-81-007	H 3159 *Salix dasyclados*	E 4856 *Salix* 'Aquatica'
V 7513	G01-81-009	H 3172 *Salix purpurea*	E 4856 *Salix* 'Aquatica'
V 7516	G01-81-003	H 3157 *Salix viminalis*	P 6010 *Salix triandra*
V 7519	G01-81-006	H 3157 *Salix viminalis*	E 7311 *Salix caprea*

* Clones E 6761 and E 7311 were used as parents in the crossings, but were not included in the field test.
** Clone SU 8955 was not used as a parent in the crossings.

Measurement of the Sprouts

In September 1986, when the stool sprouts were 2 years old and their rootstocks 3 years old, stool survival and the number of sprouts/stool were counted, and sprout height and diameter measured. Height was measured to an accuracy of 1 cm, and diameter to an accuracy of 1 mm at a height of 10 cm above the base of the sprout. Stool survival was again determined in spring 1990 and summer 1993.

Biomass Determination and the Sampling for the Nutrient Analyses

During the first week of September 1986 one sprout was taken from all five stools on each plot. If the stool was dead a sample was taken from the adjacent living stool on the same plot. The leaves and stems were separated. Branches were included in the stem samples. The samples were weighted. Separate subsamples were taken for the determination of dry matter content and nutrient concentrations. The relative proportions of stems and leaves out of the total dry mass produced were calculated. After the leaves had been shed in autumn the same year, the willows were cut back in November to leave stools about 5 cm high, and the total dry mass of the sprouts/stool was determined.

The separate compartments of the sample sprouts from all the stools on each plot were combined to give composite samples for the determination of foliar and stem nutrient concentrations. Total P, K, Ca, Mg and B of the leaf and stem samples were determined by dry ashing and extracting the ash with hydrochloric acid (Halonen et al. 1983). The elemental analyses were performed by ICP/AES (ARL 3580). Total N was determined on a CHN analyser (Leco CHN 600).

Table 2. The amount of total nitrogen, acid ammonium acetate extractable phosphorus, potassium, calcium and magnesium (kg/ha), and the carbon and nitrogen ratio and pH of the soil (0–20 cm) in autumn 1986.

Nutrient	$\bar{x}$	S.D.	F(clones)	F(blocks)
N	4342	656	1.22	15.18***
P	59	10	4.79***	37.24***
K	262	61	1.64	28.13***
Ca	2409	601	1.37	9.51***
Mg	256	86	1.49	25.87***
$pH_{(water)}$	5.4	0.2	0.87	16.64***
C/N	16	1	0.79	0.86

n = 78, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

2.3 Growing Conditions

The willows were grown in field soil with a particle size distribution corresponding to fine-sand. The mean bulk density of the soil was 0.93 g/cm^3. The soil under the different clones did not differ significantly as regards pH, C/N ratio or nutrient amounts except phosphorus (Table 2). However, there were statistically significant differences between the blocks in all nutrient contents and pH.

2.4 Statistical Analysis

The statistical significance of the differences between the clone means as regards the height, diameter and number of sprouts, and amount of biomass/stool, dry-matter content and stem proportion was tested using two-way analysis of variance and the SNK test (Ranta et al. 1991) performed on the plot means. The statistical significance of the differences in survival was tested using non-parameter Friedman's two-way analysis of variance according to Kouki et al. (1990). The statistical significance of the differences between the clone means for the nutrient concentrations in the stem, leaves and soil was tested using two-way analysis of variance. SAS and BMDP software were used in the calculations.

Table 3. Survival (%) of the willow clones in different years.

