Bioenergy from Willow
1995 Annual Report

November 1987 — December 1995

Final Report 97-10
July 1997

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Energy Research and Development Authority
NYSERDA

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A NYSERDA Report in Brief

Report: **Energy From Willow, 1995 Annual Report, 11/87 - 12/95**
Report 97-10

Project Manager: **Jeffrey M. Peterson**

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Background: In 1987, experiments began at Tully, New York, to assess the potential of willows for wood biomass production. Willows were selected rather than other tree species because they grow rapidly when young, coppice readily, and have potential for rapid genetic improvement because they flower at a young age and can be hybridized. Hybrid poplars also have great growth potential in five plus year rotations but they are susceptible to *Septoria* canker, which causes stems to break as early as four years after the initial planting or coppicing. Uncertainties about willows included their biomass production potential with annual harvesting, their response to fertilizer inputs, and the importance of clonal variation to biomass production.

Objectives: The short-term objective was to develop the technology for growing willows that can be used for energy production by direct burning, or gasification, or made into high-value chemicals. The long-term objective was to develop a willow biomass production and use industry. Specific technical objectives included determining the effects of clone type, fertilization, spacing, cutting cycle, and irrigation on biomass production.

R&D Results: Production was high, with willow clone SV1 yielding nearly 32-oven dry tons per acre with a three-year harvest cycle, irrigation, and fertilization. Clone type, fertilization, spacing, cutting cycle, and irrigation all significantly affected biomass production.

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BIOENERGY FROM WILLOW
1995 ANNUAL REPORT
November 1987 — December 1995

Final Report

Prepared for

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ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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NOTICE

ABSTRACT

Experiments were established at Tully, New York, by the State University of New York College of Environmental Science and Forestry, in cooperation with the University of Toronto and the Ontario Ministry of Natural Resources, to assess the potential of willows for wood biomass production. Specific objectives included determining the effects of clone type, fertilization, spacing, cutting cycle, and irrigation on biomass production. Production was high, with willow clone SV1 yielding nearly 32 oven dry tons per acre (odt ac^{-1}) with three-year harvest cycle, irrigation, and fertilization. Clone type, fertilization, spacing, cutting cycle, and irrigation all significantly affected biomass production. Willow clone-site trials planted at Massena, and Tully, NY in 1993 grew well during 1994 and 1995, but some clones in the Massena trial were severely damaged by deer browse.

Several new cooperators joined the project, broadening the funding base, and enabling establishment of additional willow plantings. Willow clone-site trials were planted at Himrod, King Ferry, Somerset, and Tully, NY, during 1995. A willow cutting orchard was planted during 1995 at the NYS Department of Environmental Conservation Saratoga Tree Nursery in Saratoga, NY. Plans are to begin site preparation for a 100+ acre willow bioenergy demonstration farm in central New York, and additional clone-site trials, in 1996 .

Key words: willow, bioenergy, spacing, fertilization, cutting cycle, irrigation.

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SUMMARY

Experiments were established during 1987 at Tully, NY by the State University of New York College of Environmental Science and Forestry, in cooperation with the University of Toronto and the Ontario Ministry of Natural Resources, to assess the potential of willows for wood biomass production. Initial studies tested high planting densities (0.3 by 0.3 m) with annual harvesting, and showed that willows were highly productive with this management strategy; annual biomass production was as high as 16.4 oven dry (od) tonnes ha^{-1} with irrigation and fertilization However, an annually harvested spacing study indicated that willows planted at 0.46 by 0.46 m were as productive as those planted at denser spacings, which led to an experiment to test wider spacings and longer harvest cycles. The most productive spacing and cutting cycle combination, 0.3 by 0.9 m spacing harvested triennially, yielded 71.3 od tonnes ha^{-1} (23.8 od tonnes ha^{-1} yr^{-1}) with irrigation and fertilization. This is the highest woody biomass production rate ever reported in the northeast United States. Cumulative production after three growing seasons was significantly larger with triennial harvest cycle than with annual harvest cycle. Large variation among willow clones in biomass production was observed, indicating that selecting the proper clones is essential for achieving high biomass production. Genetic improvement efforts were increased in 1995 to produce faster growing clones and expand the genetic base in our breeding program. Willow clone-site trials were established in 1993 and 1995 to determine the adaptability of willow clones to different sites. The ultimate success of the willow bioenergy production system will depend on developing faster growing willow clones that are free of insect and disease pests. Willow cutting orchards were established as a first step to planting commercial-scale willow bioenergy plantings.

Throughout these studies, techniques for growing willows in plantations were developed. Effective weed control is essential for a willow bioenergy planting to be successful. A study to test various preemergent herbicides identified effective products for Central New York. The "double-row" spacing developed in Sweden was used in plantings established in 1993 or later. This spacing was developed for maximum biomass production and is suitable for planting and harvesting machinery developed specifically for willow bioenergy plantings. Fertilization with nitrogen, phosphorous, and potassium increased biomass production, but fertilizer rate studies are necessary to determine optimum fertilizer application rates for various site types. Nutrient removal by willows harvested annually, biennially, and triennially was determined.

Willow bioenergy crop commercialization will require cooperation with private industry, government, and other universities. Demonstration farms must be established to gain information on the economics of the system in New York, and so that producers and wood users can see the system first-hand.

Section 1

INTRODUCTION

The State University of New York College of Environmental Science and Forestry, in cooperation with the University of Toronto and the Ontario Ministry of Natural Resources, began studying the potential of willows for bioenergy in 1987. The short-term objective was to develop technology for growing willows that may be used for energy production by direct burning, gasified to energy gases, or made into high value chemicals. The long-term objective was to develop a willow biomass production and utilization industry.

The primary focus of initial experiments was to develop a feedstock that could be readily gasified to methane, with annual harvesting for rapid return on initial investments. Willows were selected rather than other tree species because they have rapid juvenile growth rates, coppice readily, and have potential for rapid genetic improvement because they flower at a young age and can be hybridized. Hybrid poplars have large growth potential provided rotations are five years or longer, but poplars are susceptible to *Septoria* canker, which causes stem breakage as early as age four. Uncertainties about willows included determining their biomass production potential with annual harvesting, their response to fertilizer inputs, and the importance of clonal variation to biomass production.

The project's focus turned away from gasification towards direct burning, especially co-firing with coal, when natural gas prices declined in 1989. The change meant experiments had to be completed to determine how to rapidly produce larger trees that were suitable for co-firing with coal. Encouraging preliminary results with willows and reports from Sweden of an expanding willow bioenergy industry suggested that additional studies with willows were warranted.

Stable funding by NYSERDA from 1987 to the present and impressive willow biomass production attracted funding from numerous other sources. Initial experiments were funded by NYSERDA, New York Gas Corporation (NYGAS), and the Gas Research Institute (GRI). GRI abandoned the project when gas prices declined in 1989 and it appeared unlikely that the willow biomass-to-methane system would be able to compete economically with traditional gas sources, and NYGAS followed in 1990. Niagara Mohawk Power Corporation became a co-funder in 1990, recognizing the potential of using wood for electricity generation, though they did not have an immediate need for wood fuel. The Electric Power Research Institute (EPRI) became a co-funder in 1991 because of their interest in exploring the possibility of using willow bioenergy plantations to recycle wood ash from industry using virgin wood for fuel. One of the original studies was converted into a study to test the effect of wood ash application on willow wood biomass production and soil properties. The Empire State Electric Energy Research Corporation also became a co-funder in 1992, with general interest in the project. The United States Department of Energy Biofuels Feedstock Development Program became a co-funder in 1992, with the objective of assisting in expansion of promising willow clones in nursery beds, and establishment of willow clone-site trials. New York State Electric and Gas Corporation became involved in the project in 1992 because of a desire to co-fire coal with wood in electric generation facilities that currently burn high-sulfur coal and are due to be re-licenced before the end of the century. A paper study to determine the economic feasibility of growing willows for electric power generation was funded in 1994 by EPRI and the United States Department of Energy National Renewable Energy Laboratory. The United States Department of Agriculture Cooperative States Research, Education and Extension Service provided funding for establishing a 100+ acre willow bioenergy demonstration farm, with site preparation beginning in 1996.

Strong support for the project enabled completion of numerous experiments with willows, and many experiments are in progress. Studies on willow coppice physiology provided information guiding coppice timing for optimum regrowth. A study of preemergent herbicides was completed because forestry uses were excluded from the simazine label, the herbicide of choice for willows. The study enabled identification of alternatives to simazine. A spacing-fertilizer study with one willow clone showed there was no biomass production advantage to planting at spacings denser than 0.46 by 0.46 m. A study containing 300 willow clones representing eight species showed large clonal variation exists in biomass production potential, and enabled identification of native North American willow species with desirable characteristics for bioenergy production. This study currently serves as a clone bank. Continuing experiments include clone-fertilizer, spacing/cutting cycle, irrigation, clone-site, and genetic screening studies.

The University of Toronto has been a close cooperator since this project's inception, developing a parallel willow biomass program. The primary focus of the University of Toronto program has been genetic improvement of willows. A large cutting orchard containing genetically improved willows was established during 1992, and supplies the majority of cuttings for some clones to this project. A prototype willow bioenergy farm was planted during 1993, and three others were planted during 1995.

Section 2
EXPERIMENTS AND RESULTS

CLONE-FERTILIZER TRIAL

A clone-fertilizer trial was initiated in 1987 to determine the effect of clone and annual fertilization on willow biomass production with annual harvests and dense ("wood-grass") spacing. The study was established in 1987 at the State University of New York College of Environmental Science and Forestry's Genetics Field Station, in the village of Tully, New York (42° 47' 30" N, 76° 07' 30 W). The soil was a Palmyra gravelly silt loam (Glossoboric Hapludalf), a good quality agricultural soil. Site preparation was done mechanically and chemically. The site was sprayed with glyphosate (Roundup™, Monsanto Agricultural Company, St. Louis, MO) at the rate of 2.3 kg ai ha^{-1} during August, 1986, to kill all weeds, and upon confirmation of herbicide effectiveness, the site was plowed, cross-disked, and raked. Simazine (Princep 4L™, Ciba-Geigy Corp., Greensboro, NC) was subsequently applied at the rate of 4.5 kg a.i. ha^{-1} to prevent weed growth during the first part of the 1987 growing season.

Unrooted cuttings, 25 cm in length, from five willow clones, plus a hybrid poplar clone known to be well adapted to the site, were collected from one-year-old stems during winter 1986 from nursery stool beds and stored at 0°C until planting. Willow clones were selected for their above average biomass production potential in a genetic selection trial in Ontario, Canada. Cuttings were planted flush with the ground during the first week of April 1987, at 0.3 by 0.3 m spacing. Experimental plots were 6.0 by 6.0 m in size, including two exterior border rows; there were 256 measurement trees planted in each plot. The experimental design was a split-plot with three replicates per treatment for the whole-plot factor. Fertilization treatment was the whole-plot factor and clone was the sub-plot factor.

Three of the whole plots received fertilizer annually shortly after trees sprouted. Fertilizer was applied to minimize nutrient availability as a growth limiting factor. Elemental N, P, and K was applied as ammonium nitrate, treble superphosphate, and muriate of potash at rates of 336, 112, and 224 kg ha^{-1} yr^{-1}, respectively from 1987 to 1991. Nitrogen was applied as urea through an irrigation system in 1990 at the equivilent elemental rate. Each year's initial application consisted of the entire amount of P and K, and 56 kg ha^{-1} of N. Subsequently, five additional applications of N at 56 kg ha^{-1} were hand broadcast every three weeks until August of all years, except in 1990, when it was applied through the irrigation system. No fertilizer was applied in 1992, and only N was applied from 1993 to 1995 to previously fertilized replications, at the elemental rate of 224 kg ha^{-1}.

Plots were irrigated during the growing season from 1989-1995 with a drip system to ensure water was not a growth limiting factor, but were not irrigated during 1987 or 1988. Amounts of water added ranged from 2 to 6 cm ha week^{-1}, with the larger amounts required during August. Irrigation was terminated in mid-September each year.

Trees were harvested during late November or early December with brush saws, cutting within 4 cm of the ground each year, with the exception of the first growing season, when trees were cut with hand shears during late winter. Measurement trees were weighed fresh in the field and a 2- kg random subsample of trees was taken from each plot to estimate the percent moisture content and nutrient analyses. These samples were placed in a forced-air drying oven at 65°C, dried to constant weight, and weighed. Biomass was calculated on an oven dry weight per ha basis. Stool survival was recorded in 1988, and from 1990 to 1995 using a 100% census.

Biomass production data for the first five years of data (1987-1991) were statistically analyzed using a repeated measures technique. Biomass data for each plot were fit to the logistic equation using the geometric algorithm SIMPLEX to estimate coefficients for equation parameters A, B, and n:

$$y = A/(1 + Be^{nx}) \qquad (1)$$

where y = observed biomass production (o.d. t ha^{-1} yr^{-1}), A = asymptote (the maximum estimated production capacity (o.d. t ha^{-1} yr^{-1})), B = constant (no biological significance), n = constant (the intrinsic rate of increase), x = plantation age (years), and e = base of the natural logarithms. Goodness of fit and conformity to model assumptions were determined from r^2 values and plots of residuals. Estimated coefficients of curve parameters were treated as primary data and treatment effects tested by analysis of variance using the split-plot model described above.

Fitting the biomass data to one of the allometric functions was decided *a priori* because it was anticipated that growth would initially increase exponentially, and that an asymptote would be reached over time for biomass production due to the dense spacing. The logistic equation was selected because it was suggested by plotting biomass production versus time (year), and it gave the best fit of several functions tested during the first five growing seasons. The 1992 growing season was the coolest on record in the area, causing a large growth decline, and the logistic function did not fit the data well subsequently. A new type of curve fitting technique will be developed for 1992-1996 growing season data. Survival data were analyzed separately by year using analysis of variance and the split-plot model described above. The repeated measures technique employed for biomass production was not used because the survival response curve was not of interest. All analyses of variance were performed using the SAS computer software system.

Production by willows in this experiment was high, rapidly increasing during the first three years and maintaining high production during the fourth and fifth years (Table 2-1). A large decline in production was observed during the sixth year (1992). Reduction was attributed to low growing season temperatures. Production by all clones except willow clone SA22 increased during 1993 compared to 1992, approximating the level observed in the third (1989) growing season. Production increased slightly during 1994 compared with 1993 (Table 2-1). Two willow clones, SA22 and SAM3, were eliminated from the experiment during 1994 because of their poor growth.

With fertilization, the most productive clone (SV1) yielded 16.4 odt ha^{-1} during the fifth (1991) growing season, and this level was nearly attained during the ninth (1995) growing season. Production data from the first five growing seasons fit the logistic equation well, with all but one plot having r^2 values above 0.85 (Table 2-2, Figure 2-1). Large clonal variation in biomass production potential was observed annually, indicating that proper clone selection is critical. Fertilization with N, P, and K significantly (P=0.003) increased the rate at which trees attained their maximum production potential, with fertilized trees reaching their maximum one year earlier than non-fertilized trees. Large clone-by-fertilizer treatment interactions were observed. However, averaging all clones, fertilization did not result in a statistically significant increase in maximum annual wood biomass production. Survival of most clones was reduced by fertilization. The decrease in production during 1992 compared with 1991 and 1993 (Table 2-1) was accompanied by a decrease in growing season temperatures in 1992, which suggests that low temperatures were at least partially responsible for reduced growth in 1992. There were 2244 growing degree days (gdd) at the site in 1992, compared with 2641 gdd in 1993. The year when the most biomass was produced, 1991, had the largest number of growing degree days (3086). Biomass production in 1994 was similar to that in 1993, and there were 2694 gdd in 1994, slightly more than in 1993. The 1995 growing season was the second warmest since the study began, and production by willow clone SV1 with fertilization reflected the warm conditions. However, production by clones SH3 and NM5 in 1995 was similar to that in 1993 and 1994, and production by willow clone SA2 declined. After 1996 data is obtained, a new repeated measures analyses will be completed to determine if fertilizer effects during the second five-year period of the study declined compared with the first five-year period.

Poor growth by willow clones SA22 and SAM3 demonstrates the importance of clonal variation and site adaptability. These clones grew well in a Canadian trial but were not well adapted to annual harvest cycles in the current study. Willow clones must be tested under conditions as close to those planned for commercial plantings as possible so that reliable clone selections can be made.

Table 2-1. Biomass production (standard errors in parentheses) by five willow clones and one hybrid poplar clone, fertilized or non-fertilized, harvested annually in the clone-fertilizer study.

		Oven-dry Biomass Production (tonnes/ha)									
CLONE	TRT[1]	1987[2]	1988	1989	1990	1991	1992	1993	1994	1995	SUM
SV1	F	1.1	8.3	14.1	14.8	16.4	9.0	11.9	13.2	15.9	104.7
		(0.1)	(0.9)	(1.5)	(0.2)	(0.8)	(0.3)	(0.6)	(0.5)	(0.4)	
	NF	1.1	5.8	10.8	13.9	15.0	8.7	10.5	12.6	11.2	89.7
		(0.2)	(1.2)	(0.3)	(0.7)	(0.2)	(0.9)	(0.6)	(0.1)	(1.3)	
SH3	F	1.3	4.7	11.9	11.9	12.8	9.0	9.9	10.8	10.5	82.7
		(0.2)	(1.1)	(0.2)	(0.6)	(0.8)	(0.2)	(0.3)	(0.4)	(1.2)	
	NF	1.3	4.0	8.7	12.1	13.2	10.3	10.1	10.3	11.0	81.1
		(0.2)	(0.3)	(0.2)	(0.8)	(0.9)	(0.2)	(0.1)	(0.3)	(0.4)	
SAM3	F	1.1	3.8	7.6	7.8	8.5	4.3	4.5	Eliminated[3]		
		(0.1)	(0.1)	(0.4)	(1.5)	(0.5)	(0.6)	(2)			
	NF	0.4	1.6	4.5	8.5	6.9	2.5	3.1	Eliminated		
		(0.1)	(0.2)	(0.5)	(0.9)	(0.9)	(0.4)	(0.4)			
SA22	F	0.7	3.6	11.0	7.4	8.3	6.1	2.9	Eliminated		
		(0.1)	(0.6)	(0.5)	(1.1)	(1.1)	(1.5)	(0.9)			
	NF	0.4	2.7	6.7	8.1	5.6	2.9	1.8	Eliminated		
		(0.1)	(0.5)	(0.6)	(0.4)	(0.4)	(0.6)	(0.4)			
SA2	F	0.7	3.8	12.6	13.2	13.5	8.7	10.5	9.4	7.2	79.6
		(0.1)	(0.6)	(0.5)	(0.7)	(0.6)	(0.2)	(0.4)	(0.4)	(0.1)	
	NF	0.4	2.9	6.5	10.5	10.8	5.8	8.5	6.9	6.1	58.5
		(0.1)	(0.8)	(1.5)	(0.8)	(2.1)	(1.3)	(0.1)	(1.5)	(0.9)	
NM5	F	3.1	9.2	9.9	10.1	11.4	7.6	10.1	9.2	9.2	79.8
		(0.3)	(0.2)	(0.3)	(0.1)	(0.3)	(0.1)	(0.2)	(0.2)	(1.9)	
	NF	2.5	7.6	11.0	13.0	13.5	7.6	10.8	10.1	11.7	87.7
		(0.3)	(0.6)	(0.4)	(0.7)	(0.1)	(0.4)	(0.5)	(0.8)	(0.8)	

[1] TRT refers to fertilizer treatment; F=fertilized, NF=non-fertilized.