Clone	1986		1990		1993	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
E 4854	95	10	90	20	90	12
E 4855	95	10	95	10	95	10
E 4856	95	10	95	10	35	30
H 3157	100	0	100	0	100	0
H 3159	100	0	95	10	85	30
H 3163	95	10	85	10	85	10
H 3172	100	0	100	10	100	0
H 3178	95	10	95	10	25	38
P 6010	60	16	60	19	60	16
SU 8955	73	12	40	20	40	20
V 781	100	0	100	0	100	0
V 782	100	0	100	0	100	0
V 783	95	10	93	12	93	12
V 793	95	10	95	10	90	20
V 7507	100	0	80	23	75	19
V 7510	90	12	90	12	90	12
V 7511	100	0	100	0	90	12
V 7513	100	0	100	0	100	0
V 7516	100	0	100	0	100	0
V 7519	93	12	67	23	67	23
Average	94	12	89	19	82	27
F(clones)	4.52***		3.95***		6.72***	

* $p < 0.05$, ** < 0.01, *** < 0.001

3 Results

3.1 Survival and Growth

The survival of most of the clones in 1986 was over 90 %, apart from clones SU 8955 (*S. schwerinii*) and P 6010 (*S. triandra*) whose survival was significantly lower (Table 3). By spring 1990 the survival of clones V 7519 (*S. viminalis* × *S. caprea*), V 7507 (*S. lucida* × *S. alba* var. *vitellina*) and SU 8955 (*S. schwerinii*) had clearly deteriorated from that in the previous inventory, while the survival of the other clones had remained the same. In summer 1993 the survival of most of the clones was still over 85 %. However, the survival of both *S.* 'Aquatica' clones (E 4856 and H 3178) had deteriorated considerably after 1990.

There were highly significant differences between the clones as regards the number of sprouts/stool and the mean height and diameter of the sprouts (Table 4). The differences between the blocks were also highly significant.

The between-clone variation in the production of stem biomass/stool was large and the differences between the clones were highly significant (Table 5). Hybrid clone V 781 (*S. viminalis* × *S. caprea*) had the highest production, followed by hybrid clone V 782 (*S. viminalis* × 'Aquatica') which also showed considerably high within-clone variation. There were a number of clones with rather low production levels: P 6010 (*S.*

Table 4. Number of sprouts/stool and mean height and diameter of sprouts of the willow clones in 2-year-old shoots on 3-year-old roots.

Clone	Number of sprouts/stool			Size of sprouts height, cm		Size of sprouts diameter, mm		
	$\bar{x}$	range	n	$\bar{x}$	range	$\bar{x}$	range	n
E 4854	4	1–10	19	171	40–368	8	3–22	83
E 4855	6	2–12	19	135	7–301	8	3–17	121
E 4856	8	3–18	19	227	29–390	14	3–27	157
H 3157	11	4–19	20	241	100–375	12	4–21	210
H 3159	7	1–13	20	214	50–410	13	3–29	134
H 3163	5	3–9	19	191	70–405	12	3–24	102
H 3172	7	1–12	19	157	30–312	6	1–31	137
H 3178	8	2–13	19	236	59–400	14	4–29	157
P 6010	5	2–10	12	135	60–275	8	3–17	63
SU 8955	3	1–6	11	234	60–471	13	2–31	36
V 781	9	5–15	20	265	75–451	14	4–26	183
V 782	9	2–16	20	243	66–399	14	4–24	182
V 783	6	3–10	19	184	60–405	11	4–24	119
V 793	9	3–19	19	202	49–370	12	3–23	169
V 7507	4	1–8	20	133	21–238	7	1–17	73
V 7510	9	5–15	18	229	73–420	12	3–28	155
V 7511	10	2–17	20	227	75–403	13	4–24	194
V 7513	10	1–15	20	208	59–401	11	4–22	190
V 7516	10	4–18	20	184	63–306	10	4–19	195
V 7519	5	2–12	14	200	78–322	11	3–22	67
Average	7			208		11		
F(clones)	7.27***			15.39***		15.56***		
F(blocks)	7.24***			16.42***		7.78***		

* $p < 0.05$, ** < 0.01, *** < 0.001

Table 5. The average dry mass production in 2-year-old shoots on 3-year-old roots, dry matter content and biomass allocation of the willow clones.

Clone	Stem biomass/stool, g		Dry matter content, %		Stems % of total above ground biomass		
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	n
E 4854	145	145	48	3	79	8	19
E 4855	128	68	42	3	77	2	19
E 4856	730	570	47	2	77	7	19
H 3157	773	319	46	2	85	4	20
H 3159	508	279	47	2	77	6	19
H 3163	355	185	43	1	70	7	19
H 3172	125	83	50	3	83	4	19
H 3178	784	357	44	2	78	3	15
P 6010	111	87	47	2	84	6	12
SU 8955	258	154	46	2	84	7	11
V 781	1037	377	46	2	83	6	20
V 782	927	745	47	2	84	4	20
V 783	335	176	44	2	81	4	20
V 793	493	409	48	1	76	5	19
V 7507	81	70	43	6	78	13	19
V 7510	593	356	48	3	81	4	18
V 7511	665	349	47	3	78	6	20
V 7513	526	285	47	3	79	6	19
V 7516	442	259	49	1	80	3	20
V 7519	273	225	47	2	78	10	14
Average	478	429	46	3	80	7	
F(clones)	8.74***		2.51**		4.74***		
F(blocks)	7.26***		5.99**		0.66		

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

trianda), H 3172 (*S. purpurea*), E 4855 (*S. lucida*), E 4854 (*S. alba* var. *vitellina)* and hybrid clone V 7507 (*S. lucida* × *S. alba* var. *vitellina*). The differences between the blocks as regards production were highly significant.

The mean dry-matter content of the stems was 46 % (Table 5). The differences in stem dry-matter content between the clones and blocks were significant.

The proportion of stem biomass out of the total above ground biomass produced varied between 70–85 % (Table 5). The differences between the clones were highly significant. The proportion of stem biomass was highest in clone H 3157 (*S. viminalis*) and lowest in clone H 3163 (*S.* × *smithiana*).

3.2 Nutrient Concentrations of the Leaves and Stems

The nutrient concentrations in the leaves were higher than those in the stems (Tables 6 and 7). The differences between the clones in the concentrations of all nutrients in both the leaves and stems were highly significant.

Clones P 6010 (*S. triandra*), V 7507 (*S. lucida* × *alba* var. *vitellina*) and E 4855 (*S. lucida*) differed from the other clones as regards the concentrations of certain nutrients. The nitrogen, magnesium and boron concentrations of the stems and the boron concentrations of the leaves were higher in these three clones. Clone P 6010 also had high foliar nitrogen concentration, but the foliar nitrogen concentrations of clones V 7507 and E 4855 did not differ from those of the other clones. The foliar magnesium concentration and stem phosphorus concentration of clone P 6010 were also the highest.

Table 6. The mean foliar nutrient concentrations of the different willow clones in early September.

Clone	N		P		K g/kg		Ca		Mg		B mg/kg	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D
E 4854	18.9	1.3	2.2	0.4	26.9	3.9	13.5	2.2	2.6	1.0	51	2
E 4855	21.2	2.1	4.7	3.1	14.6	4.6	14.3	6.4	3.0	0.8	59	20
E 4856	21.5	0.7	4.8	0.8	17.1	1.2	10.7	1.3	2.8	0.1	29	8
H 3157	22.1	1.3	5.0	0.5	16.3	2.2	10.3	0.6	2.8	0.1	40	11
H 3159	20.0	0.9	7.0	1.6	12.9	0.6	13.7	2.3	3.4	0.3	25	3
H 3163	24.1	2.4	5.3	0.7	17.1	2.3	16.7	1.9	3.3	0.2	39	3
H 3172	21.3	0.8	3.9	1.0	17.9	1.3	16.0	2.3	2.4	0.5	33	3
H 3178	23.1	1.6	4.7	0.7	16.0	2.3	10.1	1.2	2.8	0.3	28	4
P 6010	24.5	1.3	5.1	1.6	19.9	5.0	8.6	2.8	3.6	0.6	59	8
SU 8955	24.2	1.5	5.2	1.6	18.9	3.3	13.2	1.6	1.8	0.2	46	7
V 781	24.2	1.3	4.6	0.5	11.8	1.4	19.3	1.4	2.9	0.3	49	6
V 782	21.6	0.6	4.3	0.7	14.1	1.9	10.5	0.7	2.7	0.3	26	3
V 783	24.8	1.1	4.1	0.3	14.9	1.3	8.4	0.5	2.9	0.4	32	4
V 793	21.4	0.2	4.9	0.3	16.2	0.7	13.0	1.3	3.3	0.4	28	2
V 7507	21.4	3.9	4.4	1.5	24.1	1.6	10.2	0.7	2.7	0.1	53	15
V 7510	20.8	1.2	3.7	0.5	15.2	1.5	8.2	1.1	2.2	0.3	24	3
V 7511	21.4	1.8	4.7	0.6	16.2	1.8	13.0	0.9	2.9	0.3	22	3
V 7513	25.1	2.2	4.6	0.6	17.5	3.4	12.8	1.3	3.3	0.2	25	1
V 7516	22.9	1.2	5.5	0.8	16.3	1.6	13.0	2.1	3.2	0.5	43	5
V 7519	22.6	2.0	5.4	0.4	17.2	2.5	15.3	0.3	2.7	0.4	45	6
Average	22.3	2.2	4.7	1.3	17.0	4.1	12.5	3.1	2.9	0.6	37	14
F(clones)	5.04***		3.99***		9.62***		8.12***		4.14***		10.32***	
F(blocks)	5.48**		11.29***		5.83**		1.86		3.32*		0.32	