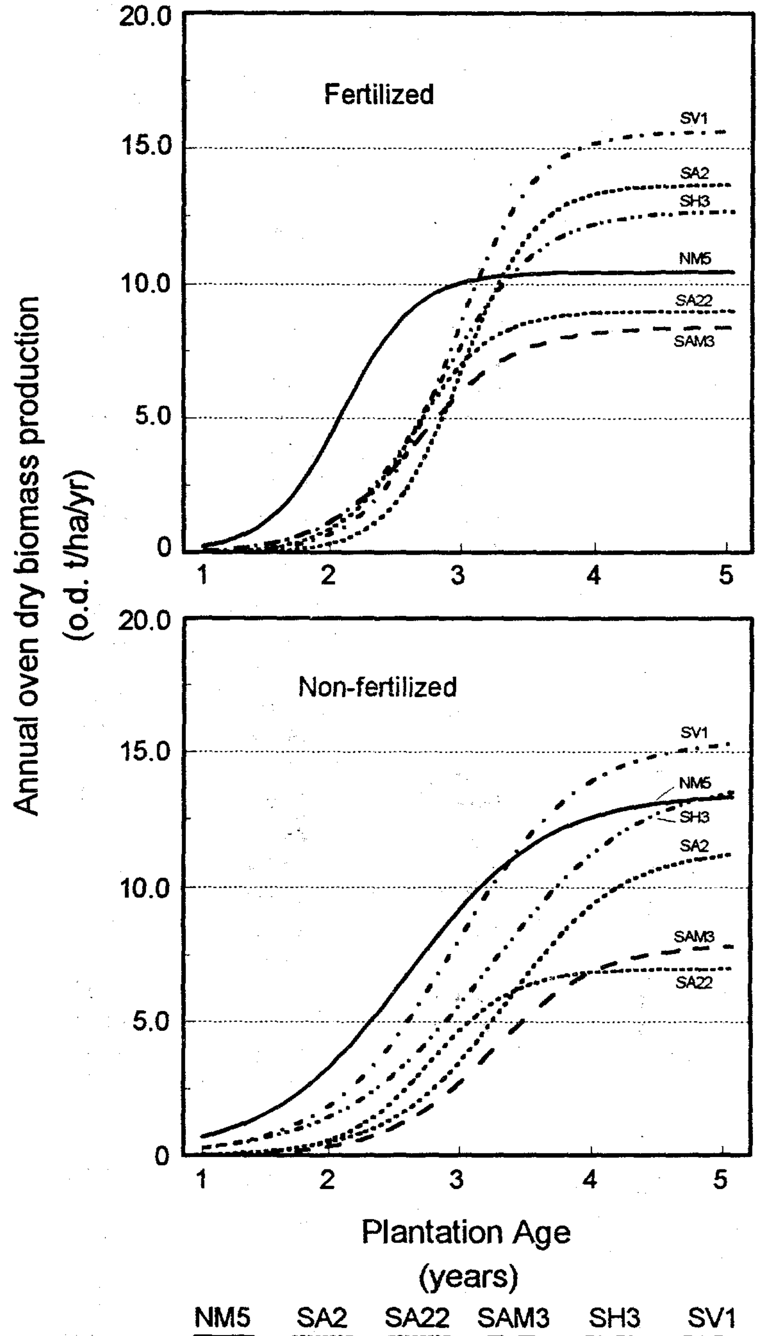
[2] Data from 1987 is non-coppice production. All other years are coppice production.

[3] ELIM indicates no biomass production data were obtained because clones were eliminated from the experiment.

Table 2-2. Estimates of parameters A (maximum production capacity), B (constant), and n (intrinsic rate of increase) calculated by fitting biomass data from five successive annual harvests to the logistic equation and used as raw data in ANOVA and the coefficient of determination (r^2), for five willow clones (SV1, SH3, SAM3, SA22, and SA2) and one hybrid poplar clone (NM5) with (F) or without (NF) fertilization.

			---------------- Parameter ----------------			
Clone	Treatment	Replication	A	B	n	r^2
SV1	F	1	16.594	1308.91	-3.49	0.98
SV1	F	2	15.409	25.41	-1.70	0.93
SV1	F	3	14.908	234.60	-2.75	0.99
SV1	NF	1	17.764	34.09	-1.20	0.99
SV1	NF	2	14.042	81.42	-1.96	0.99
SV1	NF	3	14.586	49.57	-1.90	0.99
SH3	F	1	11.947	280.57	-2.47	0.94
SH3	F	2	13.523	80.78	-2.07	0.98
SH3	F	3	12.628	74.64	-2.12	0.99
SH3	NF	1	15.080	21.07	-1.11	0.99
SH3	NF	2	11.906	48.96	-1.60	0.99
SH3	NF	3	14.979	76.77	-1.60	0.99
SAM3	F	1	9.071	75.32	-2.04	0.98
SAM3	F	2	6.583	72.01	-2.43	0.86
SAM3	F	3	9.497	127.48	-2.22	0.99
SAM3	NF	1	9.436	321.49	-2.09	0.96
SAM3	NF	2	6.126	184.29	-2.04	0.95
SAM3	NF	3	8.145	288.62	-1.95	0.92
SA22	F	1	10.501	275.99	-2.84	0.91
SA22	F	2	7.354	254.93	-2.91	0.68
SA22	F	3	9.128	278.13	-2.67	0.87
SA22	NF	1	6.544	283.89	-2.77	0.87
SA22	NF	2	7.297	185.61	-2.64	0.87
SA22	NF	3	7.079	238.89	-2.22	0.95
SA2	F	1	14.407	1017.97	-2.82	0.99
SA2	F	2	13.200	245.79	-2.63	0.97
SA2	F	3	13.323	2799.16	-3.40	0.98
SA2	NF	1	13.664	54.25	-1.58	0.99
SA2	NF	2	7.961	196.56	-2.19	0.92
SA2	NF	3	12.615	370.58	-1.82	0.99
NM5	F	1	10.399	31.13	-2.59	0.99
NM5	F	2	10.450	64.62	-3.05	0.93
NM5	F	3	10.434	42.15	-3.05	0.96
NM5	NF	1	13.204	14.95	-1.41	0.99
NM5	NF	2	13.154	25.13	-1.57	0.99
NM5	NF	3	13.924	17.13	-1.61	0.99

Figure 2-1. Annual yields from fertilized and non-fertilized trees, showing time taken to reach maximum production levels.



Speculatively, growing season temperatures appear to have a strong effect on biomass production, with warm temperatures increasing production. Willows appear to require three or four years to attain their full growth potential with annual harvesting, and thereafter are limited by a combination of genetic potential and environmental conditions. Favorable weather conditions during and after the fourth growing season enable trees to attain their full growth potential, and if weather conditions were consistent after the fourth growing season, annual biomass production of clones that respond well to annual coppicing would remain constant.

SPACING-FERTILIZER TRIAL

An experiment was established during 1987 at Tully, NY, adjacent to the clone-fertilizer study, to determine the effect of three woodgrass spacings, and fertilization with N, P, and K on biomass production by one willow clone with annual harvesting. The hypothesis was that spacing and fertilizer treatments would affect biomass production. Site preparation and planting were as described for the clone-fertilizer study. *Salix purpurea* clone SP3 was planted at three spacings, 0.15 x 0.15, 0.30 x 0.30, and 0.46 x 0.46 m (430,500, 107,600, and 45,700 trees ha^{-1}, respectively). Experimental plots were 6.0 x 6.0 m in size, including two border rows around the 0.15 x 0.15 and 0.30 x 0.30 m spaced plots, and one border around the 0.46 x 0.46 m spaced plots. The experimental design was a split-plot with three replicates per treatment for the whole-plot factor. Fertilization treatment was the whole-plot factor and spacing was the sub-plot factor. N, P, and K fertilizer was hand broadcast annually at the rates and with the techniques described for the clone-fertilizer trial. Soil moisture was maintained close to field capacity at 30 cm soil depth during the 1989-1991 growing seasons using a drip system to minimize water as a growth limiting factor. Trees were not irrigated during 1987 or 1988. Irrigation was terminated in mid-September each year. All trees were harvested annually, weighed fresh in the field, and samples were collected for estimation of percent moisture content. Biomass was calculated on an oven dry weight per ha basis. Stool survival was recorded in 1988, 1990, and 1991 using a 100% census.

Biomass production data were statistically analyzed using a repeated measures technique. Biomass data for each plot were fit to the logistic equation using the iterative geometric algorithm SIMPLEX as described for the clone-fertilizer study data. Biologically sensible parameter estimates for several plots could be obtained only by decreasing the initial parameter increments and increasing the maximum allowable error compared with those values used for the other plots. Parameter estimates were treated as primary data and analyzed by analysis of variance with the split-plot model described above. Duncan's multiple range test was used to detect differences between fertilizer treatment and spacing means.

Maximum annual biomass production observed in this experiment by willow clone SP3 was 14.0 o.d. t ha^{-1} during the fifth growing season (1991, fourth coppice) by non-fertilized trees spaced at 0.46 x 0.46 m (Table 2-3). Cumulative production after five annual harvests by trees planted at 0.46 x 0.46 and 0.30 x 0.30 m spacings was significantly ($P=0.05$) larger than by trees planted at 0.15 x 0.15 m, averaging 41.2, 39.2, and 36.5 o.d. t ha^{-1}, respectively. In 1987, trees planted at 0.15 x 0.15 m spacing yielded 2.3 times more biomass than trees planted at 0.46 x 0.46 m despite having approximately nine times more trees per unit area. Biomass production was nearly

Table 2-3. Biomass production (standard errors in parentheses) by willow clone SP3 grown at three wood-grass spacings, fertilized or non-fertilized, harvested annually in the spacing-fertilizer study.

Spacing (m)	Trt	Annual Oven-dry Biomass Production (tons ha^{-1}) 1987[1]	1988	1989	1990	1991	Sum (tons ha^{-1})
0.15 x 0.15	F	2.2	5.5	10.8	10.7	9.5	38.7
		(0.2)	(0.5)	(0.3)	(0.1)	(1.7)	
0.15 x 0.15	NF	1.5	4.8	7.3	9.2	11.4	34.2
		(0.2)	(0.2)	(0.3)	(0.9)	(0.3)	
0.30 x 0.30	F	1.2	5.5	12.2	11.6	12.7	43.2
		(0.1)	(0.9)	(0.8)	(0.4)	(0.3)	
0.30 x 0.30	NF	0.8	4.5	8.2	11.8	13.9	39.2
		(0.2)	(0.9)	(0.3)	(0.2)	(0.6)	
0.46 x 0.46	F	0.8	5.9	9.1	12.3	13.4	41.5
		(0.1)	(0.2)	(0.5)	(0.2)	(0.4)	
0.46 x 0.46	NF	0.7	4.5	5.9	11.8	14.0	36.9
		(0.1)	(0.7)	(0.6)	(0.6)	(0.4)	

[1] Data from 1987 is non-coppice production. All other years are coppice production.

the same among the three spacings during the second season (1988, first coppice), an exceptionally dry year. Biomass production during the third (1989) growing season by trees planted at 0.30 x 0.30 m was significantly larger than by trees planted at 0.46 x 0.46 and 0.15 x 0.15 m spacings. The 0.46 x 0.46 and 0.30 x 0.30 m spacings were significantly more productive than the 0.15 x 0.15 m spacing during the fourth and fifth (1990 and 1991) growing seasons, with or without fertilizer (Table 2-3). Fertilization increased biomass production during each of the first three (1987, 1988, and 1989) growing seasons with significant increases in 1987 and 1989, had little effect during the fourth (1990) growing season, and reduced production during the fifth (1991) season at all spacings (Table 2-3).

Biomass production from five successive annual harvests fit the logistic equation well, with all but two plots having r^2 values above 0.90 (Table 2-4). The maximum estimated production capacity (parameter A) was significantly (P=0.01) decreased by fertilization. Fertilization significantly (P=0.01) decreased the value of parameter n (increased its absolute value), indicating that fertilization increased the rate at which trees reached their maximum production potential (Figure 2-2). Fertilization accelerated production levels toward their maximum potential by one year. Spacing significantly affected the value of parameter A (P=0.01). Trees grown at 0.46 x 0.46 and 0.30 x 0.30 m spacing had significantly (P=0.01) higher estimated maximum production capacity (A) than trees grown at 0.15 x 0.15 m spacing (15.2, 13.4, and 11.8 o.d. t ha^{-1} yr^{-1}, respectively) (Figure 2-3). Spacing significantly (P=0.01) affected the value of parameter n, with trees spaced at 0.30 x 0.30 m having a significantly smaller value of n (larger intrinsic rate of biomass increase) than trees spaced at 0.15 x 0.15 m (Figure 2-3). There were no significant fertilizer treatment-by-spacing interactions detected for parameters A, B, or n, and parameter B was not affected by fertilizer treatment or spacing.

Survival was not significantly affected by fertilization or spacing, averaging 91, 85, and 83% in 1988, 1990, and 1991, respectively (Table 2-5). The planting was free of serious insect pests. *Melampsora* rust was observed in the third, fourth, and fifth growing seasons (1989-1991) in all spacing and fertilizer treatments, causing foliage to drop in late September in 1989 and 1990, and in mid-September in 1991. In 1987 and 1988, leaves dropped during mid-October. This study showed that woodgrass spacings denser than 0.46 by 0.46 m are not desireable for maximum biomass production efficiency, though dense spacing provides a product that may be preferred for some applications. Trees grown at the widest spacing in this experiment, 0.46 by 0.46 m, had a significantly higher estimated maximum production potential (parameter A) than those grown at 0.30 by 0.30m and 0.15 by 0.15 m spacing. Competition among trees limited growth at the two densest spacings, and was strong even during the first growing season when root systems were becoming established, though competition above-ground appeared minimal. In the absence of competition, the 0.15 x 0.15 m spacing would have yielded approximately nine times

Table 2-4. Estimates of parameters A (maximum production capacity), B, and n (intrinsic rate of increase) calculated by fitting biomass data from five successive annual harvests to the logistic equation and used as raw data in ANOVA, and the coefficient of determination r^2, for willow clone SP3 grown at three planting densities (0.15 x 0.15, 0.30 x 0.30, or 0.46 x 0.46 m) with (F) or without (NF) fertilization, grown in an intensive culture system.

Spacing (m)	Trt	Rep	A	B	n	r^2
0.15 x 0.15	F	A	9.1	37.3	-2.3	0.7
0.15 x 0.15	F	B	11.5	249.2	-2.6	0.99
0.15 x 0.15	F	C	11.0	26.5	-1.9	1.0
0.15 x 0.15	NF	A	9.7	280.5	-2.7	0.8
0.15 x 0.15	NF	B	12.0	21.9	-1.3	1.0
0.15 x 0.15	NF	C	12.3	11.1	-0.9	1.0
0.30 x 0.30	F	A	12.5	4,909.8	-3.9	1.0
0.30 x 0.30	F	B	12.2	67.3	-2.1	1.0
0.30 x 0.30	F	C	12.7	255.3	-2.7	1.0
0.30 x 0.30	NF	A	16.1	25.8	-1.1	1.0
0.30 x 0.30	NF	B	14.2	89.1	-1.6	1.0
0.30 x 0.30	NF	C	13.1	24.8	-1.3	1.0
0.46 x 0.46	F	A	14.8	24.0	-1.2	1.0
0.46 x 0.46	F	B	13.2	35.1	-1.6	1.0
0.46 x 0.46	F	C	12.9	34.0	-1.5	1.0
0.46 x 0.46	NF	A	16.5	52.1	-1.2	1.0
0.46 x 0.46	NF	B	16.8	28.2	-0.9	1.0
0.46 x 0.46	NF	C	16.8	23.3	-1.0	0.9

Figure 2-2. Annual oven-dry biomass production by willow clone SP3, fertilized or non-fertilized, from 1987-1991 fitted to the logistic equation.

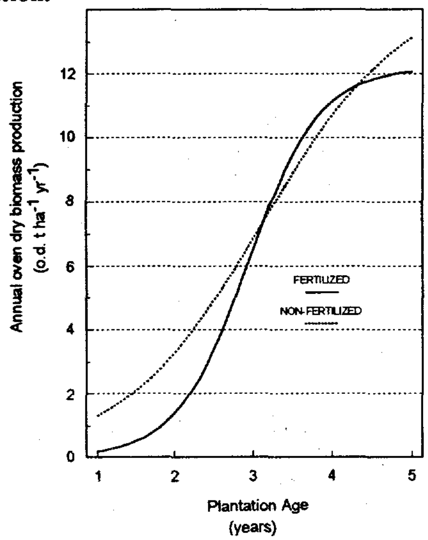


Figure 2-3. Annual oven-dry biomass production by willow clone SP3, grown at three spacings from 1987-1991, fitted to the logistic equation.

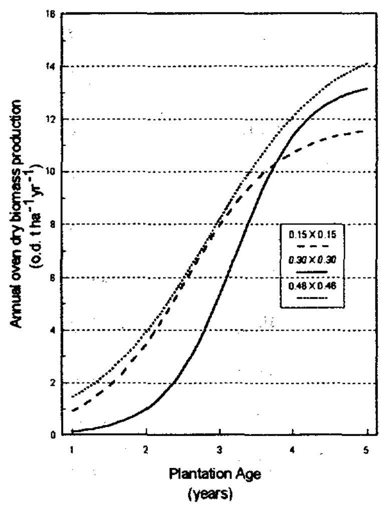


Table 2-5. Survival (standard errors in parentheses) by willow clone SP3 grown at three wood-grass spacings, fertilized (F) or non-fertilized (NF), harvested annually in the spacing-fertilizer study.

		Survival (%)		
Spacing (m)	Fertilizer Treatment	1988	1990	1991
0.15 x 0.15	F	94.0	75.0	67.0
		(3.1)	(1.3)	(1.3)
0.15 x 0.15	NF	92.0	90.0	85.0
		(5.5)	(4.4)	(6.7)
0.30 x 0.30	F	93.0	88.0	87.0
		(1.5)	(1.6)	(2.3)
0.30 x 0.30	NF	80.0	80.0	80.0
		(17.5)	(15.8)	(17.9)
0.46 x 0.46	F	91.0	86.0	86.0
		(2.4)	(3.3)	(3.3)
0.46 x 0.46	NF	94.0	92.0	92.0
		(4.4)	(3.5)	(3.5)

more biomass than the 0.46 x 0.46 m spacing, but the observed first-year yield was only 2.3 times larger. Competition at the two denser spacings intensified relative to the widest spacing during the second growing season, as evidenced by nearly equal biomass production among spacings. Fertilization significantly reduced the estimated maximum production potential (parameter A) of willow clone SP3, but significantly increased the rate trees attained their maximum production (increased the absolute value of parameter n). The reason for reduced production by fertilized trees was not determined, but may be related to a reduction in soil pH in fertilized plots due to nitrogen fertilization and/or soil nutrient imbalance. In 1991, soil pH averaged 5.4 and 6.1 in fertilized and non-fertilized plots, respectively. The optimum pH range for willows was reported to be 5.0-6.0, and acceptable willow growth was observed when peat pH was 4.5 or higher. Though soil pH probably was in an acceptable range in fertilized and non-fertilized plots, the large change in pH may have reduced availability of some nutrients. Fertilization did not decrease survival in this study as it did in the clone-fertilizer study.

SPACING/CUTTING CYCLE TRIAL

A study was established in 1990 to compare production of willows grown using a woodgrass system with those grown at wider spacings and one-, two-, and three-year harvest rotations. The hypotheses were that mean annual production would be ranked triennial > biennial > annual, and wider spacings would be as productive as narrower spacings at these harvest ages. The study was established in 1990 at the SUNY-ESF Genetics Field Station adjacent to the clone-fertilizer study. Site preparation was done chemically and mechanically, with glyphosate plus 2,4-dichlorophenoxyacetic acid herbicide application, plowing, disking, raking, and application of oxyfluorfen preemergent herbicide (Goal 1.6e Rohm & Haas Co., Philadelphia, PA) at 2.24 kg ai ha^{-1} the fall prior to planting.

Stem cuttings, 25 cm in length, from willow clones SV1 (*Salix dasyclados*), SH3 (*S. purpurea*), and SA22 (*S. alba*) were collected from one-year-old stems during winter 1989 from an established experiment and stored at 0-4°C until planting. Unrooted cuttings were planted flush with the ground during the third week of April 1990, at three spacings, 0.3 by 0.3, 1.0 by 3.0, and 0.6 by 1.1 m (111,111, 37,037, and 15,151 cuttings ha^{-1}, respectively). Experimental plots were 6.0 by 6.0 m in size including two border rows around the 0.3 by 0.3 and 0.3 by 0.9 m spaced plots, and one border around the 0.6 by 1.1 m spaced plots.

All trees were coppiced 4 cm above groundline during December 1990, to promote multiple stem production. N (ammonium nitrate), P (treble superphosphate), and K (muriate of potash) fertilizers were hand broadcast at the elemental rates of 37, 112, and 224 kg ha^{-1} respectively, shortly after trees sprouted in 1991. Nitrogen was subsequently applied biweekly at 37 kg ha^{-1} until mid-July (five additional applications) for a total annual application rate of 224 kg ha^{-1}. All trees were fertilized similarly during 1992. During 1993 to 1995, only N was applied at 224 kg ha^{-1} in six 37 kg ha^{-1} biweekly applications. Plots were irrigated during the growing season beginning in 1991 (the second growing season) with a drip system to ensure water was not a growth-limiting factor. Soil moisture was maintained close to field capacity based on gypsum block sensor readings at a depth of 0.3 m from May until early September each year.

Biomass measurements began for annually harvested trees in 1991. Biennially harvested trees were harvested in 1992 and 1994, and triennially harvested trees were harvested during 1993. All harvests were made during December of each year. Trees were cut at 2-5 cm above groundline with a power brushcutter. Moisture content of biennially- and triennially-harvested trees was estimated based on samples collected from three randomly selected trees in every plot. In annually harvested plots, 2-kg samples were collected from randomly selected stems in every plot. Samples were dried at 65°C and biomass production was calculated on an oven dry weight per ha basis. Stool survival was measured annually during May using a 100% census.

Trees in biennial and triennial harvest cycles were damaged by rabbits during January - March, 1992. Annually harvested trees were not damaged because they had already been coppiced. Damage was surveyed during April 1992, using a numerical rating as follows:

1 = little or no damage;

2 = no major stems girdled, and one or more stems with damage on less than 50% of the stem's circumference;

3 = one or more stems girdled but at least one main stem with damage on less than 50% of its circumference, or if the tree had only one stem, damage on 50-75% of the stem's circumference;

4 = one or more stems girdled and largest stem that was not girdled had damage on more than 50% of it's circumference, or if the tree had one stem, 76-90% of the stem's circumference was damaged; and

5 = all major stems were girdled.