n = 78, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The foliar nitrogen and phosphorus concentrations of clone E 4854 (*S. alba* var. *vitellina*) were lower, but the foliar potassium concentration higher than those of the other clones. Both the foliar and stem calcium concentrations of hybrid clone V 781 (*S. viminalis* × *caprea*) were higher than those of the other clones. The stem calcium concentration of clone E 4855 was also high.

There were significant differences between the blocks as regards the foliar nitrogen, phosphorus, potassium and magnesium concentrations, as well as the stem calcium and boron concentrations.

4 Discussion

Growing Conditions

The phosphorus amount of the soil in all parts of the experiment was at a level considered satisfactory for agricultural soil, and with respect to potassium, calcium and magnesium passable (Viljavuuspalvelu 1991). The soil nutrients were compared to Viljavuuspalvelu's standard values af-

Table 7. The mean stem nutrient concentrations of the different willow clones in early September.

Clone	N		P		K g/kg		Ca		Mg		B mg/kg	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D
E 4854	3.8	1.1	0.7	0.1	4.5	0.7	4.6	0.6	0.6	0.1	8.8	0.6
E 4855	4.1	0.4	0.8	0.1	3.1	0.3	6.0	1.3	0.7	0.1	10.3	0.8
E 4856	3.1	0.7	0.8	0.1	2.8	0.2	4.2	0.3	0.6	0.1	7.7	0.4
H 3157	2.7	0.3	0.9	0.1	3.5	0.5	3.7	0.3	0.6	0.1	7.9	0.4
H 3159	2.7	0.5	0.6	0.1	2.6	0.3	3.6	0.8	0.5	0.1	6.9	0.6
H 3163	3.9	0.1	1.0	0.1	4.8	0.4	5.5	0.4	0.6	0.1	8.5	0.1
H 3172	3.3	0.5	1.0	0.1	4.3	0.5	3.2	0.9	0.5	0.0	6.8	0.3
H 3178	3.0	0.1	0.7	0.1	2.6	0.1	4.7	0.6	0.6	0.1	7.4	0.2
P 6010	5.7	0.6	1.2	0.2	3.5	0.3	4.0	0.9	0.8	0.1	12.2	1.7
SU 8955	3.0	0.7	1.0	0.1	4.2	0.6	4.6	0.7	0.5	0.1	8.5	1.0
V 781	3.7	0.5	0.8	0.1	2.8	0.2	6.1	1.5	0.5	0.1	7.3	1.0
V 782	3.0	0.2	0.7	0.0	2.8	0.2	5.0	1.1	0.5	0.1	7.5	0.6
V 783	3.4	0.3	0.9	0.1	4.9	0.8	3.7	0.6	0.5	0.1	8.2	0.6
V 793	3.1	0.1	0.7	0.2	3.1	0.5	3.9	0.8	0.6	0.1	7.5	0.9
V 7507	4.2	0.8	0.7	0.1	4.2	0.5	5.5	0.6	0.8	0.1	10.7	1.0
V 7510	2.9	0.3	0.8	0.1	3.0	0.3	4.5	0.9	0.5	0.1	7.6	0.8
V 7511	2.8	0.3	0.7	0.1	2.8	0.3	4.3	0.4	0.5	0.1	7.6	0.5
V 7513	2.9	0.5	0.7	0.2	2.9	0.5	3.7	0.3	0.5	0.1	7.0	0.5
V 7516	3.2	0.5	0.9	0.1	3.5	0.3	3.9	0.6	0.5	0.1	7.3	0.7
V 7519	3.7	0.8	0.9	0.2	3.0	0.5	5.1	0.9	0.5	0.1	7.2	1.0
Average	3.4	0.8	0.8	0.2	3.4	0.8	4.5	1.1	0.6	0.1	8.1	1.6
F(clones)	7.44***		6.96***		12.31***		6.01***		7.25***		15.75***	
F(blocks)	1.36		0.64		1.27		8.52***		1.45		3.78*	