Re-evaluation of randomly selected trees showed the rating system was consistent and reliable.

The statistical design was a split-plot with three replications; cutting cycle was the whole-plot factor and spacing was the sub-plot factor. Statistical analyses were restricted to comparing cumulative production of annual with biennial harvest cycles, and annual with triennial harvest cycles. Statistical comparisons between biennial and triennial harvest cycles for biomass production were not possible because production by these trees was not measured during the same years. Survival and rabbit damage data were analyzed with all harvest cycles together. All analyses of variance were performed using the SAS computer software system.

Maximum average annual willow biomass production by willow clone SV1 with fertilization and irrigation was 24 odt ha^{-1} yr^{-1}, obtained using triennial harvesting and 0.3 by 0.9 m spacing, and total oven-dry biomass production over the three-year period was 71 odt ha^{-1} (Table 2-6). Cumulative biomass production at all harvest cycles was highest when trees were planted at 0.3 by 0.9 m spacing, but differences among spacings were not statistically significant. Clone SH3 was eliminated from the experiment because initial survival was unacceptably low due unsatisfactory winter cutting storage conditions. Clone SA22 was eliminated from the experiment due to severe rabbit damage during 1992, and growth stunting caused by annual infestations of potato leafhoppers (*Empoasca fabae* Harris).

Table 2-6. Oven-dry biomass production (standard errors in parentheses) by willow clone SV1 in the spacing/cutting cycle study at Tully, NY., planted and coppiced in 1990, and harvested annually, biennially, or triennially at three spacings.

Cutting Cycle	Spacing (m)	1991	1992	1993	1994 (odt ha^{-1})	1995	Sum 91-94	Sum 91-95	Mean odt ha^{-1} yr^{-}
Annual	0.3x0.3	19.3	11.2	10.1	11.4	14.3	52.0	66.3	13.3
		(2.2)	(0.2)	(0.4)	(0.8)	(0.3)			
	0.3x0.9	19.1	11.2	11.4	12.6	13.7	54.3	68.0	13.6
		(0.5)	(0.2)	(0.7)	(0.7)	(0.8)			
	0.6x1.1	15.0	10.1	10.1	8.7	15.0	43.9	58.9	11.8
		(1.1)	(0.5)	(2.0)	(2.8)	(6.2)			
	mean	17.8	10.8	10.5	10.9	14.6	50.0	64.6	
Biennial	0.3x0.3	-	28.0	-	31.4	-	59.4	-	14.9
			(3.4)		(1.9)				
	0.3x0.9	-	34.8	-	35.0	-	69.8	-	17.5
			(1.6)		(6.5)				
	0.6x1.1	-	30.3	-	33.4	-	63.7	-	15.9
			(1.4)		(5.9)				
	mean		31.0		33.3	-	64.3	-	
Triennial	0.3x0.3	-	-	54.9	-	-	-	-	18.3
				(8.3)					
	0.3x0.9	-	-	71.3	-	-	-	-	23.8
				(4.3)					
	0.6x1.1	-	-	67.3	-	-	-	-	22.4
				(5.8)					
	mean			64.5		-	-	-	

Triennial harvest cycle resulted in significantly (P=0.003) higher total biomass production than the sum of three annual harvests during the same growing period (64 versus 39 odt ha^{-1}, respectively, averaging spacings) (Table 2-6). Total biomass yield obtained from the first biennial harvest (1992) was similar (P=0.15) to cumulative yield from two annual harvests during 1991 and 1992 (31 versus 29 odt ha^{-1}, respectively, averaging spacings) (Table 2-

6). However, yield from the second biennial harvest (1994) was significantly (P=0.08) larger than yield from two annual harvests during 1993 and 1994 (33 versus 21 odt ha^{-1}, respectively, averaging spacings) (Table 2-6). Total biomass production after two biennial harvests was significantly (P=0.09) larger than total biomass production after four annual harvests (64 versus 50 odt ha^{-1}, respectively, averaging spacings) (Table 2-6). Averaging spacings, annual production from 1991 to 1994 by biennially and annually harvested trees (two and four harvests, respectively) was 16 and 13 odt ha^{-1} yr^{-1}, respectively, while average annual production from 1991 to 1993 by triennially harvested trees was 22 odt ha^{-1} yr^{-1}.

Partitioning biomass production of biennially and triennially harvested trees into yearly production components showed that the large production increase from biennial to triennial harvests was due to third-year productivity of triennially harvested trees far exceeding first- or second-year productivity in either of the two biennial harvests. Estimated production by triennially harvested trees planted at 0.3 by 0.9 m spacing during their first, second, and third growing seasons was 19.1, 15.7, and 36.5 odt ha^{-1}, respectively. Trees spaced at 0.3 by 0.3 and 0.6 by 1.1 m with triennial harvests showed a similar pattern of large increase in biomass production between the second and third years. Third-year production by triennially harvested trees (one year of growth) was larger than the sum of first- and second-year production by biennially harvested trees (two years of growth) for both biennial harvests. These estimates were derived from the following assumptions: 1) annual production during the first growing season for all cutting cycles was equal (19 odt ha^{-1}); and 2) production during the second growing season (1992) was equal for trees harvested biennially and triennially. There was no reason to reject these assumptions based on field observations.

Survival of clone SV1 averaged 92% across the three cutting cycles at the end of the first (1990) growing season, declining to 72% by the sixth (1995) growing season (Table 2-7). Survival was similar (P=0.72) among harvest cycles, averaging 68, 72, and 76% by trees harvested annually, biennially, and triennially, respectively, during the sixth growing season (1995). Statistically significant (P=0.0001) differences in survival were detected among spacings, averaging 87, 77, and 51% at 0.60 by 1.1, 0.3 by 0.9, and 0.3 by 0.3 m spacings, respectively, during 1995.

Statistically significant (P=0.03) harvest cycle-by-spacing interaction was observed for survival. Survival by biennially harvested trees spaced at 0.3 by 0.3 and 0.3 by 0.9 m decreased after the first harvest (1992) by 32%, but survival of trees spaced at 0.6 by 1.1 m did not decline appreciably after the first or second harvests (Table 2-7). Survival of triennially harvested trees spaced at 0.3 by 0.3 m was 26% less in 1993 than it was in 1992, but

Table 2-7. Survival (standard errors in parentheses) for willow clone SV1 in the spacing/cutting cycle study at Tully, NY, planted and coppiced in 1990, and harvested annually, biennially, or triennially at three spacings.

Cutting Cycle	Spacing (m)	1990	1991	1992	1993	1994	1995
			Survival %				
Annual	0.3x0.3	92.0	91.4	89.5	87.0	68.3	59.1
		(1.0)	(0.6)	(0.6)	(1.3)	(9.3)	(8.0)
	0.3x0.9	91.0	89.5	89.5	89.5	72.7	69.1
		(4.0)	(4.0)	(4.0)	(4.0)	(18.2)	(16.5)
	0.6x1.1	91.4	91.4	91.4	91.4	78.7	74.9
		(1.7)	(1.9)	(1.9)	(1.9)	(10.7)	(13.4)
Biennial	0.3x0.3	94.3	94.2	92.6	60.6	52.3	46.9
		(1.9)	(1.5)	(1.4)	(5.3)	(6.4)	(5.8)
	0.3x0.9	85.7	85.3	85.3	80.5	79.3	77.6
		(1.9)	(2.1)	(2.1)	(2.7)	(3.0)	(3.9)
	0.6x1.1	93.0	92.9	92.9	90.6	90.6	90.6
		(3.6)	(3.7)	(3.7)	(3.1)	(3.1)	(3.1)
Triennial	0.3x0.3	95.7	94.5	92.1	66.3	51.2	48.3
		(1.9)	(2.1)	(2.3)	(5.1)	(4.0)	(4.9)
	0.3x0.9	92.0	91.5	91.5	90.3	87.0	85.8
		(2.1)	(2.2)	(2.2)	(2.8)	(0.8)	(0.9)
	0.6x1.1	95.7	95.6	95.6	94.8	94.8	94.8
		(2.6)	(2.6)	(2.6)	(2.7)	(2.7)	(2.7)

only a minor decline, or no decline, was observed during the same period by triennially harvested trees grown at the other two spacings (Table 2-7). Averaging spacings, survival by trees harvested annually declined 22% from 1993 to 1995, while during the same period, survival by trees harvested biennially and triennially declined 6 and 8%, respectively.

Rabbit browse damage occurring during winter 1991-1992 was significantly (P=0.03) more severe in the biennial harvest cycle area than in the triennial harvest cycle area, with damage ratings averaging 2.65 and 2.20 in the biennial and triennial harvest areas, respectively. Statistically significant (P=0.0004) differences in rabbit browse damage among spacings were observed, with 0.3 by 0.3 m spacings being significantly more severely damaged (damage rating = 3.3) than both 0.3 by 0.9 and 0.6 by 1.1 m spacings (damage ratings = 2.1 and 1.9, respectively). The correlation (R^2) between rabbit damage rating (measured in 1992) and tree survival during 1992 and 1993 was 0.001 and 0.82, respectively. Damage was most severe in experimental plots that were closest to a large area containing unmowed vegetation.

In fall 1993, dead stools and stools with necrotic stems were observed in patches in two of the three replications of 0.3 by 0.3 m spacing in the annual harvest cycle area. Necrosis began at stem bases and progressed upward. Pink fruiting bodies of *Cryptodiaporthe salicella* (Fr.) Petr., a known willow pathogen, were observed growing on stumps of some of the recently killed trees, but pathogenicity could not be proven. Approximately one-third of the trees in affected plots were damaged.

The highest annual biomass production by willow clone SV1 observed in the current experiment, 24 odt ha^{-1} yr^{-1}. This level of production was achieved starting from one-year-old coppiced trees with three-year harvest cycle, 0.3 by 0.9 m spacing, irrigation, fertilization with N, P, and K, and effective competition control. The 1991 growing season had above-average temperatures, but the 1992 growing season had the fewest growing-degree days on record for the region. Agricultural production in the region was approximately 30% below normal in 1992. Presumably, growth of willow clone SV1 also was approximately 30% below its normal production potential in 1992.

Triennial and biennial harvesting resulted in significantly higher annual biomass production than annual harvesting, but direct statistical comparisons of biennial and triennial harvest cycles were not possible because trees in the two cycles were not harvested during the same year. After one triennial, and two biennial harvests, triennial harvesting provided higher annual biomass production than biennial harvesting. These results support experience in Sweden, where optimum rotation length for commercial willow biomass production was shown to be three to five years.

The three spacings tested resulted in similar biomass yields at all harvest cycles tested. Competition among trees planted at 0.3 by 0.3, and 0.3 by 0.9 m spacings was severe even during the first growing season; there were approximately seven- and two-times more trees at these two spacings, respectively, than at the 0.6 by 1.1 m spacing, but first-year production at the two denser spacings with annual harvests exceeded the widest spacing by only 26%. Trees spaced at 0.3 by 0.3 m had fewer stems, and their diameters were smaller than trees planted at either of the wider spacings. Rabbit damage increased as planting density increased, probably due to rabbit's preference for smaller diameter stems. Increased mortality with the densest spacing was highly correlated with rabbit damage. Therefore, unless the small diameter product of dense spacing is specifically desired, spacings of 0.6 by 1.1 m appear better suited to willow biomass production than 0.3 by 0.3 or 0.3 by 0.9 m spacing because the same amount of biomass can be produced with a fewer number of cuttings. Swedish research has shown that optimum planting density for commercial willow biomass plantings is between 10,000 and 20,000 trees ha^{-1}.

This study will be completed at the end of the 1996 growing season when all three harvest cycles will be harvested concurrently for the first time. A manuscript describing 6-year results of this study will be submitted to a peer reviewed journal.

IRRIGATION TRIAL

An irrigation experiment was established at Tully, NY in 1990 to determine the effect of minimizing water stress on biomass production by willow clones SV1, SA22, and SH3. The hypotheses were that irrigation increases biomass production, and clones differ in biomass production.

Site preparation, plant material, planting, and fertilization were as described for the spacing/cutting cycle study. Half the trees were irrigated with a drip system from 1990 to 1995, the other half were not irrigated. Soil moisture in the irrigated portion of the study was maintained close to field capacity based on gypsum block sensor readings at a depth of 0.3 m from May until early September each year, and soil moisture was monitored in the non-irrigated area concurrently. Tree spacing was 0.3 by 0.9 m. Trees were coppiced at the end of the first growing season and biomass production was measured during winter 1993-1994 (triennial harvest cycle). The experimental design was a completely randomized split-plot, with three replicates of irrigated and non-irrigated whole-plots, and three replicates of each clone sub-plot randomized within whole-plots. Experimental plots were 6.0 x 6.0 m with two border rows. Rabbit browse damage occurred during January-March 1992. Browse damage was surveyed using the system described for the spacing/cutting cycle study. Tree survival was measured annually during May using a 100% census.

Biomass production by willow clone SV1 harvested in 1993 (after three growing seasons) with irrigation averaged 27.8 odt ha^{-1} yr^{-1}, the highest wood biomass yield ever reported in the northeastern United States. Irrigated trees were significantly ($P<0.01$) more productive than non-irrigated trees (51.1 versus 17.3 odt ha^{-1}, averaging clones).

Willow clone SV1 was significantly ($P<0.01$) more productive than willow clone SA22 (18.1 versus 4.5 odt ha^{-1} yr^{-1}, averaging irrigated and non-irrigated trees). Significant ($P<0.01$) clone-by-irrigation interactions were observed. Irrigation increased biomass production by willow clone SV1 by 309% compared to 256% for willow clone SA22.

Survival after the first growing season by willow clones SV1 and SA22 with irrigation averaged 99 and 92%, respectively, while with no irrigation, survival by clones SV1 and SA22 averaged 97 and 81%, respectively. Little change in survival was observed from 1991 to 1993. Trees were coppiced during winter 1993-1994, and resprouted and grew vigorously during 1994 and 1995. Survival during 1994 by willow clones SV1 and SA22 with irrigation was 94 and 61%, respectively, while with no irrigation, survival during 1994 by willow clones SV1 and SA22 was 83 and 57%, respectively. Survival during 1995 was nearly the same as in 1994. The decline in survival of approximately 10% after triennial harvest is similar to the pattern of change in survival observed in the spacing/cutting cycle study harvested on a three-year cycle.

Rabbit browse damage was significantly ($P=0.03$) more severe on willow clone SV1 than clone SA22, with damage ratings averaging 3.1 and 2.2, respectively. Irrigation treatment did not significantly affect browse damage. Significant ($P=0.02$) irrigation treatment-by-clone interaction was observed because non-irrigated trees of clone SV1 were damaged more severely than irrigated trees, while non-irrigated trees of clone SA22 were damaged less severely than irrigated trees. Speculatively, rabbits appear to prefer small diameter stems, and prefer clone SV1 to SA22 if stems are similar in size. Rabbits may have damaged clone SV1 more than SA22 in the non-irrigated area because stem sizes were similar, but in the irrigated area, stems of clone SV1 were too large for rabbits, while SA22 stems were an acceptable size. Evidence from other studies at Tully suggests that rabbits prefer clone SV1 over most other clones.

Survival and biomass production data from this study must be interpreted cautiously due to differential rabbit browse damage between clones, site differences between the irrigated and non-irrigated areas, exceptional weather conditions during the 1991 and 1992 growing seasons, and the possibility that some trees in the non-irrigated area extended their roots into the irrigated area. Soil in the non-irrigated area was shallower than in the irrigated area. The 1991 growing season was abnormally hot and dry, while the 1992 growing season was abnormally cool and wet. The effects of these abnormal weather conditions on tree growth and survival could not be determined. Some trees in the non-irrigated area immediately adjacent to the irrigated area probably were able to extend roots into the irrigated area, but the extent to which this occurred could not be determined. Clearly, irrigation has a large effect on biomass production, but the increase in production due to irrigation may not be as large as suggested by this experiment. The study will be completed in fall 1996 with the second triennial harvest.

WILLOW CLONE-SITE TRIALS

Experiments were established on five sites across New York from 1993 to 1995 to obtain clone-site information on willow clones that grew well in genetic selection trials at Tully, NY, and three sites in Ontario, Canada. The hypothesis was that large variation in growth potential and site adaptability exists among willow clones. In 1993, unrooted dormant willow cuttings from 14 and 19 willow clones were planted at Massena and Tully, respectively, using a double row spacing design developed in Sweden for commercial bioenergy plantations. Tree spacing was 0.6 m within rows, 0.7 m between rows, and 1.5 m between double rows. No-till weed control was used at Massena, while mechanical and chemical site preparation was completed at Tully. All trees were coppiced during December 1993. Trees were fertilized with N, P, and K at elemental rates of 112, 34, and 78 kg ha^{-1} during 1994. Three-year harvest cycle will be used, with the first measurement harvest scheduled for 1996.

During 1995, willow clone-site trials were planted at Somerset, King Ferry, and Himrod, NY, and a demonstration area approximately 2 ha in size was planted at Tully, NY. The Somerset, King Ferry, and Tully demonstration plantings used the Swedish design and will be harvested on a three-year cycle. Weed competition was a severe problem on the King Ferry and Himrod sites, and combined with the exceptionally dry growing season, first-year growth on these sites was poor. First-year growth in the Somerset trial and Tully demonstration area was as good as could be expected given the weather conditions. These plantings are scheduled for harvest during fall 1998.

Survival was measured during 1994 in the Massena and Tully clone-site trials, and during 1995 in all the clone-site trials and the Tully demonstration area (Table 2-8). First-year survival was generally good, though some clones had poor survival. First-year survival varied across sites and may be attributable to differing site preparation, timing of planting, and clones planted. Insect, disease, and mammal browse surveys were completed during summer 1994, at Massena, and Tully (Table 2-9). Deer severely browsed some clones at Massena, and was related to planting location. No serious insect or disease problems were observed, though *Melampsora* rust was observed on foliage of several clones that previously were free of rust. Rust did not cause defoliation, but presence of *Melampsora* on willow clones never previously attacked by rust suggests that these plantings should be monitored closely for rust in the future. In the Tully clone-site trial during 1995, rust was observed on only one clone (SP3), but foliage spots believed to be caused by *Marssonina* spp. were observed on four clones (S566, S599, S652, and SA2). Trees that were severely infected with the foliage spot were prematurely defoliated. Rabbit browse severely damaged willow clone SH3 in the Tully clone-site trial during winter 1994-1995, and again during

Table 2-8. Survival of willow and poplar clones planted during 1995, plus clone-site trials planted during 1993.

Clone	Tully Clone-Site		Massena Clone-		Tully	Somer-	King	Himrod
	1994	1995	1994	1995	1995	1995	1995	1995
	Survival (%)							
DN74	np[1]	np	np	np	np	np	np	98.5
NM6	np	np	np	np	98.4	97.4	94.0	98.0
S185	90.0	90.0	np	np	np	np	81.7	np
S19	88.9	88.9	89.6	87.5	np	np	75.0	np
S25	96.7	94.4	98.0	89.6	80.9	99.1	82.5	91.3
S287	97.8	97.8	np	np	np	np	74.0	99.5
S301	96.7	96.7	94.0	75.0	86.0	96.9	75.5	97.4
S34	76.7	74.4	np	np	np	np	np	np
S365	97.8	97.8	94.0	83.3	99.7	np	95.2	98.0
S546	77.8	77.8	83.6	66.7	79.1	98.5	76.7	97.4
S557	55.6	56.7	81.6	58.3	np	np	np	np
S566	58.9	58.9	85.6	68.8	np	np	67.8	94.4
S599	70.0	70.0	85.3	75.0	np	np	np	np
S625	71.1	71.1	91.6	85.4	np	np	68.3	np
S646	64.4	64.4	77.3	70.8	np	np	81.3	95.4
S652	90.0	87.8	np	np	np	np	np	np
S71	34.4	34.4	92.0	79.2	np	np	np	np
SA2	98.9	97.8	93.6	81.3	99.8	98.3	77.2	100.0
SH3	91.1	91.1	81.3	75.0	67.0	98.7	57.0	93.4
SP3	98.9	98.9	np	np	np	np	np	np
SV1	93.3	93.3	92.0	56.3	97.0	98.5	92.2	99.0
avg.	81.5	81.2	83.2	75.1	88.5	98.2	78.5	96.9

[1] np indicates the clone was not planted.

Table 2-9. Insect, mammal browse, and pathogen damage observed in willow clone-site trials at Massena (M) and Tully (T), NY during 1994.

Clone	Foliage Feeding Insects	Gall Mites	Deer Browse	Rabbit Browse	*Melampsora* Rust	Other Foliage Spots
S185[1]						
S19		T	M		T	
S25	T		M			M,T
S287[1]					T	T
S301					T	M
S34[1]					T	
S365	M	M		T		
S546			M			
S557	T		M		T	
S566			M			M,T
S599			M			M,T
S625		T	M			
S646			M			T
S652[1]		T				T
S71			M		T	T
SA2			M			M,T
SH3				T		
SP3[1]						
SV1	T			T		

[1]Clones followed by [1] were not planted at Massena.

early winter 1995. Willow clones SV1 and S365 were also damaged by rabbits to a lesser extent, but no other clones were damaged. Rabbit damage was also observed during summer 1995 in the Himrod planting. Damage level was related to clone and planting location, with trees nearest to rabbit cover being most severely damaged. Clonal variation in insect, mammal and disease damage was observed at each site and was striking in some instances. Clonal variation in biomass production will be quantified when trees are harvested.

PREEMERGENT HERBICIDE TRIAL

Experiments were initiated in 1988 to identify preemergent herbicides with potential for use in willow bioenergy plantings. Simazine has been the herbicide of choice for this use in poplar and willow plantings, but the manufacturer no longer includes forestry uses on its label, so alternative herbicides must be identified. Additionally, triazine-resistant weeds are increasingly common, limiting effectiveness of triazine herbicides. Second-year weed control may be required since, with the Swedish willow production system, trees are coppiced after the first growing season, leaving the site with no tree canopy to suppress weed growth early in the second growing season. Identifying effective preemergent herbicides that could be safely applied over dormant coppiced willows to replace the use of contact herbicides applied with shielded sprayers during the growing season would be desireable.

Variation may exist among willow clones in tolerance to various herbicides as has been observed in poplars, especially since the genus exhibits large variation with respect to many other traits. Variation in herbicide tolerance could influence clonal selection criteria, as excessively sensitive clones would have to be avoided.

Two experiments were established with the following objectives: 1) identify commercially available preemergent herbicides that exhibit no phytotoxic effects on intensively cultured willow plantings when applied before planting, and over coppiced willows at the start of the growing season (Experiment 1), and; 2) the same as Experiment 1 plus, to determine if herbicides affect willows similarly on three different sites (Experiment 2).

Experiment 1 was established at the SUNY Genetics Field Station, Tully, NY. Site preparation was initiated during late July 1988. Weeds on the site were mowed, allowed to resume vigorous growth for approximately three weeks, and then treated with glyphosate at the 2.24 kg ai ha^{-1} rate. The site was plowed, cross disked, and raked during late October 1988. Linuron, oxyfluorfen, pendimethalin, pronamide, simazine, and sulfometuron methyl were applied in mid-November 1988, the fall before planting, with a calibrated manual sprayer (Table 2-10). These herbicides were selected because of previous research, or labeling, indicating they may cause no phytotoxic effects on willows. Untreated plots were included as a control treatment. Willow planting material, provided by the Ontario Ministry of Natural Resources, consisted of dormant unrooted cuttings approximately 20 cm in length and 8 to 12 mm in diameter from 16 willow clones representing seven Salix species with potential for high biomass production (Table 2-11). Cuttings were hand planted flush with the ground during late April 1989. All plots were visually weed-free at the time of planting. All trees were coppiced in late November 1989. Visible

Table 2-10. Preemergent herbicides and rates applied to bare soil in Experiments 1 and 2 during fall 1988, and over coppiced willows in Experiment 1 during spring 1990.

			Application Rate ($kg\ ai\ ha^{-1}$)	
Herbicide	Trade Name	Manufacturer	Fall 1988	Spring 1990
Linuron	Lorox DF	E.I. DuPont de Nemours, & Co. Inc.	3.6	1.8
Oxyfluorfen	Goal 1.6e	Rohm & Haas Co.	2.4	1.2
Pendimethalin	Prowl	American Cyanamid	4.8	2.4
Pronamide	Kerb 50-W	Rohm & Haas Co.	3.6	1.8
Simazine	Princep 4L	Ciba Geigy Co.	4.8	2.4
Sulfometuron methyl	Oust	E.I. DuPont de Nemours, & Co. Inc.	0.2	0.1

weeds were mechanically removed in October 1989 so that herbicides could be reapplied to bare soil the following spring. The same herbicides were reapplied over the coppiced trees in late April 1990 (Table 2-10). The second herbicide application was in spring 1990, rather than fall 1989, so that herbicides did not contact freshly cut stumps.

The experimental design was a split-plot with herbicide treatments as the whole plot and willow clones as the subplot. The control and six herbicide treatments were randomly located in three replications. Each of the willow clones was represented by six trees in rectangular plots randomly placed in each weed control treatment plot. Tree spacing was 0.3 by 0.3 m, with two border rows surrounding each treatment plot, for a total plot size of 5.7 by 2.7 m. Tree survival, height, and visible phytotoxicity symptoms were used to assess whether or not herbicides were phytotoxic to trees. Tests of significance were at the 0.05 level.

Weed cover was measured and weed species identified in early and late June 1989, and late May and early July 1990; two surveys were completed to determine if herbicide effectiveness decreased in early summer when many weed seeds germinate. Weed cover data were analyzed using a randomized complete block design since clone did not enter into the model. All plots were sprayed with Fusilade 2000 (fluazifop-butyl [butyl 2-[4-[(5-trifluoromethyl)-2-pyridyloxy]phenoxy]propanoic acid]) after the first weed survey in 1989 at the rate of 0.3 kg ai ha^{-1} to control quackgrass (Elytrigia repens Nevski) arising from rhizomes that were not killed by initial site preparation.

Table 2-11. *Salix* species and clones planted in Experiments 1 and 2 at the SUNY ESF Genetics Field Station, Tully, NY, and the S. O. Heiberg Memorial Forest, Tully, NY during April 1989.

----------Experiment 1 ----------		-------------Experiment 2 -------------	
Species	Clone ID	Female species x Male species	Clone ID
S. bebbiana	BEBB30	*S. bebbiana* (clone)	BEBB37
S. discolor	DIS26	*S. bebbiana* x *eriocephala*	1-39-2
S. eriocephala	ERIO23	*S. discolor* (clone)	DIS14
	ERIO28	*S. eriocephala* x *eriocephala*	6-29-2
	ERIO39	*S. eriocephala* x *eriocephala*	3-7-4
	ERIO57	*S. eriocephala* x *eriocephala*	6-27-2
S. lucida	LUC32	*S. eriocephala* x *eriocephala*	6-7-1
	LUC43	*S. eriocephala* x *eriocephala*	S553
	SL12	*S. eriocephala* x *eriocephala*	S537
	SL13	*S. eriocephala* x *eriocephala*	3-26-1
	SL36	*S. eriocephala* x *eriocephala*	S558
	SL39	*S. eriocephala* x *petiolaris*	S79
S. pellita	SPEL2	*S. interior* x *discolor*	B-E-4
S. petiolaris	PET53	*S. interior* x *eriocephala*	4-3-1
	SPET19	*S. lucida* x *lucida*	S41
S. purpurea	SP3	*S. lucida* x *lucida*	S160
		S. lucida x *lucida*	5-16-3
		S. petiolaris x *eriocephala*	3-35-4
		S. petiolaris x *interior*	B-6-6

Experiment 2 was established at three sites at the same time as Experiment 1 during 1988. Site 1 was adjacent to Experiment 1 in Tully, NY on the same Palmyra soil. Sites 2 and 3 were abandoned agricultural sites at the Sven O. Heiberg Memorial Forest near Tully, NY. Weed control treatments were identical to those of Experiment 1. Fluazifop-butyl was applied to site 1 between the first and second weed surveys in 1989 at the rate of 0.3 kg ai ha^{-1} to control quackgrass; sites 2 and 3 had no quackgrass and were not treated. Plant material for Experiment 2 consisted of 22 genetically improved willow clones provided by the University of Toronto. Some were developed by intra- and interspecific matings (Table 2-11). Poor survival on two sites due to frost heave during the 1989-90 winter forced termination of the experiment. Therefore, only one year of data from Experiment 2 could be utilized. The experimental design was a completely randomized split-plot. Sites were treated as replications, weed control treatments were the whole plot, and willow clones were the subplot. Each treatment was randomly located at each of the three sites, and each clone was represented by a randomly located, rectangular six-tree plot in each weed control treatment plot. Tree spacing was 0.3 by 0.3 m with one border row surrounding each treatment plot, for a total plot size of 7.5 by 2.7 m. Data collection and analyses during 1989 were identical to that in Experiment 1.

Survival.

Statistically significant differences in Salix survival were detected among herbicide treatments in Experiment 1 during 1989, with simazine and sulfometuron methyl significantly reducing survival (82 and 81%, respectively) compared with all other treatments (88 to 93%) (Table 2-12). In 1990 in Experiment 1, significant differences in survival were detected among treatments, with sulfometuron methyl the only herbicide that significantly reduced survival compared with the no herbicide control (63 and 85%, respectively) (Table 2-12). Survival after two years averaged 86%, excluding sulfometuron methyl. Survival decreased 6% or less from 1989 to 1990 in all treatments except sulfometuron methyl, where survival decreased 18%. In Experiment 2 during 1989, survival was high, averaging 97%, and did not differ among treatments (Table 2-12). No significant clone-by-treatment interactions for survival were detected in either experiment. Survival was considered acceptable in all treatments except sulfometuron methyl in Experiment 1. Though first year survival in plots treated with sulfometuron methyl was acceptable, higher than average second-year mortality in plots treated with sulfometuron methyl in Experiment 1 indicates a phytotoxic effect on willow from that herbicide. Differences in survival between the two experiments may be attributable to differences in clones, cutting collection and storage procedures, and planting conditions. Sulfometuron methyl has potential for leaching, and may have moved into the willow's rooting zone, injuring or killing them, or it may have been absorbed by aboveground portions of trees. Simazine applied at 2.2 kg ai ha^{-1} has been reported to reduce first-year survival of some Populus spp., so the minor reduction in first-year survival by willows in plots treated with simazine was not completely unexpected. By the second year, survival in simazine plots was no different than the control. Simazine has been shown to be safe for use in both willow and poplar plantings on many sites provided the application rate was appropriate for soil and site conditions.

Table 2-12. Survival and height growth during 1989 and 1990 by Salix in plots treated with preemergent herbicides or an untreated control in Experiment 1, and during 1989 in Experiment 2[1].

	Experiment 1				Experiment 2	
	1989		1990		1989	
Treatment	Survival (%)	Tree Height (cm)	Survival (%)	Tree Height (cm)	Survival (%)[2]	Tree Height (cm)
Control	91 a	44 c	85 bc	94 b	97.0	33 c
Linuron	91 a	53 b	87 ab	114 a	97.0	38 b
Oxyfluorfen	88 a	54 b	87 ab	120 a	96.0	42 a
Pendimethalin	92 a	65 a	88 ab	116 a	98.0	38 b
Pronamide	93 a	66 a	91 a	115 a	97.0	39 b
Simazine	82 b	48 bc	79 c	117 a	95.0	38 b
Sulfometuron methyl	81 b	16 d	63 d	57 c	98.0	25 d

[1] Means within a column followed by the same letter were not significantly (alpha = 0.05) different (Duncan's mean separation procedure). Letters following survival percentages were obtained from mean separation tests peformed on arcsin-transformed data.

[2] Statistically significant differences among herbicide treatments were not detected so a mean separation test was not performed.

Height Growth.

There was no evidence that any of the herbicides other than sulfometuron methyl were phytotoxic to willows based on tree height growth. In Experiment 1, statistically significant differences in tree height were observed among weed control treatments during 1989 and 1990, ranging from 16 (sulfometuron methyl) to 66 cm (pronamide) in 1989, and 57 (sulfometuron methyl) to 120 cm (oxyfluorfen) in 1990 (Table 2-12). Sulfometuron methyl significantly reduced height growth compared with the control (64% and 40% in 1989 and 1990, respectively). Except simazine in 1989, other herbicides significantly increased height growth compared with the control, with an average increase of 30% and 23% in 1989 and 1990, respectively. The range in tree height among herbicide treatments, excluding sulfometuron methyl, was small (48 to 66 cm in 1989 and 114 to 120 cm in 1990).

In Experiment 2, as in Experiment 1, only sulfometuron methyl caused phytotoxic effects. Though the experimental design did not enable statistical analyses of site-by-treatment interaction, sulfometuron methyl consistently had the shortest trees followed by the no herbicide control (Table 2-12). Ranks of the other treatments differed among sites but, the cause of these differences could not be determined. Trees were taller on site 1 (44 cm) than on sites 2 and 3 (35 and 30 cm, respectively). These differences are most likely due to suitability of these sites for willow growth rather than herbicide performance.

Foliage of trees in plots treated with sulfometuron methyl was chlorotic and stunted in both experiments in 1989, a symptom typically caused by sulfonylurea herbicides. Visual symptoms of phytotoxicity were not observed in other herbicide treatment plots.

Second year application of linuron, oxyfluorfen, pendimethalin, pronamide, and simazine over coppiced willows prior to budbreak in spring 1990 significantly increased tree height compared with the control and caused no noticeable phytotoxic symptoms, suggesting that these herbicides can be applied as soon as sites become accessible in spring after dormant season coppicing. Sulfometuron methyl reduced tree height and caused foliar chlorosis when applied to coppiced Salix in spring 1990. Poor second year height growth in plots treated with sulfometuron methyl could be related to poor growth during the first year, but chlorotic foliage during 1990 suggests that growth reduction was due, at least in part, to the phytotoxic effects of the herbicide applied in spring 1990. Additional studies are necessary to determine how late into the growing season linuron, oxyfluorfen, pendimethalin, pronamide, and simazine can be safely applied over sprouted, coppiced willow.

Treatment-by-clone interactions for tree height were observed in both experiments and were attributed to generally minor changes in herbicide ranks among clones. Most clones performed better in plots treated with herbicide than the no herbicide control with the exception of sulfometuron methyl, which reduced growth of all but two clones compared with any other treatment. One clone (3-35-4) appeared to be exceptionally sensitive to all the herbicides, as it performed poorer in all of the herbicide plots than the no herbicide control. Growth reduction of certain clones in specific herbicide treatments could be due to variation in herbicide tolerance or susceptibility to weed competition. Clonal variability in response to weed control treatments has been reported for willows. Testing willow clones with the herbicide and application rate in question before large scale planting is advisable, and herbicide treatments in genetic selection trials should be documented for possible phytotoxic effects.

Weed cover.

In Experiment 1, all plots had little weed cover in early and late June 1989, the first growing season (Table 2-13). Weed species composition differed among treatments. In early June 1989, most plots had up to 5% cover due to quackgrass, but because it became established from rhizomes that were not killed by initial site preparation, all plots except sulfometuron methyl were treated with fluazifop-butyl herbicide at the rate of 0.3 kg ai ha^{-1} sprayed over the tops of growing willows. No quackgrass was present in plots treated with sulfometuron methyl.

Statistically significant differences in weed cover were present among herbicide treatments in the first and second surveys (late-May and early-July) of 1990 in Experiment 1, ranging from 2% (oxyfluorfen) to 37% (linuron) in late-May, and 4% (oxyfluorfen) to 47% (control) in early-July, respectively (Table 2-13). In early-July, plots treated with oxyfluorfen, simazine, and sulfometuron methyl had less than 15% weed cover. Weed species composition differed among treatments, and was similar to that in 1989.

In Experiment 2, weed cover was low during the first (early June) weed survey in 1989 (Table 2-13). All the herbicide treatment plots except pronamide had significantly less weed cover than the no-herbicide treatment, with a range of 0% (simazine and sulfometuron methyl) to 22% (control) (Table 2-13). Weed cover was similar among sites, averaging 8%. In the second weed survey in Experiment 2 during 1989, plots treated with oxyfluorfen, pendimethalin, simazine, and sulfometuron methyl had significantly less weed cover than plots treated with pronamide and the no herbicide control, ranging from 1% (oxyfluorfen, simazine, and sulfometuron methyl) to 71% (pronamide) (Table 2-13). The level of weed cover was similar across sites, averaging 30%.
Weed cover was not clearly related to tree growth in either experiment. The coefficients of correlation (r) between tree height and late June or early July weed cover, excluding plots treated with sulfometuron methyl because of known phytotoxic effects on trees, were -0.13 ($p=0.61$, $n=18$), -0.41 ($p=0.09$, $n=18$), and -0.38 ($p=0.12$, $n=18$) in Experiment 1 in 1989 and 1990, and Experiment 2 in 1989, respectively. This suggests that the weeds in this study had little impact on tree growth. Weed species present, climatic conditions, and slow weed establishment due to effective site preparation apparently resulted in limited weed competition in all herbicide treatments and the control.

All the herbicides tested except sulfometuron methyl appear to have potential for application in willow plantings either before planting or over coppiced willows before sprouting. Reduced tree height growth and chlorotic foliage in 1989 and 1990 in plots treated with sulfometuron methyl, and reduced tree survival in 1990 in Experiment 1, indicates that sulfometuron methyl was phytotoxic to willows in this study. Oxyfluorfen appears to be particularly well suited to replace simazine on the sites and willow species tested based on tree survival and growth, and weed

Table 2-13. Weed cover and control in Experiment 1 during 1989 and 1990, and Experiment 2 during 1989, in plots treated with preemergent herbicides or an untreated control[1].

	Experiment 1				Experiment 2	
	1989		1990		1989	
	Early June	Late June	Late May	Early July	Early June	Late June
Treatment	Percent Cover					
Control	5 bc	16 d	35 b	47 c	22 c	66 c
Linuron	6 c	13 cd	37 b	38 c	6 a	45 bc
Oxyfluorfen	3 abc	3 ab	2 a	4 a	1 a	1 a
Pendimethalin	5 bc	10 cd	25 b	39 c	7 ab	30 ab
Pronamide	2 ab	9 bc	23 b	29 bc	19 bc	71 c
Simazine	1 a	1 a	8 a	11 ab	0 a	1 a
Sulfometuron methyl	0 a	1 a	4 a	13 ab	0 a	1 a

[1] Means within a column followed the same letter were not significantly (alpha=0.05) different (Duncan's mean separation procedure).

control. The genetically diverse willow clones tested responded similarly to herbicides, with a small number of exceptions. Additional testing of these herbicides on a range of soil types and at different rates is necessary before generalized herbicide recommendations for willow plantings can be made with confidence. Sulfometuron methyl should not be excluded from future tests because it may not damage willows at lower rates or on different soil types, and it is an effective herbicide, especially against perennial grasses. Results from preliminary tests with lower rates of sulfometuron methyl applied at the start of the second growing season to coppiced willows showed promise as no phytotoxic response by willows was observed

GENETIC IMPROVEMENT

The University of Toronto has been involved with the project Bioenergy from Willows from its inception, developing and screening improved willow clones for deployment in bioenergy plantations. Almost all of the willow clones currently being studied in New York were collected from native trees in Ontario, or created by hybridizing willows native to Ontario, and preliminary screening was completed in Canada. A general rule in forest tree improvement is that trees can safely be planted 150 km north of their origin because they "overadapt" to their environment. Typically, planting trees originating from environments slightly more mild than the planting site is desireable because these trees begin growth earlier in the year, and cease growth later in the year, than trees originating at the planting site, or northward. Therefore, a project was initiated in 1995 to collect cuttings from willows native to southern New York and Pennsylvania, and test them against clones currently being propagated for bioenergy plantings in New York.

State-owned lands were searched during June and July 1995 for willows exhibiting superior growth, form, competitive ability, and insect resistance relative to other willows growing nearby. Willow species currently in University of Toronto's breeding program were favored so that superior clones could easily be incorporated into their program. The area searched included all of New York State south of Syracuse plus locations close to Lake Ontario where climate is moderated, all of Pennsylvania, and northern New Jersey. Desired specimens were located, growth characteristics recorded, greenwood cuttings were collected, trees were coppiced, identification numbers were assigned, and the area was clearly marked so that trees could be re-located. Cuttings collected were rooted in water, planted in pots in a greenhouse, and planted in a cutting orchard during fall 1995 in a site prepared at Tully, NY. All trees were visited again during November and December 1995, and hardwood cuttings were collected from stumps that resprouted.

Willows were collected from 28 sites across New York and Pennsylvania (Figure 2-4). The total number of clones collected was approximately 100. The majority of clones were *S. eriocephala*, and other species represented in the collection include *S. alba, S. bebbiana, S. discolor, S. interior,* and *S. purpurea* (Table 2-14). Willows were most commonly found along fast-flowing creeks that frequently flood, leaving little competition for willows. Occasionally trees were found on dry sites or growing with heavy weed competition, and such trees were always included in the collection because they have demonstrated ability to effectively compete against weeds. Greenhouse survival of greenwood cuttings was generally poor; approximately 200 of the approximately 2,000 cuttings collected survived to be planted in the field. Many plants rooted but were destroyed by rodents. Coppice regrowth by trees selected in the field was variable. Some clones were lost due to flooding, and some failed to sprout. Ten to twenty hardwood cuttings six inches in length were obtained from most clones. These will be rooted in a greenhouse during winter and spring 1996, and planted at Tully in a cutting orchard.

Figure 2-4 Sites visited in search of native willows during June and July 1995; numbers indicate areas where willows were collected, x indicates areas that were searched but no selections were made.