n = 78, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

ter first converting the gravimetric results obtained in this study into volumetric values using the bulk density values. The soil pH was satisfactory for the cultivation of willow (Ericsson and Lindsjö 1981). The ratio between total nitrogen and carbon of the soil indicates that nitrogen was not a limiting factor for micro-organisms decomposing organic matter (Howard and Howard 1980).

Survival and Growth

The average survival of the clones was good. This was partly due to the fact that the trial was established using ready-rooted, pot cuttings. Thus the differences in survival do not provide any information about the ability of the clones to form roots on cuttings, but only the capacity of the seedlings to survive in the local climate, on the site in question and under the prevailing competition conditions. Both *S.* 'Aquatica' clones had good survival and production in 1986, but were almost completely destroyed in 1993. The reason appears to be the rust (*Melampsora* sp.) damage followed by frost damage on the shoots, or else the clones' poor ability to resist repeated harvesting. On the other hand, the survival of those clones which had *S.* 'Aquatica' as one of the parents and *S. viminalis*, *S. dasyclados* or *S. purpurea* as the other, was considerably better in 1993 than that of the *S.* 'Aquatica' clones.

The poor survival of clone P 6010 (*S. triandra*) may be due to the northern origin of the clone (Liminka; 64°49'N, 25°25'E). The clone has presumably suffered from the long transfer from the north to the south, and from the great changes in the light climate associated with such a transfer. The properties of the experiment site also differed significantly from the natural growing site of this willow species along the rivers of the northern part of west coast of Finland. The different survival of clones V 781 and V 7519, selected from different half-sib progeny of *S. viminalis* and *S. caprea*, is also interesting: the progeny of paternal clone E 7311 was significantly weaker than that of paternal clone E 6761.

There were large differences in the sprouting ability of the clones and the growth of the sprouts owing to the fact that the material had a very heterogeneous background. The material included species which naturally sprout very vigorously such as *S. viminalis* and *S. purpurea*, and treelike species such as *S. schwerinii*. Sprout size can vary considerably within clones and even within individual stools. Clones SU 8955 (*S. schwerinii*) and V 781 (*S. viminalis* × *caprea*) had the longest individual sprouts.

The differences between the clones in the production of stem biomass/stool were great. These differences were probably accentuated by the competition between the clones because the trial was a row experiment and the distance between the plots was small. The fast-growing clones probably obtained a competitive advantage when growing next to slow-growing clones. Thus the production levels of the best growing clones overestimated the production capacity of the same clones in dense monoclonal stands and vice versa.

The mean stem biomass production of the best clone was, during the two-year rotation, 1037 g/stool with no irrigation or fertilization. With a cultivation density used in our experiment (0.8 × 0.8 m spacing, 15 625 plants/ha), this is equivalent to about 16 t/ha. Values of 3–10 t/ha/year have been obtained for the woody dry mass production of willow in different parts of Finland (Hytönen 1982, 1985, 1986, Rossi 1982, Lumme et al. 1984).

There were significant differences between the blocks in both stem biomass production and dry matter content. Willows are presumably sensitive to the fertility and moisture conditions of the site. Owing to the design of the trial it was not possible to determine possible interactions between the genotype and site; Rönnberg-Wästljung and Thorsen (1988) have drawn attention to this interaction.