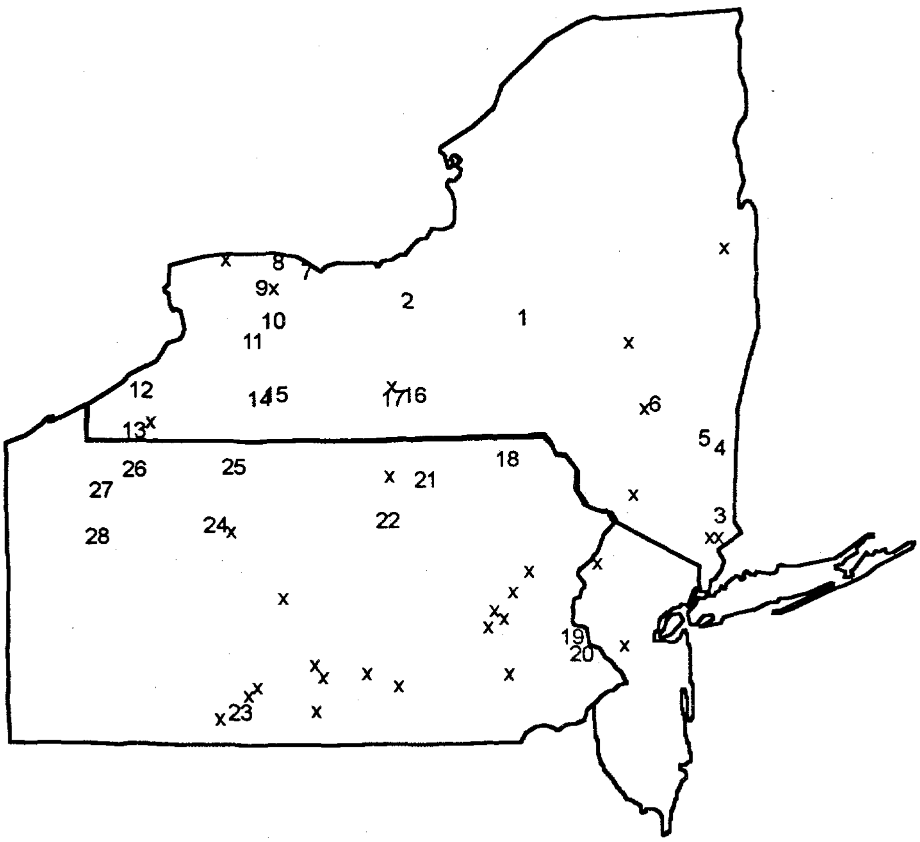


Table 2-14. Notes from native willow collections completed during summer, 1995. Trees were selected based on vigor as assessed by length of current year's shoots, form, and lack of insect or disease damage, compared with nearby trees. Selections were made by Richard Kopp and Christopher Fox.

Site #	Site Location (State)	Species Collected (# Clones)	Notes
1	Tioghnioga Wildlife Management Area (NY)	*S. purpurea* (2), *S alba* (2), *S. bebbiana* (2)	The two *S. purpurea* have excellent form on dry sites, others on damp meadow sites
2	Howland Island Wildlife Management Area (NY)	*S. bebbiana* (3)	All trees growing well despite severe weed competition - next to pond
3	West Branch Reservoir (NY)	*S. eriocephala* (2)	Trees growing in rip-rap close to lake
4	Lafayetteville Multiple Use Area (NY)	*S. eriocephala* (4)	Wet meadow with heavy weed competition yet good tree growth
5	Wasaic Multiple Use Area (NY)	*S. eriocephala* (2), *S. purpurea* (1)	Dry fill, odd site to find willows
6	Schoharie Creek Public Fishing Access (NY)	*S. eriocephala* (4)	Trees growing close to fast-flowing water
7	Duran Beach/Eastman State Park (NY)	*S. eriocephala* (2)	Trees growing in pure sand close to lake
8	Hamlin Beach State Park (NY)	*S. interior* (1)	Tree growing in rip rap close to lake
9	Oak Orchard Wildlife Management Area (NY)	*S. eriocephala* (3), *S. interior* (1)	Damp meadow, trees had been recently coppiced
10	Carlton Hill Multiple Use Area (NY)	*S. eriocephala* (3), *S. interior* (2), *S. purpurea* (2)	Trees were mostly older, as if flooding had not occurred recently to remove older trees, slow flowing water
11	Tonawanda Creek (NY)	*S. eriocephala* (2), *S. interior* (2)	Severe pine cone gall midge on surrounding trees, fewer on collected clones, growing in gravel next to fast-flowing creek
12	Canadaway Creek Wildlife Management Area (NY)	*S. eriocephala* (3), *S. purpurea* (1)	Severe pine cone gall midge on surrounding eriocephala, fewer on collected clones, growing in gravel next to fast-flowing creek
13	Broken Straw Creek (NY)	*S. eriocephala* (2)	Trees growing with severe weed competition next to slow-flowing creek

Site #	Site Location (State)	Species Collected (# Clones)	Notes
14	Hanging Bog Wildlife Management Area (NY)	*S. eriocephala* (2), *S. purpurea* (2)	Trees were growing with severe weed competition, damp meadow
15	Genesee River - Belfast (NY)	*S. eriocephala* (4)	A very impressive stand - tall, straight trees with no insects or disease, growing in gravel next to fast-flowing creek
16	Connecticut Hill Wildlife Management Area (NY)	*S. eriocephala* (5), *S. discolor* (1)	Most trees growing with severe weed competition, various habitats
17	Catherines Creek Public Fishing Access (NY)	*S. purpurea* (2)	Both trees growing in a stand of exceptionally tall, straight trees, next to fast-flowing creek
18	State Gameland #35 (PA)	*S. eriocephala* (3)	Large trees that appear to have been coppiced many years ago, growing next to fast-flowing creek
19	Delaware River - Narrowsville (PA)	*S. eriocephala* (4)	Trees growing on first floodplain that floods annually - growing in gravel with little weed competition
20	Point Pleasant (PA)	*S. eriocephala* (1)	Tree appeared quite vigorous - damaged frequently by floods - growing in gravel next to fast-flowing creek with no weed competition
21	State Gameland #289 (PA)	*S. eriocephala* (3)	Average growth rate but no insects or disease, growing next to fast-flowing creek with weed competition
22	Lycoming Creek (PA)	*S. eriocephala* (5)	Trees growing vigorously, damaged frequently by floods, growing in gravel next to fast-flowing creek
23	Juniata River, Bedford (PA)	*S. eriocephala* (3), *S. interior* (1)	Unimpressive growth, collected because of southern location, growing next to fast-flowing creek with severe weed competition
24	Bennet Branch of Sinnemahoniga Creek (PA)	*S. eriocephala* (2)	Trees free of insects and disease, growing in damp meadow with severe weed competition

Site #	Site Location (State)	Species Collected (# Clones)	Notes
25	Rt. 46 near Bradford (PA)	*S. eriocephala* (4), *S. bebbiana* (2)	Good form, some disease in stand, growing in damp meadow
26	Broken Straw Creek (PA)	*S. eriocephala* (3)	Vigorous trees growing in gravel next to fast-flowing creek
27	Pine Creek (PA)	*S. eriocephala* (4)	Large trees growing in gravel next to fast-flowing creek
28	East Sandy Creek (PA)	*S. eriocephala* (4)	Vigorous trees with good upright habit, growing in sand next to fast-flowing creek.

In another avenue of genetic improvement of willows, approximately 75 willow clones were started from seed collected from willow clone SV1 during spring 1995. Male parents of these seedlings are unknown, as flowers were open pollinated. These plants were grown in a greenhouse, and hardwood cuttings will be collected from the small plants during January 1996. These cuttings will be rooted in a greenhouse during winter and spring 1996 and planted at Tully.

Section 3

SCALE-UP AND COMMERCIALIZATION

One of the factors currently limiting expansion to commercial-scale willow bioenergy plantations is availability of planting stock. Four willow cutting orchards were planted since 1992. A large irrigated willow cutting orchard was planted at the Ontario Ministry of Natural Resources Orono Nursery, Orono, Ontario, by the University of Toronto. This orchard contains 18 willow clones and approximately 17,000 trees (Table 3-1). Conservatively, each tree yields 10 cuttings, so this orchard can provide approximately 170,000 cuttings per year. Relatively small willow cutting orchards were planted at the SUNY ESF Genetics Field Station, Tully, NY, and the SUNY ESF Lafayette Road Experiment Station, Syracuse, NY, during 1993, with funding from the US Department of Energy. The number of clones planted at Tully was 16 (total of approximately 2,000 cuttings), and Syracuse contains 19 clones (1,200 cuttings), so the total number of cuttings available from these orchards combined is approximately 32,000 per year (Table 3-1). A large irrigated willow cutting orchard was planted in 1995 at the New York State Department of Environmental Conservation Saratoga Tree Nursery, Saratoga, NY with funding from NYSERDA. The number of clones was 15 and approximately 46,000 trees were planted, so the orchard should yield 460,000 cuttings per year. The total number of cuttings available for planting in spring 1997 is conservatively estimated at 660,000, enough for approximately 44 ha (109 acres).

Table 3-1. Willow clones and numbers of cuttings planted in willow cutting orchards in Orono, Ontario, and Tully, Syracuse, and Saratoga, NY.

Clone	Species	Approximate Number of Cuttings Planted (Planting Year)				
		Orono ('92)	Tully ('93)	Syracuse ('93)	Saratoga ('95)	Sum
S19	*S. eriocephala*	1,200	0	60	650	1,910
S25	*S. eriocephala*	1,200	190	60	6,900	8,350
S34	*S. eriocephala*	600	120	60	0	780
S71	*S. petiolaris* x *eriocephala*	600	60	60	0	720
S185	*S. eriocephala*	600	100	60	0	760
S287	*S. eriocephala*	1,200	190	60	4,600	6,050
S301	*S. interior* x *eriocephala*	1,200	190	60	5,700	7,150
S365	*S. discolor*	1,200	60	60	1,400	2,720
S546	*S. eriocephala*	1,200	190	60	4,600	6,050
S557	*S. eriocephala*	1,200	0	60	0	1,260
S566	*S. eriocephala*	1,200	60	60	4,600	5,920
S599	*S. eriocephala x petiolaris*	600	60	60	0	720
S625	*S. eriocephala* x *interior*	600	60	60	0	720
S646	*S. eriocephala*	1,200	60	60	3,400	4,720
S652	*S. eriocephala*	0	120	60	900	1,080
SV1	*S. dasyclados*	1,200	190	60	6,900	8,350
SH3	*S. purpurea*	0	190	0	3,400	3,590
SA2	*S. alba* var. *sanquinea*	0	150	0	2,300	2,450
Sx61	*S. udensis*[a]	600	0	100	250	950
Sx64	*S. udensis*[a]	600	0	100	350	1,050
Sx67	*S. udensis*[a]	600	0	100	150	850
Sum		16,800	1,990	1,260	46,100	66,150

[a]Clones Sx61, Sx64, and Sx67 were tentatively identified as *Salix udensis*, but some characteristics suggest they may be *S. sachalinensis*. Until the trees flower, positive identification can not be made.

Section 4

GRADUATE THESES COMPLETED OR IN PROGRESS AND FUNDED BY THE PROJECT BIOENERGY FROM WILLOW

COMPLETED THESES

Adegbidi, H.G. (1994) Nutrient return via litterfall and removal during harvest in a one-year rotation bioenergy plantation. Master of Science thesis.

Abstract. Soil improvement through litter effects has lately been the ground for promoting agroforestry in tropical countries. To investigate effects of trees on soils, the quantities of litter production and N, PI, K, Ca and Mg recycled through litterfall were estimated in a one-year rotation plantation of willow and hybrid poplar.

Annual litter production and litter concentrations and contents of N, PI, K, Ca and Mg depended on clone and fertilization treatment. Respectively, 1200-6200, 23-129, 14-110, 27-151 and 3-13 kg/ha of litter, N, P, K, Ca and Mg were returned to soil. Removals of N, P, K, Ca and Mg by annual stem harvesting were respectively 30-70, 4-10, 14-40, 19-59 and 3-5 kg/ha. Seven years of litter input and nutrients removal did not noticeably affect soil properties. A decrease of soil pH due to NH_4NO_3 fertilizer was observed in fertilized plots. Willow clone SVI had the highest stem biomass production and also the highest nutrient use efficiency.

Chapman, J. A. (1992) Growth and carbohydrate reserves in coppiced and defoliated willow (*Salix purpurea* L.). Doctor of Philosophy dissertation.

Abstract. The dynamics of carbohydrate allocation, root growth, and coppice responses were studied in two-year-old field-grown purple osier (*Salix purpurea* L.), clone SP-3, to investigate whether carbohydrate resource availability can limit coppice growth by constraining root growth. There were three treatments: intact, coppice, and defoliated-coppice (defoliated in August of the first growing season), and 12 harvest dates: January to October 1988.

The main effects of coppicing were to delay bud break by at least one week and to extend the duration of growth by as much as four weeks. Coppicing did not increase net assimilation rate (NAR) or whole plant relative growth rate (RGR) in comparison with intact plants, with the exception of the first two-week harvest interval following initial leaf development, and September. Shoot-root ratios of the coppice and intact treatments converged within two

months of bud break. Below-ground growth was reduced but not fully suppressed by coppicing, even immediately following initial leaf development.

All treatments depleted cutting and root reserves in the early spring. There was evidence of limited reserve availability in cutting tissue such that depletion of root reserves was inversely related to initial cutting reserve concentration.

Intact plants exhibited biweekly oscillations in below-ground RGR that were inversely related to oscillations in reserve concentrations of non-woody roots. The inverse relationship held for the coppice treatments, which indicated use of root reserves in root growth, but the oscillations were dampened.

First-season defoliation reduced biomass increment by one-third, but did not affect dormant season reserve concentrations. In the subsequent growing season, the defoliated-coppice growth rate was reduced by 60% (May to early June), and initiation of root growth was delayed by four weeks, in comparison with undefoliated coppice. Growth rate was affected by reductions in both leaf area and NAR. The differences in NAR and root growth between the coppice treatments were not related to shoot-root ratio. There was an apparent relationship between greater proportional depletion of root reserves in the defoliated-coppice treatment and suppression of below-ground growth. However, an interaction between reserve availability, root activity, and above-ground growth could not be confirmed.

Lo, M.H. (1994) Canker impacts on the relative performance of hybrid poplar clones. Master of Science Thesis.
Abstract. Biomass energy crops of the family *Salicaceae* are being researched as a renewable and sustainable fuel source. Consequently, poplar and willow clones have been established in test plantations throughout New York State. A multivariate method for evaluating relative clone performance is needed because factors, such as stem canker pathogen (i.e., *Septoria musiva*) can significantly reduce plantation yields. The hypothesis that early growth and canker incidence can indicate hybrid poplar clone growth potential was tested among 54 clones and found to be correct for some of them. Principal component analysis can be applied to several growth and canker disease variables to evaluate the relative performance of nine-year-old hybrid poplar clones. Fungi isolated from canker samples included: two *Fusarium species, Discosporium populeum, Microsphaeropsis olivacea, Paecilomyces lilaciniis* and two unknown fungi. Stem inoculations on clone NM6 demonstrated that the relative pathogenicity of the two unknown and *Fusarium* species was higher than that of known *S. musiva* cultures.

Sah, J-G. (1990) Nutrient and biomass patterns of willow (*Salix* spp.) clones as affected by fertilization and spacing in a wood-grass energy plantation system in New York. Doctor of Philosophy Dissertation.
Abstract. A wood-grass biomass energy plantation was installed at the Genetics Field Station, Tully, NY in the spring of 1987. Annual and seasonal changes in willow growth, biomass production, nutrient accumulation and

nutrient use efficiency were examined for three years. Comparison among five willow clones and one hybrid popular clone, planting density, N, P and K fertilizer application, and years were made in this study.

Hybrid poplar clone NM5 *(Populus nigra x maximowiczii)* had significantly higher biomass production compared to all willow clones in the first year. In the second year willow clone SVl *(S. viminalis)* and poplar clone NM5 produced the highest biomass yield and had a higher nutrient use efficiency than all other clones. Willow clone SVl produced the highest biomass yield in the third year and had a higher nutrient use efficiency than all other clones. Without fertilizer applied, NM5 and SVl produced the greatest biomass in 1989.

Three planting densities (15cm x 15cm, 30cm, x 30cm, and 46cm x 46cm) were examined. Trees in highest density plots (15cm x 15cm) produced larger amounts of biomass in the first year. Space and light competition limited tree growth in the third year in the highest density plots. Trees in the lowest density plots (46cm x 46cm) produced more biomass than trees in the highest density plots in the third year.

Although large amounts of the nutrients were returned to the site through leaf fall, nitrogen and phosphorus were retranslocated to root and stool during leaf fall.

Nitrogen, phosphorus and potassium fertilizer application had no effect on biomass production during the first growing season because nutrients contained in the cutting and/or initial soil fertility were adequate for the small amount of biomass produced with limited root systems. In the second year, water was believed to be the major factor limiting growth. During the third year, with irrigation, fertilization with N, P and K increased willow biomass production. Nitrogen was the major growth limiting factor in the third year.

During the third growing season of this study, the best willow clone SVl produced 15 odt ha^{-1} yr^{-1} of biomass. It is expected that with adequate growing space, fertilization and irrigation, production of 20 odt ha^{-1} yr^{-1} of biomass could be achieved.

Sahm, J. M. (1995) Wood ash as a soil amendment in willow plantations. Master of Science thesis.
Abstract. In an intensively managed willow bioenergy system, removal of N, P, K, Ca, and Mg with harvest is a major concern. Direct combustion of the annual above-ground crop, typically 8 to 12 dry Mg ha^{-1}, can yield as much as 720 kg ha^{-1} ash residue rich in P, K, Ca, and Mg. When this ash is applied to the harvested area, it can help ameliorate negative soil effects of intensive harvesting practices. This study examined the response of soil capital, soil solution, and a single willow clone, SP3 (*Salix purpurea*), to wood ash additions of 10 and 20 Mg ha^{-1}. Wood ash was applied to annually coppiced willow plantations, on five-year-old root stock, that were previously under intensive management to maximize biomass production. Ash was applied to plantations prior to growth initiation in April 1992, with harvest completed the following December. Soil samples collected at harvest showed

significantly elevated levels of P and increased pH at the 0- 10 cm sampling depth. Leaching of N, P, K, Ca, and Mg was not influenced by a single application of wood ash at the levels examined. Stem biomass samples collected at harvest showed little difference between treated and control plot total biomass production or nutrient content (N, P, K, Ca, and Mg). Analysis of foliar response to ash treatment showed no significant difference among treatments for measured parameters. There were, however, slight reductions in both foliar N and P content due to treatment. System nutrient input-output budgets for N, P, K, Ca, Mg, and Na show net accumulation of all examined elements except for Na at the 10 Mg ha^{-1} treatment level and N at both levels.

Graduate Research in Progress

Adegbidi, H.G. Start Date: September 1995. Title: Use of various organic wastes as soil ammendments in willow biomass plantations.

Ballard, B.D. Start Date: December 1995. Title: Effects of slow-release nitrogen fertilizer on growth response of six willow clones and one hybrid poplar clone in a short-rotation intensive culture bioenergy plantation.

Rooney, T.E. Start Date: January 1994. Title: Production costs and economic supply of industrial wood fuel in Central New York.

Volk, T.A. Start Date: November 1995. Title: Alternate establishment techniques for willow biomass crops.

Section 5

PUBLICATIONS

Abrahamson, L.P., R.C. McKittrick, E.H. White, R.F. Kopp, and C.A. Nowak. 1992. Successful no-till hybrid poplar establishment in New York. Proceedings of the Poplar Councils of Canada and the United States joint meeting, August 26-29, 1991, Ottawa, Canada. Forestry Chronicle 68(2):218.

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APPENDIX A.
CLONE-FERTILIZER TRIAL STEM NUTRIENT DATA FROM 1987 TO 1994.

APPENDIX A

Table A-1. Mean and standard error of stem N concentrations of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... N%						
NM5	1.08	1.18	1.04	0.77	0.67	0.63	0.68	0.68	0.76	0.67	0.75	0.69
	(0.03)	(0.01)	(0.01)	(0.02)	(0.05)	(0.06)	(0.01)	(0.01)	(0.03)	(0.02)	(0.02)	(0.04)
SAM3	1.31	1.47	1.16	0.89	0.66	0.65	0.83	0.83	0.82	0.78	0.79	0.78
	(0.04)	(0.04)	(0.01)	(0.05)	(0.06)	(0.07)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.03)
SA2	1.48	1.6	1.31	0.85	0.61	0.7	0.74	0.77	0.83	0.77	0.7	0.74
	(0.03)	(0.05)	(0.04)	(0.03)	(0.07)	(0.05)	(0.02)	(0.02)	(0.01)	(0.03)	(0.01)	(0.01)
SA22	1.3	1.32	1.17	0.73	0.74	0.66	0.94	0.82	0.95	0.75	0.73	0.77
	(0.02)	(0.07)	(0.06)	(0.06)	(0.07)	(0.05)	(0.01)	(0.04)	(0.01)	(0.02)	(0.01)	(0.22)
SH3	1.2	1.3	1.31	0.69	0.78	0.56	0.66	0.63	0.81	0.68	0.64	0.6
	(0.08)	(0.06)	(0.06)	(0.03)	(0.06)	(0.03)	(0.02)	(0.002)	(0.06)	(0.03)	(0.01)	(0.05)
SV1	0.89	0.98	0.85	0.65	0.58	0.55	0.53	0.52	0.62	0.55	0.6	0.58
	(0.03)	(0.03)	(0.02)	(0.01)	(0.02)	(0.06)	(0.02)	(0.02)	(0.01)	(0.02)	(0.03)	(0.02)

continued

Table A-1 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
	.... N%			
NM5	0.72	0.63	0.76	0.71
	(0.01)	(0.025)	0.058	0.027
SAM3	0.81	0.68	n/a[1]	n/a
	(0.01)	(0.02)		
SA2	0.71	0.66	0.7	0.68
	(0.02)	(0.02)	0.024	0.04
SA22	0.88	0.7	n/a	n/a
	(0.02)	(0.07)		
SH3	0.76	0.65	0.73	0.69
	(0.03)	(0.01)	0.028	0.012
SV1	0.68	0.57	0.63	0.57
	(0.02)	(0.03)	0.026	0.026

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-2. Mean and standard error of stem N contents of five *Salix* clones and one *Populus* clone with one-year-old stems on 1-(1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... N, kg ha^{-1} yr^{-1}						
NM5	32.87	28.71	95.69	58.42	68.25	71.92	68.44	88.09	87.37	90.47	56.61	51.03
	(2.56)	(4.12)	(1.45)	(5.57)	(7.20)	(8.67)	(0.13)	(3.20)	(1.30)	(2.94)	(1.85)	(1.40)
SAM3	14.02	6.12	44.55	13.67	52.81	29.13	65.24	71.2	69.32	54.99	33.36	19.79
	(0.16)	(0.75)	(1.31)	(2.57)	(6.36)	(2.84)	(11.36)	(8.91)	(4.67)	(8.64)	(5.33)	(3.26)
SA2	8.32	7.49	49.18	23.45	78.9	47.16	97.11	81.4	113.05	83.18	59.63	42.06
	(1.12)	(2.11)	(6.79)	(5.94)	(9.40)	(9.37)	(2.75)	(8.13)	(5.98)	(16.05)	(1.54)	(10.60)
SA22	7.98	7.05	42.56	19.76	84.28	42.56	70.41	66.4	78.5	41.86	35.22	24.68
	(0.91)	(1.34)	(8.69)	(2.17)	(5.21)	(1.83)	(10.65)	(5.10)	(10.43)	(1.73)	(0.32)	(14.68)
SH3	16.16	17.86	63.08	27.77	95.3	50.31	79.2	77.35	102.67	89.75	51.35	55.18
	(1.49)	(1.57)	(16.25)	(0.93)	(8.33)	(3.39)	(6.67)	(4.76)	(9.60)	(2.95)	(1.28)	(3.30)
SV1	10.7	10.64	70.81	38.18	85.41	61.17	77.9	72.35	101	83.63	55.86	52.19
	(0.29)	(1.97)	(6.03)	(3.68)	(12.27)	(10.12)	(3.14)	(1.23)	(4.83)	(4.86)	(1.62)	(3.01)

continued.

Table A-2 continued.

Clone	1993 (1/7) F	1993 (1/7) NF	1994 (1/8) F	1994 (1/8) NF
	..... N, kg ha-1 yr-1			
NM5	71.93	67.32	69.61	71.63
	(1.73)	(5.84)	6.67	4.96
SAM3	37.02	20.69	n/a[1]	n/a
	(15.83	(2.37)		
SA2	74.38	55.42	65.86	46.33
	(3.05)	(2.81)	4.95	8.98
SA22	24.61	12.69	n/a	n/a
	(7.24)	(1.97)		
SH3	74.86	64.66	78.41	72.07
	(5.03)	(1.30)	0.9	1.08
SV1	80.76	58.81	83.77	71.61
	(5.94)	(2.17)	6.6	3.72

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-3. Mean and standard error of stem biomass to N content ratio of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... N%						
NM5	92.51	84.88	96.38	129.28	151.46	161.18	146.83	146.46	131.39	148.74	133.82	146.31
	(2.26)	(0.856)	(1.22)	(2.70)	(11.69)	(16.92)	(2.02)	(2.63)	(5.08)	(4.00)	(4.17)	(8.08)
SAM3	76.57	68.14	85.93	112.6	138.3	152.54	120.87	120.17	122.48	128.43	126.4	128.01
	(2.13)	(1.83)	(0.69)	(6.14)	(13.61)	(11.00)	(2.16)	(1.87)	(1.33)	(3.81)	(3.90)	(4.71)
SA2	67.84	62.45	76.29	118.49	154.13	156.32	136.22	130.33	120.02	129.63	141.97	134.51
	(1.35)	(1.95)	(2.35)	(4.56)	(13.42)	(15.90)	(4.19)	(3.00)	(0.97)	(4.63)	(2.89)	(1.80)
SA22	76.92	76.25	85.65	138.4	168.96	143.47	106.21	122.74	105.65	133.54	137.03	142.41
	(1.04)	(3.76)	(4.29)	(10.92)	(21.30)	(9.09)	(1.10)	(6.80)	(0.99)	(3.64)	(0.911)	(41.52)
SH3	84.32	77.22	76.48	145.45	129.67	180.9	152.15	157.8	124.98	148.25	156.34	169.29
	(5.96)	(3.21)	(3.63)	(6.35)	(9.35)	(8.84)	(5.41)	(0.614)	(9.65)	(5.80)	(3.25)	(15.05)
SV1	112.39	102.58	117.25	154.83	173.46	187.66	191.17	191.75	161.38	181.12	169.09	172.3
	(3.30)	(2.82)	(2.26)	(0.56)	(7.59)	(19.50)	(9.24)	(7.43)	(2.65)	(5.90)	(10.30)	(6.74)

continued

Table A-3 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
	.... N%			
NM5	139.24 (1.30)	159.84 (6.55)	133.05 (10.81)	141.78 (5.30)
SAM3	123.8 (1.55)	147.12 (3.87)	N/A	N/A
SA2	141.32 (4.97)	152.61 (5.62)	142.79 (4.92)	148.33 (7.79)
SA22	114.32 (2.66)	146.06 (15.25)	N/A	N/A
SH3	131.55 (5.63)	154.44 (1.81)	136.63 (5.17)	144.59 (2.43)
SV1	147.9 (3.73)	177.24 (9.59)	158.86 (6.60)	177.23 (8.29)

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-4. Mean and standard error of stem P concentrations of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
					...... P%							
NM5	0.1	0.11	0.09	0.11	0.1	0.11	0.12	0.12	0.12	0.11	0.14	0.11
	(0.003)	(0.002)	(0.002)	(0.003)	(0.006)	(0.007)	(0.001)	(0.003)	(0.002)	(0.002)	(0.003)	(0.014)
SAM3	0.11	0.12	0.1	0.1	0.07	0.1	0.11	0.1	0.09	0.1	0.11	0.12
	(0.003)	(0.012)	(0.001)	(0.005)	(0.004)	(0.002)	(0.003)	(0.001)	(0.002)	(0.002)	(0.024)	(0.002)
SA2	0.13	0.14	0.12	0.11	0.09	0.12	0.11	0.13	0.1	0.11	0.11	0.12
	(0.003)	(0.008)	(0.007)	(0.001)	(0.016)	(0.007)	(0.004)	(0.003)	(0.001)	(0.003)	(0.015)	(0.007)
SA22	0.12	0.13	0.11	0.09	0.09	0.1	0.13	0.13	0.16	0.12	0.12	0.13
	(0.006)	(0.007)	(0.011)	(0.007)	(0.004)	(0.002)	(0.002)	(0.005)	(0.033)	(0.003)	(0.006)	(0.006)
SH3	0.12	0.14	0.13	0.09	0.1	0.09	0.11	0.11	0.12	0.11	0.12	0.12
	(0.005)	(0.011)	(0.005)	(0.001)	(0.001)	(0.002)	(0.007)	(0.003)	(0.008)	(0.006)	(0.001)	(0.003)
SV1	0.09	0.1	0.08	0.09	0.07	0.07	0.08	0.07	0.09	0.08	0.1	0.1
	(0.004)	(0.003)	(0.005)	(0.003)	(0.002)	(0.004)	(0.002)	(0.002)	(0.001)	(0.002)	(0.005)	(0.007)

continued.

Table A-4 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
	.... P%			
NM5	0.1	0.1	0.11	0.1
	(0.003)	(0.005)	0.01	0.003
SAM3	0.08	0.1	n/a[1]	n/a
	(0.005)	(0.002)		
SA2	0.08	0.1	0.08	0.1
	(0.002)	(0.004)	0.005	0.004
SA22	0.11	0.12	n/a	n/a
	(0.006)	(0.011)		
SH3	0.1	0.1	0.09	0.1
	(0.005)	(0.003)	0.003	0.003
SV1	0.08	0.08	0.08	0.07
	(0.002)	(0.001)	0.002	0.004

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-5. Mean and standard error of stem P contents of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
					......P, kg ha^{-1} yr^{-1}							
NM5	2.92	2.66	7.97	8.01	10.35	12.4	11.61	15.05	13.63	14.06	10.2	8.37
	(0.21)	(0.41)	(0.38)	(0.73)	(0.89)	(1.18)	(0.14)	(0.45)	(0.19)	(0.31)	(0.23)	(0.72)
SAM3	1.17	0.49	3.93	1.62	5.66	4.57	8.31	8.86	7.82	6.84	4.47	3.05
	(0.02)	(0.09)	(0.14)	(0.34)	(0.53)	(0.43)	(1.38)	(1.02)	(0.58)	(0.97)	(0.69)	(0.52)
SA2	0.74	0.66	4.37	3.18	11.21	8.01	14.84	13.26	13.76	11.81	8.56	6.89
	(0.11)	(0.24)	(0.47)	(0.88)	(2.13)	(1.29)	(0.28)	(1.18)	(0.78)	(2.09)	(1.13)	(1.92)
SA22	0.77	0.73	4.1	2.5	10.37	6.51	9.98	10.31	12.26	6.94	8.05	3.54
	(0.12)	(0.18)	(1.02)	(0.62)	(0.30)	(0.59)	(1.42)	(0.74)	(1.27)	(0.37)	(2.34)	(0.77)
SH3	1.57	1.96	6.04	3.75	12.06	7.81	12.8	13.32	14.81	14.65	9.77	11.08
	(0.18)	(0.20)	(1.54)	(0.27)	(0.28)	(0.29)	(1.39)	(0.52)	(1.20)	(0.29)	(0.38)	(0.59)
SV1	1.09	1.1	6.74	5.19	9.79	8	11.22	10.23	13.93	12.3	9.09	8.68
	(0.09)	(0.20)	(0.78)	(0.32)	(1.12)	(1.14)	(0.16)	(0.24)	(0.77)	(0.78)	(0.33)	(0.72)

continued.

Table A-5 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
	..... P, kg ha^{-1} yr^{-1}			
NM5	9.9	10.6	9.91	10.25
	(0.16)	(0.72)	0.5	0.58
SAM3	37.02	2.9	n/a[1]	n/a
	(1.58)	(0.30)		
SA2	8.82	8.56	7.68	6.89
	(0.43)	(0.27)	0.81	1.43
SA22	3.05	2.12	n/a	n/a
	(0.85)	(0.35)		
SH3	9.98	9.69	9.94	10.07
	(0.76)	(0.34)	0.12	0.39
SV1	9.82	7.9	10.03	9.43
	(0.30)	(0.63)	0.67	0.56

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-6. Mean and standard error of stem biomass to P content ratio of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... N%						
NM5	1,040.4	917.79	1,161.1	944.46	992.85	923.51	865.44	857.64	841.42	956.35	742.31	908.88
	(35.47)	(12.71)	(32.42)	(29.95)	(61.42)	(62.58)	(7.82)	(24.89)	(12.20)	(15.51)	(15.72)	(105.58)
SAM3	921.32	874.05	974.39	963.82	1,111.48	998.47	947	962.4	1,087.51	1,027.71	939.94	830.17
	(22.07)	(96.19)	(6.03)	(44.56)	(43.50)	(15.32)	(24.67)	(12.80)	(23.21)	(19.69)	(16.17)	(16.32)
SA2	766.06	742.73	854.94	886.14	1,422.11	984.65	891.63	799.13	986.87	908.41	971.15	842.44
	(16.92)	(45.48)	(52.90)	(3.41)	(80.30)	(22.00)	(33.98)	(20.87)	(12.52)	(27.10)	(137.07)	(50.30)
SA22	808.84	747.88	917.17	1,156.66	1,259.13	830.55	746.62	789.28	696.65	806.46	810.45	804.53
	(43.65)	(35.42)	(96.62)	(88.53)	(278.44)	(52.08)	(13.22)	(35.84)	(125.17)	(21.47)	(37.90)	(42.59)
SH3	870.81	708.83	796.78	1,079.24	1,012.16	1,159.48	949.74	915.48	862.48	908.94	822.38	836.13
	(39.74)	(52.75)	(34.49)	(7.27)	(12.76)	(30.26)	(65.71)	(27.01)	(53.96)	(46.39)	(5.16)	(19.15)
SV1	1,114.64	985.86	1,244.69	1,134.92	1,498.9	1,413.07	1,323.84	1,356.5	1,171.45	1,231.65	1,038.37	1,045.49
	(45.21)	(33.80)	(78.61)	(40.24)	(34.55)	(81.54)	(34.23)	(37.64)	(14.35)	(31.58)	(52.31)	(82.38)

continued

Table A-6 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
		.... N%		
NM5	1,011.98	1,013.54	925	988.91
	(30.45)	(58.42)	(47.10)	(31.49)
SAM3	1,213.27	1,046.53	N/A	N/A
	(71.19)	(25.29)		
SA2	1,191.25	986.72	1,233.82	1,003.28
	(21.34)	(39.07)	(73.60)	(40.65)
SA22	910.1	874.41	N/A	N/A
	(55.79)	(80.97)		
SH3	988.76	1,032.49	1,077.35	1,036.47
	(50.34)	(28.61)	(33.49)	(32.42)
SV1	1,211.59	1,321.95	1,323.74	1,349.47
	(33.83)	(15.51)	(37.25)	(84.88)

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-7. Mean and standard error of stem K concentrations of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF)[1] in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						......K%......						
NM5	0.36	0.36	0.43	0.46	0.42	0.41	0.38	0.39	0.47	0.38	0.7	0.65
	(0.005)	(0.008)	(0.009)	(0.014)	(0.056)	(0.053)	(0.054)	(0.056)	(0.026)	(0.021)	(0.026)	(0.048)
SAM3	0.31	0.33	0.37	0.32	0.34	0.26	0.51	0.36	0.36	0.33	0.64	0.76
	(0.019)	(0.006)	(0.041)	(0.005)	(0.015)	(0.028)	(0.040)	(0.038)	(0.029)	(0.033)	(0.037)	(0.121)
SA2	0.34	0.37	0.35	0.33	0.25	0.28	0.42	0.4	0.36	0.41	0.56	0.53
	(0.013)	(0.012)	(0.010)	(0.002)	(0.018)	(0.001)	(0.059)	(0.087)	(0.021)	(0.050)	(0.004)	(0.037)
SA22	0.44	0.43	0.39	0.34	0.35	0.36	0.61	0.72	0.5	0.51	0.74	0.5
	(0.021)	(0.014)	(0.002)	(0.014)	(0.019)	(0.020)	(0.020)	(0.220)	(0.041)	(0.067)	(0.015)	(0.115)
SH3	0.42	0.47	0.39	0.34	0.3	0.27	0.37	0.24	0.35	0.43	0.54	0.46
	(0.006)	(0.031)	(0.011)	(0.004)	(0.033)	(0.014)	(0.072)	(0.019)	(0.014)	(0.050)	(0.027)	(0.082)
SV1	0.23	0.23	0.19	0.21	0.19	0.18	0.16	0.17	0.19	0.19	0.23	0.23
	(0.008)	(0.027)	(0.006)	(0.009)	(0.006)	(0.014)	(0.012)	(0.004)	(0.005)	(0.015)	(0.015)	(0.014)

continued.

Table A-7 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
		.... K%		
NM5	0.41	0.39	0.36	0.41
	(0.025)	(0.010)	0.027	0.02
SAM3	0.4	0.37	n/a[2]	n/a
	(0.021)	(0.030)		
SA2	0.35	0.31	0.29	0.32
	(0.026)	(0.009)	0.004	0.039
SA22	0.5	0.49	n/a	n/a
	(0.022)	(0.026)		
SH3	0.35	0.31	0.31	0.29
	(0.048)	(0.003)	0.034	0.004
SV1	0.23	0.19	0.2	0.18
	(0.009)	(0.001)	0.015	0.002

[1] There were no significant differences between fertilization treatments during any year.
[2] Clones followed by n/a were removed from the experiment during 1994.

Table A-8. Mean and standard error of stem K contents of five *Salix* clones and one *Populus* clone with one-year-old stems on 1-(1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
	K, kg ha^{-1} yr^{-1}											
NM5	11	8.89	39.71	34.33	42.76	47	38.12	49.06	54.33	51.08	52.66	48
	(1.08)	(1.42)	(0.87)	(3.07)	(6.02)	(7.24)	(5.35)	(5.54)	(4.13)	(3.18)	(1.89)	(0.96)
SAM3	3.36	1.37	13.91	4.97	26.94	11.89	41.42	30.41	30.59	23	27.17	18.26
	(0.17)	(0.13)	(1.04)	(0.90)	(0.31)	(2.00)	(9.65)	(2.44)	(4.08)	(3.37)	(5.42)	(0.98)
SA2	1.93	1.77	13.04	9.39	31.9	18.99	54.84	43.88	48.68	44.4	45.77	30.59
	(0.33)	(0.60)	(1.96)	(2.63)	(3.47)	(4.30)	(5.54)	(12.31)	(4.02)	(10.48)	(0.07)	(9.04)
SA22	2.73	2.29	13.98	9.5	40.02	28.9	45.05	59.75	42.12	28.95	46.54	12.85
	(0.44)	(0.47)	(2.43)	(1.80)	(0.56)	(1.65)	(6.46)	(21.22)	(7.84)	(5.18)	(10.83)	(1.89)
SH3	5.77	6.37	18.7	13.78	36.74	23.96	44.65	28.99	45.02	57.15	43.62	42.09
	(0.71)	(0.44)	(4.53)	(0.97)	(4.53)	(1.55)	(8.94)	(2.02)	(4.24)	(9.07)	(3.21)	(7.07)
SV1	2.78	2.47	16.01	12.49	28.1	19.56	23.75	22.92	31.12	29.03	21.37	20.48
	(0.05)	(0.42)	(1.57)	(1.30)	(3.38)	(2.50)	(1.98)	(0.70)	(0.85)	(1.15)	(0.58)	(1.63)

continued.