Nutrient Concentrations of the Leaves and Stems

The formation of the composite samples for nutrient analysis in this study may have biased the average foliar and stem nutrient values of the clone within each plot, since not exactly the same amount of dried plant material from each subsample was weighted into the composite sample. Differences in the foliar and stem nutrient concentrations between clones, however, followed the same pattern in all replications.

The foliar nitrogen concentration of *S.* 'Aquatica' cultivated with a short rotation period has varied from 26 to 39 g/kg, and the phosphorus concentration from 2 to 4 g/kg (Näsi and Pohjonen 1981, Saarsalmi 1984, Ferm 1985, Hytönen 1986, 1987). According to Rytter and Ericsson (1992), the foliar nitrogen concentration of willow clones with a good biomass production is 30–40 g/kg. The foliar nitrogen concentrations of all the clones in this study were smaller than these values, but the foliar phosphorus concentration of most of the clones higher. The foliar potassium concentrations were of the same order of magnitude as those presented by Ferm (1985) and Hytönen (1986) for *S.* 'Aquatica' and *S. viminalis*.

The high foliar phosphorus concentrations of the willows appears to be due to the fact that the growing site was an abandoned field, and the phosphorus content of the soil at the start of the experiment was still at a level considered satisfactory for agricultural purposes (Viljavuuspalvelu 1991).

The results of this study are supported by Näsi and Pohjonen (1981), Ericsson (1984) and Simon et al. (1990), who have reported that there are significant differences in the foliar and stem nutrient concentrations between different species of willow and also between clones of the same species. On the other hand, the nutrient concentrations of the same willow clone can vary according to the fertilization regime and the production level (Hytönen 1986).

The closely related clones P 6010 (*S. triandra*) and E 4855 (*S. lucida*) and hybrid clone V 7507 (*S. lucida* × *alba* var. *vitellina*), which are all representatives of species of the *Salix* subgenus, proved to be similar with respect to some of the nutrients. The stem nitrogen and magnesium concentrations and the stem and foliar boron concentrations were higher in these clones compared to other clones.

The Genetic Gain Obtained through Hybridization and Selection

The growth of the hybrid clones varied considerably compared to that of their parents. The biomass production of hybrid clones V 781 and V 782 was clearly greater than that of their parents. Hybrid clones V 7511, V 7513 and V 7516 were intermediate, and hybrid clones V 783, V 793, V 7507, V 7510 and V 7519 less productive compared to their parents.

The clone with the best biomass production was hybrid V 781, the mother of which was H 3157 (*S. viminalis*) and father E 6761 (*S. caprea*). Its production was 34 % better than that of the maternal clone. Clone V 781 had inherited a good rooting capacity from its *S. viminalis* mother. In addition, the survival of clone V 781 was 100 % after ten growing seasons and repeated harvesting of the sprouts.

The clone with the second best biomass production was hybrid V 782 (H 3157 *S. viminalis* × E 4856 *S.* 'Aquatica'). As regards dry matter production it was 20 % better than its maternal clone and 27 % better than its paternal clone. The beneficial properties (survival, sprout size and proportion of stem out of total biomass produced) inherited from its parents appear to have been combined in the hybrid clone.

The success of *S.* 'Aquatica' in Finnish conditions is uncertain. Although both clones of *S.* 'Aquatica' were among the best clones as regards biomass production after three years, they had been almost completely destroyed after ten years. In addition to hybrid clone V 782, the survival of the other *S.* 'Aquatica' hybrids (V 7510, V 7511, V 7513) was considerably better than that of the *S.* 'Aquatica' fathers. The production of these clones was not, however, particularly high.

Hybrid clones V 781 and V 7519, which had the same *S. viminalis* clone (H 3157) as mother but different *S. caprea* clones (E 6761 and E 7311) as father, differed considerably from each other. This may be a sign of the variation between the southern Finnish *S. caprea* clones, which should be taken into account when selecting breeding material.

The results presented above show that it is possible, through interspecific hybridization and selection, to improve production and to combine the desired properties of different species. However, it is not possible to make any broad generalizations about the heterosis on the basis of this material.

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