Table A-8 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
	.... K, kg ha^{-1} yr^{-1}			
NM5	41.41	41.41	33.11	41.06
	(2.31)	(1.85)	3.06	2.48
SAM3	17.86	11.21	n/a[1]	n/a
	(6.90)	(1.25)		
SA2	36.97	26.34	27.48	23.03
	(2.34)	(0.77)	1.52	6.05
SA22	14.49	9.09	n/a	n/a
	(4.63)	(1.88)		
SH3	33.96	30.41	33.18	29.86
	(5.42)	(0.06)	2.79	1.11
SV1	27.33	19.12	26.17	22.69
	(1.63)	(0.89)	2.03	0.31

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-9. **Mean and standard error of stem biomass to K content ratio of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.**

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... N%						
NM5	277.38	275.48	232.37	220.18	247.7	251.81	276.34	272.72	212.87	264.76	143.88	155.82
	(3.99)	(5.82)	(4.86)	(6.85)	(34.95)	(37.26)	(45.90)	(44.19)	(12.28)	(14.18)	(5.36)	(10.97)
SAM3	321.44	302.02	279.59	309.06	288.11	283.88	197	281.39	283.79	308.96	157.66	137.65
	(18.83)	(5.62)	(28.58)	(5.12)	(15.92)	(16.65)	(14.25)	(28.98)	(25.02)	(28.39)	(9.09)	(19.04)
SA2	295.87	272.1	288.58	300.38	295.78	392.18	247.31	278.19	280.65	252.02	178.18	191.96
	(11.33)	(8.93)	(7.85)	(1.78)	(13.24)	(44.34)	(30.35)	(69.86)	(16.01)	(27.63)	(1.43)	(13.88)
SA22	227.94	235.28	256.66	294.67	412	357.24	165.59	164.32	200.9	201.74	136.23	233.78
	(10.76)	(8.08)	(1.04)	(11.49)	(30.27)	(1.55)	(5.64)	(42.29)	(16.02)	(26.01)	(2.78)	(70.63)
SH3	236.7	216.33	254.43	293.84	342.27	379.75	286.47	424.12	283.57	240.68	185.27	235.67
	(3.60)	(13.29)	(7.06)	(3.11)	(41.25)	(20.57)	(47.79)	(31.07)	(11.40)	(25.57)	(8.75)	(49.57)
SV1	432.73	443.29	520.23	475.17	522.87	576.18	631.9	605.39	523.13	523.46	442.49	441.33
	(15.31)	(47.07)	(16.93)	(21.73)	(17.15)	(42.71)	(44.02)	(16.00)	(12.64)	(41.85)	(30.14)	(26.08)

continued

Table A-9 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
	.... N%			
NM5	243.44	258.07	279.52	247.29
	(15.67)	(6.67)	(22.19)	(11.90)
SAM3	250.32	273.2	N/A	N/A
	(12.80)	(20.84)		
SA2	286.29	320.36	341.07	316.09
	(22.17)	(9.20)	(5.16)	(33.85)
SA22	200.69	206.56	N/A	N/A
	(9.26)	(11.31)		
SH3	300.46	328.29	328.09	349.38
	(37.97)	(3.12)	(32.83)	(4.97)
SV1	436.65	547.03	510.78	556.79
	(16.44)	(42.56)	(38.61)	(7.53)

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-10. Mean and standard error of stem Ca concentrations of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF)[1] in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						.... Ca%						
NM5	0.65	0.7	0.58	0.61	0.4	0.42	0.47	0.5	0.53	0.53	0.45	0.58
	(0.04)	(0.05)	(0.02)	(0.05)	(0.01)	(0.04)	(0.005)	(0.015)	(0.019)	(0.044)	(0.019)	(0.053)
SAM3	0.93	0.97	0.7	0.73	0.34	0.43	0.45	0.44	0.44	0.47	0.41	0.49
	(0.02)	(0.04)	(0.06)	(0.06)	(0.03)	(0.06)	(0.015)	(0.007)	(0.024)	(0.025)	(0.018)	(0.074)
SA2	1.1	1.02	0.75	0.72	0.32	0.44	0.38	0.42	0.44	0.44	0.35	0.52
	(0.03)	(0.07)	(0.03)	(0.02)	(0.02)	(0.02)	(0.010)	(0.011)	(0.014)	(0.009)	(0.014)	(0.010)
SA22	1.09	1.12	0.87	0.89	0.39	0.47	0.6	0.6	0.63	0.65	0.59	0.74
	(0.04)	(0.09)	(0.04)	(0.04)	(0.06)	(0.01)	(0.023)	(0.045)	(0.065)	(0.046)	(0.113)	(0.017)
SH3	1.06	1.18	0.9	0.95	0.56	0.47	0.6	0.64	0.61	0.67	0.61	0.77
	(0.11)	(0.08)	(0.05)	(0.09)	(0.07)	(0.02)	(0.037)	(0.016)	(0.031)	(0.015)	(0.045)	(0.024)
SV1	1.01	1.12	0.67	0.78	0.41	0.48	0.36	0.44	0.39	0.43	0.4	0.58
	(0.08)	(0.12)	(0.01)	(0.01)	(0.03)	(0.09)	(0.010)	(0.023)	(0.025)	(0.027)	(0.016)	(0.037)

continued.

Table A-10 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
		.... Ca%		
NM5	0.56	0.59	0.57	0.84
	(0.03)	(0.04)	0.026	0.12
SAM3	0.5	0.59	n/a[1]	n/a
	(0.04)	(0.02)		
SA2	0.35	0.51	0.4	0.49
	(0.02)	(0.03)	0.026	0.031
SA22	0.66	0.71	n/a	n/a
	(0.05)	(0.06)		
SH3	0.66	0.78	0.75	0.9
	(0.03)	(0.03)	0.1	0.01
SV1	0.43	0.51	0.42	0.51
	(0.01)	(0.01)	0.06	0.031

[1] There were no significant differences between fertilization treatments during any year.
[2] Clones followed by n/a were removed from the experiment during 1994.

Table A-11. Mean and standard error of stem Ca contents of five *Salix* clones and one *Populus* clone with one-year-old stems on 1-(1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
					........Ca, kg ha^{-1} yr^{-1}........							
NM5	19.71	16.87	53.27	46.22	40.64	47.44	47.33	63.91	60.92	71.32	34.28	42.8
	(0.98)	(2.18)	(1.09)	(4.57)	(2.72)	(5.73)	(0.84)	(2.87)	(3.62)	(5.96)	(1.46)	(1.70)
SAM3	9.98	4.03	26.63	10.85	24.47	19.51	35.47	37.82	37.42	33.45	17.25	12.59
	(0.08)	(0.42)	(2.38)	(1.30)	(2.78)	(3.43)	(5.91)	(4.74)	(0.73)	(5.77)	(2.28)	(2.92)
SA2	6.19	4.74	28.26	20.06	41.56	29.25	50.73	44.5	59.24	47.2	28.37	29.13
	(0.87)	(1.30)	(4.39)	(5.14)	(2.44)	(5.02)	(2.56)	(4.19)	(4.44)	(9.08)	(0.91)	(6.74)
SA22	6.67	6.04	30.57	24.29	44.13	30.89	44.35	48.02	50.89	36.19	33.42	21.04
	(0.74)	(1.39)	(3.69)	(3.35)	(5.57)	(3.06)	(4.96)	(1.80)	(2.17)	(2.82)	(5.43)	(4.47)
SH3	14.23	16.16	43.45	38.01	68.1	42.48	72.07	78.19	77.38	89.65	49.28	71.02
	(1.08)	(1.48)	(11.59)	(3.29)	(9.00)	(2.31)	(7.46)	(6.99)	(8.95)	(4.21)	(5.12)	(2.06)
SV1	12.16	11.86	56.01	46.09	60.04	54.63	52.99	61.17	63.71	64.85	38.08	52.19
	(0.93)	(1.34)	(5.35)	(4.47)	(10.09)	(13.50)	(1.96)	(2.42)	(0.99)	(6.40)	(3.03)	(3.54)

continued.

Table A-11 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
	..... Ca, kg ha^{-1} yr^{-1}			
NM5	56.44	63.41	52.21	57.3
	(3.63)	(7.20)	3.03	10.49
SAM3	24.41	17.84	n/a[1]	n/a
	(11.82	(1.74)		
SA2	36.14	42.7	37.42	33.54
	(1.97)	(3.46)	2.27	6.39
SA22	19.39	13.09	n/a	n/a
	(6.55)	(2.41)		
SH3	64.81	77.44	79.78	94.07
	(4.80)	(3.96)	8.07	1.68
SV1	50.81	53.55	55.82	63.86
	(2.00)	(5.91)	6.85	3.5

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-12. Mean and standard error of stem biomass to Ca content ratio of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... N%						
NM5	154.23	144.73	173.32	164.54	251.41	243.52	212.36	202.14	188.99	191.04	221.1	175.61
	(10.41)	(10.59)	(5.59)	(12.86)	(8.23)	(21.91)	(2.42)	(5.99)	(6.59)	(16.47)	(9.07)	(16.60)
SAM3	107.56	103.21	145.65	139.45	270.07	210.88	221.78	226.35	226.58	212.19	242.78	212.44
	(2.81)	(4.58)	(11.06)	(10.28)	(36.83)	(1.51)	(7.67)	(3.66)	(11.73)	(10.65)	(9.96)	(29.72)
SA2	91.42	98.67	133.39	139.28	294.45	241.86	261.08	238.13	229.94	228.43	287.84	191.63
	(2.70)	(5.96)	(4.35)	(3.64)	(23.27)	(34.05)	(6.50)	(6.49)	(7.31)	(4.54)	(11.95)	(3.89)
SA22	92.22	90.92	115.89	113.07	313.28	228.05	167.03	169.36	161.73	155.83	192.48	134.81
	(3.62)	(7.95)	(5.84)	(5.57)	(19.04)	(12.25)	(6.51)	(11.69)	(15.24)	(11.72)	(32.89)	(3.15)
SH3	96.06	85.56	112.1	107.73	184.59	213.85	168.39	156.83	165.77	148.44	165.6	130.31
	(10.67)	(5.29)	(7.08)	(10.49)	(20.44)	(10.21)	(10.98)	(3.93)	(8.12)	(3.25)	(12.92)	(4.21)
SV1	99.91	91.29	148.48	128.33	248.81	226.2	280.56	227.38	256.24	235.95	248.87	172.98
	(7.50)	(10.53)	(2.81)	(1.97)	(17.15)	(44.98)	(7.46)	(11.80)	(15.49)	(15.20)	(9.62)	(10.96)

continued

Table A-12 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
		.... N%		
NM5	178.67	171.08	175.59	124.36
	(10.65)	(12.38)	(8.37)	(20.06)
SAM3	201.27	170.1	N/A	N/A
	(18.31)	(5.91)		
SA2	292.24	199.62	251.53	205.6
	(20.04)	(14.05)	(15.17)	(14.03)
SA22	152.49	142.26	N/A	N/A
	(11.05)	(10.95)		
SH3	152.22	129.46	138.55	110.77
	(7.52)	(5.47)	(21.18)	(1.26)
SV1	234.17	196.53	244.31	199.11
	(4.30)	(5.69)	(30.83)	(12.13)

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-13. Mean and standard error of stem Mg concentrations of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF)[1] in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... Mg%						
NM5	0.06	0.07	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.04	0.05	0.05
	(0.002)	(0.005)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.008)	(0.003)	(0.002)	(0.001)	(0.001)
SAM3	0.1	0.13	0.08	0.1	0.05	0.07	0.07	0.07	0.06	0.06	0.07	0.08
	(0.004)	(0.010)	(0.003)	(0.008)	(0.005)	(0.007)	(0.003)	(0.006)	(0.006)	(0.003)	(0.005)	(0.003)
SA2	0.08	0.1	0.07	0.09	0.05	0.07	0.06	0.07	0.06	0.06	0.07	0.08
	(0.002)	(0.016)	(0.003)	(0.006)	(0.004)	(0.001)	(0.001)	(0.004)	(0.001)	(0.001)	(0.002)	(0.003)
SA22	0.11	0.11	0.09	0.1	0.06	0.07	0.08	0.09	0.07	0.08	0.07	0.08
	(0.003)	(0.001)	(0.004)	(0.006)	(0.005)	(0.002)	(0.008)	(0.006)	(0.004)	(0.009)	(0.002)	(0.003)
SH3	0.06	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	(0.003)	(0.004)	(0.002)	(0.003)	(0.003)	(0.002)	(0.004)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
SV1	0.04	0.05	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	(0.003)	(0.004)	(0.004)	(0.002)	(0.001)	(0.004)	(0.0001)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)

continued.

Table A-13 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
		.... Mg%		
NM5	0.04	0.04	0.05	0.05
	(0.001)	(0.001)	0.001	0.001
SAM3	0.07	0.07	n/a[1]	n/a
	(0.001)	(0.002)		
SA2	0.05	0.06	0.09	0.1
	(0.001)	(0.002)	0.004	0.009
SA22	0.06	0.07	n/a	n/a
	(0.003)	(0.006)		
SH3	0.03	0.03	0.04	0.04
	(0.002)	(0.001)	0.001	0.001
SV1	0.04	0.04	0.04	0.04
	(0.002)	(0.001)	0.001	0.001

[1] There were no significant differences between fertilization treatments during any year.
[2] Clones followed by n/a were removed from the experiment during 1994.

Table A-14. **Mean and standard error of stem Mg contents of five *Salix* clones and one *Populus* clone with one-year-old stems on 1-(1/1), 2- (1/2), 3-(1/3), 4 (1/4), 5- (1/5), 6- (1/6), and 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.**

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
	......Mg, kg ha^{-1} yr^{-1}......											
NM5	1.87	1.72	4.59	3.84	4.17	5.14	4.94	6.01	5.33	5.4	3.51	3.33
	(0.11)	(0.27)	(0.19)	(0.27)	(0.24)	(0.38)	(0.06)	(0.74)	(0.39)	(0.35)	(0.04)	(0.15)
SAM3	1.07	0.53	3.15	1.59	4.29	2.96	5.58	5.98	4.84	4.53	3.03	1.99
	(0.04)	(0.09)	(0.18)	(0.33)	(0.45)	(0.55)	(1.21)	(0.89)	(0.36)	(0.71)	(0.31)	(0.32)
SA2	0.44	0.44	2.63	2.38	6.16	4.48	8.27	7.2	7.73	6.77	5.45	4.24
	(0.07)	(0.08)	(0.35)	(0.53)	(0.61)	(1.03)	(0.46)	(0.31)	(0.42)	(1.30)	(0.07)	(1.00)
SA22	0.69	0.6	3.05	2.63	6.95	4.37	6.09	7.06	5.64	4.56	4.56	2.15
	(0.08)	(0.12)	(0.52)	(0.33)	(0.51)	(0.49)	(0.84)	(0.16)	(0.45)	(0.33)	(1.04)	(0.46)
SH3	0.77	1	2.25	1.82	4.68	3.19	4.7	5.17	4.41	4.66	2.93	3.48
	(0.08)	(0.13)	(0.48)	(0.18)	(0.41)	(0.21)	(0.63)	(0.16)	(0.24)	(0.34)	(0.09)	(0.09)
SV1	0.51	0.51	2.91	2.53	4.98	4.82	5.29	5.37	6.01	5.59	3.52	3.91
	(0.05)	(0.06)	(0.43)	(0.17)	(0.64)	(0.79)	(0.11)	(0.40)	(0.57)	(0.58)	(0.10)	(0.32)

continued.

Table A-14 continued.

Clone	1993 (1/7) F	1993 (1/7) NF	1994 (1/8) F	1994 (1/8) NF
	..... Mg, kg ha^{-1} yr^{-1}			
NM5	3.84	4.24	4.47	4.97
	(0.12)	(0.23)	0.1	0.37
SAM3	2.98	2.14	n/a[1]	n/a
	(1.26)	(0.20)		
SA2	5.5	5.23	8.12	6.83
	(0.34)	(0.21)	0.15	1.57
SA22	1.84	1.32	n/a	n/a
	(0.59)	(0.24)		
SH3	3.37	3.39	4.31	4.2
	(0.26)	(0.11)	0.09	0.1
SV1	4.1	3.89	4.68	4.88
	(0.10)	(0.27)	0.22	0.09

[1] Clones followed by n/a were removed from the experiment during 1994.

Table A-15. Mean and standard error of stem biomass to Mg content ratio of five *Salix* clones and one *Populus* clone with one-year-old stems on 1- (1/1), 2- (1/2), 3- (1/3), 4- (1/4), 5- (1/5), 6- (1/6), 7- (1/7), and 8-year-old (1/8) root systems, with or without fertilization (F and NF) in a wood-grass energy plantation system.

	1987 (1/1)		1988 (1/2)		1989 (1/3)		1990 (1/4)		1991 (1/5)		1992 (1/6)	
Clone	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
						...... N%						
NM5	1,625.17	1,434.54	2,015.27	1,959.93	2,444.62	2,214.79	2,036.13	2,249.38	2,173.54	2,504.82	2,157.8	2,235.67
	(53.95)	(9251)	(54.51)	(43.22)	(64.08)	(118.75)	(42.82)	(417.52)	(157.96)	(142.85)	(25.39)	(39.63)
SAM3	1,010.09	802.87	1,222.03	974.68	1,673.66	1,497.2	1,449.63	1,447.06	1,775.34	1,563.04	1,376.57	1,269.95
	(40.94)	(70.28)	(47.74)	(77.44)	(131.19)	(35.15)	(69.07)	(134.17)	(186.61)	(71.28)	(96.49)	(48.88)
SA2	1,301.04	1,034.82	1,424.02	1,152.28	1,888.22	1,589.42	1,601.06	1,465.83	1,756.93	1,597.52	1,497.29	1,317.73
	(39.07)	(146.45)	(54.41)	(70.57)	(164.01)	(200.98)	(24.83)	(77.31)	(18.56)	(36.46)	(34.72)	(44.53)
SA22	894.35	887.68	1,173.98	1,042.22	2,136.6	1,513.73	1,234.84	1,150.27	1,455.43	1,244.82	1,389.43	1,330.82
	(26.03)	(6.98)	(58.50)	(62.10)	(193.66)	(19.28)	(127.51)	(82.74)	(74.00)	(131.62)	(46.11)	(45.83)
SH3	1,773.9	1,392.33	2,069.76	2,239.73	2,642.31	2,851.33	2,617.79	2,354.94	2,878.91	2,864.34	2,737.12	2,659.23
	(89.73)	(85.23)	(68.84)	(145.65)	(187.43)	(141.62)	(262.87)	(86.24)	(90.68)	(44.21)	(52.93)	(121.14)
SV1	2,385.31	2,115.38	2,942.5	2,326.17	2,960.52	2,380.38	2,804.3	2,602.6	2,742.14	2,744.43	2,680.29	2,315.52
	(168.67)	(192.31)	(349.14)	(83.00)	(81.71)	(225.85)	(23.13)	(148.22)	(146.49)	(192.92)	(148.39)	(175.75)

continued

Table A-15 continued.

	1993 (1/7)		1994 (1/8)	
Clone	F	NF	F	NF
		.... N%		
NM5	2,611.43 (59.38)	2,522.41 (41.69)	2,041.38 (24.06)	2,043.09 (48.19)
SAM3	1,531.17 (20.52)	1,417.1 (38.12)	N/A	N/A
SA2	1,913.25 (47.53)	1,616.38 (53.88)	1,153.52 (49.39)	1,035.06 (95.21)
SA22	1,569.09 (70.26)	1,413.8 (111.83)	N/A	N/A
SH3	2,928.55 (155.17)	2,946.43 (89.29)	2,480.72 (41.69)	2,481.68 (53.66)
SV1	2,904.84 (173.19)	2,684.27 (88.60)	2,830.69 (26.46)	2,588.94 (59.82)

[1] Clones followed by n/a were removed from the experiment during 1994.

APPENDIX B
CLONE-FERTILIZER TRIAL FOLIAGE NUTRIENT DATA FROM 1990 TO 1994.

APPENDIX B

Table B-1. Mean and standard error (in parentheses) of foliage nutrient concentrations of five *Salix* clones and one *Populus* clone sampled annually in early fall from 1990 to 1994 with or without fertilization (F or NF), in an irrigated energy plantation established in 1987 and coppiced annually.

		N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
Clone	Year	F	NF	F	NF	F	NF	F	NF	F	NF
NM5	1990	3.25	3.18	0.34	0.38	2.43	2.8	1.47	1.97	0.18	0.21
		(0.14)	(0.01)	(0.01)	(0.02)	(0.18)	(0.30)	(0.09)	(0.10)	(0.005)	(0.01)
	1991	3.2	2.97	0.29	0.24	2.07	1.65	1.17	1.7	0.18	0.2
		(0.11)	(0.08)	(0.03)	(0.04)	(0.24)	(0.05)	(0.17)	(0.26)	(0.02)	(0.01)
	1992	2.83	2.56	0.4	0.38	1.89	1.83	1.71	1.79	0.19	0.18
		(0.13)	(0.27)	(0.03)	(0.03)	(0.02)	(0.16)	(0.25)	(0.31)	(0.01)	(0.01)
	1993	3.52	2.92	0.4	0.38	1.81	1.84	0.83	1.04	0.18	0.17
		(0.11)	(0.14)	(0.01)	(0.02)	(0.05)	(0.09)	(0.03)	(0.18)	(0.004)	(0.01)
	1994	3.12	2.99	0.29	0.32	1.24	1.29	1.01	1.19	0.19	0.18
		(0.15)	(0.12)	(0.01)	(0.01)	(0.19)	(0.07)	(0.09)	(0.07)	(0.01)	(0.01)
SAM3	1990	3.68	3.21	0.34	0.3	2.64	2.58	1.4	1.56	0.33	0.27
		(0.33)	(0.06)	(0.03)	(0.02)	(0.30)	(0.18)	(0.08)	(0.07)	(0.02)	(0.02)
	1991	3.29	3.15	0.27	0.26	1.87	1.78	1.02	1.36	0.33	0.49
		(0.29)	(0.24)	(0.03)	(0.02)	(0.05)	(0.03)	(0.15)	(0.03)	(0.08)	(0.07)
	1992	3.15	3.06	0.47	0.42	2.14	2.09	1.25	1.66	0.33	0.32
		(0.18)	(0.20)	(0.04)	(0.02)	(0.11)	(0.05)	(0.08)	(0.13)	(0.02)	(0.11)
	1993	3.44	2.54	0.26	0.31	1.47	1.82	1.12	1.13	0.3	0.36
		(0.10)	(0.01)	(0.005)	(0.005)	(0.04)	(0.04)	(0.06)	(0.06)	(0.01)	(0.03)
	1994	Clone SAM3 was eliminated during 1994									

Table B.1 continued.

Clone	Year	N (%) F	N (%) NF	P (%) F	P (%) NF	K (%) F	K (%) NF	Ca (%) F	Ca (%) NF	Mg (%) F	Mg (%) NF
SA2	1990	3.62	3.41	0.28	0.33	2.34	2.37	1.51	1.66	0.21	0.28
		(0.07)	(0.06)	(0.02)	(0.02)	(0.33)	(0.03)	(0.16)	(0.13)	(0.05)	(0.01)
	1991	3.17	2.77	0.24	0.23	1.85	1.48	1.57	1.61	0.24	0.31
		(0.22)	(0.21)	(0.03)	(0.02)	(0.11)	(0.17)	(0.21)	(0.20)	(0.01)	(0.05)
	1992	3.08	2.51	0.43	0.37	2.26	1.86	1.3	1.3	0.27	0.25
		(0.22)	(0.10)	(0.03)	(0.02)	(0.05)	(0.17)	(0.10)	(0.09)	(0.01)	(0.03)
	1993	3.58	3.03	0.31	0.31	2.08	1.75	1.06	1.11	0.23	0.27
		(0.09)	(0.29)	(0.001)	(0.02)	(0.10)	(0.13)	(0.04)	(0.09)	(0.004)	(0.02)
	1994	3.44	3.17	0.25	0.27	1.38	1.3	1.2	1.25	0.3	0.33
		(0.13)	(0.22)	(0.03)	(0.02)	(0.01)	(0.01)	(0.13)	(0.1)	(0.02)	(0.02)
SA22	1990	3.49	3.4	0.33	0.35	2.23	2.64	1.45	1.52	0.14	0.22
		(0.05)	(0.12)	(0.01)	(0.01)	(0.09)	(0.09)	(0.05)	(0.15)	(0.03)	(0.01)
	1991	3.84	3.08	0.31	0.29	2.12	1.84	0.94	1.17	0.17	0.19
		(0.07)	(0.09)	(0.003)	(0.02)	(0.04)	(0.25)	(0.02)	(0.09)	(0.005	(0.004
	1992	3.16	2.87	0.46	0.45	2.12	2.18	1.51	1.8	0.21	0.22
		(0.16)	(0.10)	(0.05)	(0.03)	(0.07)	(0.14)	(0.22)	(0.33)	(0.01)	(0.03)
	1993	3.15	2.62	0.29	0.28	1.72	1.62	1.26	1.53	0.18	0.25
		(0.16)	(0.14)	(0.01)	(0.02)	(0.03)	(0.08)	(0.004)	(0.05)	(0.003)	(0.004)
	1994	Clone SA22 was eliminated during 1994									
SH3	1990	3.16	3.24	0.34	0.34	1.5	1.68	1.9	1.88	0.1	0.12
		(0.06)	(0.14)	(0.01)	(0.01)	(0.01)	(0.15)	(0.06)	(0.10)	(0.01)	(0.01)
	1991	3.2	2.7	0.25	0.24	1.03	1.04	1.33	2.13	0.11	0.1
		(0.21)	(0.15)	(0.02)	(0.02)	(0.04)	(0.16)	(0.25)	(0.15)	(0.01)	(0.01)
	1992	2.62	2.26	0.47	0.42	1.42	1.27	1.88	2.15	0.14	0.13
		(0.13)	(0.37)	(0.04)	(0.05)	(0.34)	(0.13)	(0.08)	(0.20)	(0.01)	(0.01)
	1993	3.36	2.75	0.27	0.28	1.18	1.05	1.39	1.66	0.12	0.13
		(0.06)	(0.11)	(0.01)	(0.02)	(0.05)	(0.15)	(0.02)	(0.07)	(0.002)	(0.005)
	1994	3.14	2.77	0.24	0.23	0.73	0.62	1.4	1.61	0.11	0.13
		(0.07)	(0.04)	(0.01)	(0.02)	(0.09)	(0.05)	(0.15)	(0.14)	(0.008)	(0.02)

Table B.1 continued.

		N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
Clone	Year	F	NF	F	NF	F	NF	F	NF	F	NF
SV1	1990	3.46	3.22	0.36	0.37	1.8	2.07	1.79	2.22	0.21	0.22
		(0.05)	(0.07)	(0.02)	(0.01)	(0.10)	(0.22)	(0.12)	(0.17)	(0.02)	(0.03)
	1991	3.45	3.08	0.3	0.34	1.96	1.64	0.96	1.45	0.18	0.19
		(0.16)	(0.05)	(0.02)	(0.03)	(0.07)	(0.04)	(0.08)	(0.18)	(0.03)	(0.01)
	1992	3.52	2.97	0.63	0.65	1.88	1.94	1.27	1.61	0.19	0.19
		(0.10)	(0.14)	(0.06)	(0.06)	(0.03)	(0.10)	(0.03)	(0.22)	(0.01)	(0.01)
	1993	3.99	3.44	0.37	0.43	1.92	1.93	0.92	1.26	0.17	0.23
		(0.03)	(0.06)	(0.003)	(0.02)	(0.04)	(0.05)	(0.09)	(0.06)	(0.02)	(0.01)
	1994	3.7	3.43	0.34	0.34	1.27	1.24	0.86	1.11	0.19	0.22
		(0.09)	(0.07)	(0.02)	(0.02)	(0.06)	(0.05)	(0.09)	(0.03)	(0.01)	(0.01)

APPENDIX C
SPACING/CUTTING CYCLE STUDY STEM NUTRIENT DATA FROM 1990 to 1994.

Table C-1. Mean and standard error (in parentheses) of stem nutrient concentrations of two *Salix* clones sampled in late fall 1991-1994, harvested on one, two, and three year cycles at three spacings (1x1, 1x3, or 2x3.5 ft). The experiment was established and coppiced in 1990 and fertilized and irrigated from 1991 to 1994.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
1	SA22	1x1	1991	1	0.13	0.48	0.55	0.07
				(0.03)	(0.004)	(0.04)	(0.008)	(0.005)
			1992	0.95	0.16	0.78	0.55	0.08
				(0.14)	(0.008)	(0.03)	(0.04)	(0.004)
			1993	0.84	0.1	0.57	0.49	0.08
				(0.03)	(0.005)	(0.05)	(0.02)	(0.001)
			1994	Clone SA22 eliminated from experiment in 1994.				
1	SA22	1x3	1991	0.096	0.12	0.42	0.58	0.08
				(0.02)	(0.001)	(0.02)	(0.006)	(0.004)
			1992	0.91	0.15	0.58	0.46	0.08
				(0.16)	(0.005)	(0.03)	(0.003)	(0.008)
			1993	0.89	0.09	0.15	0.45	0.07
				(0.07)	(0.03)	(0.03)	(0.008)	(0.003)
			1994	Clone SA22 eliminated from experiment in 1994.				
1	SA22	2x3.5	1991	1	0.12	0.46	0.62	0.07
				(0.04)	(0.006)	(0.04)	(0.05)	(0.008)
			1992	1.13	0.16	0.66	0.58	0.08
				(0.004)	(0.002)	(0.03)	(0.08)	(0.003)
			1993	0.89	0.1	0.48	0.49	0.08
				(0.03)	(0.004)	(0.005)	(0.002)	(0.006)
			1994	Clone SA22 eliminated from experiment in 1994.				

Table C-1 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
1	SV1	1x1	1991	0.57	0.08	0.2	0.32	0.04
				(0.003)	(0.003)	(0.02)	(0.02)	(0.005)
			1992	0.75	0.11	0.3	0.35	0.04
				(0.02)	(0.006)	(0.02)	(0.02)	(0.001)
			1993	0.66	0.08	0.24	0.37	0.04
				(0.02)	(0.002)	(0.01)	(0.02)	(0.002
			1994	0.63	0.09	0.19	0.4	0.04
				(0.02)	(0.003)	(0.01)	(0.01)	(0.002)
1	SV1	1x3	1991	0.53	0.07	0.22	0.33	0.04
				(0.02)	(0.002)	(0.02)	(0.02)	(0.005)
			1992	0.7	0.1	0.24	0.39	0.04
				(0.02)	(0.002)	(0.01)	(0.02)	(0.001)
			1993	0.6	0.07	0.2	0.38	0.03
				(0.02)	(0.002)	(0.01)	(0.01)	(0.001)
			1994	0.67	0.06	0.19	0.39	0.04
				(0.04)	(0.01)	(0.01)	(0.02)	(0.002)
1	SV1	2x3.5	1991	0.52	0.07	0.2	0.37	0.04
				(0.003)	(0.001)	(0.02)	(0.02)	(0.003)
			1992	0.65	0.11	0.2	0.39	0.03
				(0.03)	(0.006)	(0.01)	(0.03)	(0.002)
			1993	0.62	0.07	0.19	0.4	0.03
				(0.03)	(0.006)	(0.008)	(0.01)	(0.001)
			1994	0.69	0.09	0.23	0.46	0.04
				(0.02)	(0.002)	(0.01)	(0.02)	(0.001)
2	SA22	1x1	1991	N/A	N/A	N/A	N/A	N/A
			1992	0.88	0.14	0.56	0.6	0.07
				(0.03)	(0.009)	(0.04)	(0.10)	(0.001)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	Clone SA22 eliminated from experiment in 1994.				

Table C-1 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
2	SA22	1x3	1991	N/A	N/A	N/A	N/A	N/A
			1992	0.79	0.11	0.58	0.45	0.07
				(0.009)	(0.008)	(0.02)	(0.01)	(0.002)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	Clone SA22 eliminated from experiment in 1994.				
2	SA22	2x3.5	1991	N/A	N/A	N/A	N/A	N/A
			1992	0.86	0.13	0.53	0.59	0.07
				(0.02)	(0.01)	(0.002)	(0.06)	(0.005
			1993	N/A	N/A	N/A	N/A	N/A
			1994	Clone SA22 eliminated from experiment in 1994.				
2	SV1	1x1	1991	N/A	N/A	N/A	N/A	N/A
			1992	0.48	0.07	0.18	0.31	0.03
				(0.03)	(0.004)	(0.01)	(0.02)	(0.003)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	0.51	0.07	0.18	0.34	0.03
				(0.04)	(0.003)	(0.01)	(0.01)	(0.001)
2	SV1	1x3	1991	N/A	N/A	N/A	N/A	N/A
			1992	0.45	0.07	0.17	0.29	0.03
				(0.01)	(0.0002)	(0.008)	(0.009)	(0.001)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	0.53	0.06	0.17	0.35	0.03
				(0.05)	(0.005)	(0.01)	(0.03)	(0.003)
2	SV1	2x3.5	1991	N/A	N/A	N/A	N/A	N/A
			1992	0.45	0.07	0.17	0.33	0.03
				(0.05)	(0.005)	(0.006)	(0.03)	(0.001)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	0.52	0.07	0.15	0.33	0.03
				(0.07)	(0.01)	(0.02)	(0.04)	(0.003)
3	SA22	1x1	1993	0.59	0.07	0.32	0.58	0.06
				(0.038)	(0.007)	(0.031)	(0.033)	(0.003)

Table C-1 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
3	SA22	1x3	1993	0.55	0.07	0.29	0.55	0.05
				(0.019)	(0.002)	(0.01)	(0.01)	(0.001)
3	SA22	2x3.5	1993	0.55	0.08	0.29	0.55	0.05
				(0.016)	(0.004)	(0.024)	(0.043)	(0.006)
3	SV1	1x1	1993	0.37	0.06	0.15	0.36	0.02
				(0.02)	(0.011)	(0.009)	(0.016)	(0.001)
3	SV1	1x3	1993	0.38	0.05	0.16	0.37	0.02
				(0.016)	(0.001)	(0.002)	(0.014)	(0.001)
3	SV1	2x3.5	1993	0.039	0.04	0.14	0.37	0.02
				(0.018)	(0.001)	(0.003)	(0.025)	(0.001)

Table C-2. Mean and standard error (in parentheses) of stem nutrient contents of two *Salix* clones sampled in late fall 1991-1994, harvested on one and two year cycles at three spacings (1x1, 1x3, or 2x3.5 ft). The experiment was established and coppiced in 1990, and fertilized and irrigated in 1991 to 1994.

Cutting Cycle	Clone	Spacing (ft)	Year	N	P	K	Ca	Mg
				----------(kg/ha)----------				
1	SA22	1x1	1991	119.2	15.2	57.9	0.55	0.07
				(12.47	(1.69)	(9.65)	(4.97)	(1.40)
			1992	59.23	9.73	48.55	33.42	5.05
				(13.19)	(1.44)	(6.58)	(2.97)	(0.64)
			1993	58.22	6.81	39.06	33.7	5.15
				(6.55)	(0.73)	(1.42)	(1.41)	(0.36)
			1994	Clone SA22 was eliminated from the experiment in 1994.				
1	SA22	1x3	1991	60.8	7.94	26.58	36.9	4.98
				(15.87	(2.20)	(7.67)	(9.71)	(1.37)
			1992	51.33	8.64	33.89	27.22	4.69
				(7.67)	(1.57)	(4.64)	(4.46)	(0.53)
			1993	51.52	4.94	8.46	26.77	4.21
				(7.44)	(1.17)	(0.46)	(5.07)	(0.60)
			1994	Clone SA22 was eliminated from the experiment in 1994.				
1	SA22	2x3.5	1991	21.14	2.6	10.22	12.59	1.46
				(8.66)	(1.08)	(4.65)	(4.93)	(0.60)
			1992	37.92	5.26	22.16	21.59	2.72
				(14.81)	(2.05)	(8.81)	(10.00)	(1.03)
			1993	35.11	3.9	18.78	19.23	3.17
				(7.52)	(0.83)	(4.43)	(4.67)	(0.58)
			1994	Clone SA22 was eliminated from the experiment in 1994.				
1	SV1	1x1	1991	108.75	15.27	39.87	61.44	6.91
				(12.72)	(2.24)	(7.90)	(8.24)	(1.62)
			1992	82.53	12.46	32	40.86	4.36
				(1.17)	(0.79)	(1.48)	(2.63)	(0.14)
			1993	67.03	8.11	24.19	37.47	3.58
				(4.56)	(0.50)	(2.11)	(3.21)	(0.25)
			1994	72.42	10.08	21.61	45.39	4.38
				(2.85)	(0.42)	(0.85)	(2.44)	(0.15)

continued

Table C-2 continued

Cutting Cycle	Clone	Spacing (ft)	Year	N	P	K	Ca	Mg
						(kg/ha)		
1	SV1	1x3	1991	100.32	13.58	41.17	63.68	7.28
				(2.59)	(0.23)	(4.81)	(5.83)	(0.93)
			1992	78.58	11.13	26.54	44.14	3.96
				(2.50)	(0.49)	(1.97)	(1.45)	(1.13)
			1993	68.97	8.07	22.6	43.33	3.65
				(6.74)	(0.74)	(0.49)	(0.68)	(0.32)
			1994	84.47	8.15	23.68	48.24	4.45
				(9.08)	(2.11)	(2.38)	(5.04)	(0.42)
1	SV1	2x3.5	1991	78.67	10.99	29.02	55.82	5.34
				(6.57)	(0.71)	(0.39)	(2.86)	(0.63)
			1992	66.29	11.04	19.9	39.71	3.52
				(4.14)	(0.23)	(1.06)	(4.22)	(0.35)
			1993	64.17	7.3	19.36	40.78	3.35
				(14.85)	(1.89)	(3.89)	(8.61)	(0.73)
			1994	60.61	7.54	19.95	38.44	3.53
				(20.18)	(2.56)	(6.46)	(11)	(1.08)
2	SA22	1x1	1991	N/A	N/A	N/A	N/A	N/A
			1992	48.24	7.47	31.19	32.83	4.11
				(3.37)	(0.25)	(4.75)	(5.84)	(0.38)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	Clone SA22 was eliminated from the experiment in 1994.				
2	SA22	1x3	1991	N/A	N/A	N/A	N/A	N/A
			1992	56.84	7.98	42.25	32.38	5.08
				(8.62)	(1.21)	(6.97)	(5.54)	(0.78)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	Clone SA22 was eliminated from the experiment in 1994.				
2	SA22	2x3.5	1991	N/A	N/A	N/A	N/A	N/A
			1992	31.59	4.27	17.63	20.31	2.25
				(6.53)	(1.26)	(6.33)	(9.14)	(0.66)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	Clone SA22 was eliminated from the experiment in 1994.				

continued

Table C-2 continued

Cutting Cycle	Clone	Spacing (ft)	Year	N	P	K	Ca	Mg
				----------(kg/ha)----------				
2	SV1	1x1	1991	N/A	N/A	N/A	N/A	N/A
			1992	132.61	19.55	48.83	87.24	8.46
				(14.56)	(1.63)	(4.46)	(9.72)	(1.15)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	162.3	21.75	55.44	108.23	10.05
				(21.26)	(2.07)	(1.51)	(7.94)	(0.68)
2	SV1	1x3	1991	N/A	N/A	N/A	N/A	N/A
			1992	154.86	24.04	58.97	101.13	9.53
				(7.46)	(1.06)	(4.77)	(3.17)	(0.51)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	177.23	21.95	56.7	117.43	10.35
				(19.81)	(2.95)	(7.92)	(14.57)	(1.28)
2	SV1	2x3.5	1991	N/A	N/A	N/A	N/A	N/A
			1992	134.68	20.39	51.03	100.29	8.12
				(9.92)	(0.80)	(2.74)	(8.33)	(0.06)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	165.1	21.2	48.91	107.29	10.39
				(11.44)	(1.8)	(3.83)	(15.46)	(1.19)
3	SA22	1x1	1993	98.11	11.31	54.06	99.76	9.69
				(30.21)	(2.90)	(16.76)	(34.72)	(3.47)
3	SA22	1x3	1993	113.47	15.09	59.24	112.43	10.5
				(31.36)	(4.40)	(15.72)	(30.97)	(2.87)
3	SA22	2x3.5	1993	44.65	6.22	21.69	41.49	3.98
				(29.82)	(3.87)	(13.05)	(25.11)	(2.32)
3	SV1	1x1	1993	204.92	33.24	80.39	196.72	13.14
				(37.93)	(11.31)	(8.06)	(32.65)	(2.45)
3	SV1	1x3	1993	280.82	32.47	111.47	270.9	17.99
				(10.42)	(1.43)	(5.49)	(15.97)	(0.61)

continued

Table C-2 continued

Cutting Cycle	Clone	Spacing (ft)	Year	N	P	K	Ca	Mg
				----------(kg/ha)----------				
3	SV1	2x3.5	1993	261.64	29.22	96.17	245.62	16.51
				(29.64)	(1.90)	(7.49)	(12.81)	(1.15)

Table C-3. Mean and standard error (in parentheses) of stem biomass to nutrient content ratio of one *Salix* clones sampled in late fall 1991-1994, harvested on one, two, and three year cycles at three spacings (1x1, 1x3, or 2x3.5 ft). The experiment was established and coppiced in 1990, and fertilized and irrigated from 1991 to 1994.

Cutting Cycle	Clone	Spacing (ft)	Year	N (KG/KG)	P (KG/KG)	K (KG/KG)	Ca (KG/KG)	Mg (KG/KG)
1	SV1	1x1	1991	176.48	1,268.74	500.96	315.48	3,011.54
				(1.044)	(38.20)	(48.81)	(24.10)	(500.52)
			1992	135.92	905.31	352.72	276.12	2,577.85
				(2.65)	(39.77)	(23.94)	(13.01)	(53.78)
			1993	152.93	1,262.72	425.84	274.98	2,867.69
				(5.69)	(37.64)	(24.15)	(17.05)	(120.82)
			1994	64.23	1,138.39	531.12	253.07	2,619.05
				(1.067)	(33.71)	(23.64)	(8.35)	(119.05)
1	SV1	1x3	1991	190.44	1,404.93	474.3	303.49	2,735.62
				(7.42)	(40.87)	(46.98)	(21.79)	(451.12)
			1992	143.26	1,011.89	426.65	255.56	2,845.51
				(3.16)	(18.79)	(20.07)	(12.81)	(49.34)
			1993	166.2	1,417.73	503.33	263.03	3,131.31
				(6.06)	(42.64)	(24.69)	(6.51)	(101.01)
			1994	76.08	1,621.42	530.3	260.44	2,821.94
				(10.42)	(339.37)	(25.25)	(13.53)	(119.24)
1	SV1	2x3.5	1991	191.1	1,364.15	518.49	268.99	2,867.12
				(1.21)	(28.21)	(45.45)	(14.45)	(265.74)
			1992	154.46	924.71	514.26	260.31	2,931.47
				(7.77)	(50.12)	(29.63)	(17.67)	(193.06)
			1993	161.6	1,440.16	525.26	251.61	3,065.76
				(7.25)	(110.54)	(21.57)	(6.70)	(84.06)
			1994	59.11	1,169.03	443.96	220.85	2,441.86
				(4.33)	(31.51)	(18.06)	(10.68)	(58.14)

Table C-3 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (KG/KG)	P (KG/KG)	K (KG/KG)	Ca (KG/KG)	Mg (KG/KG)
2	SV1	1x1	1991	N/A	N/A	N/A	N/A	N/A
			1992	211.04	1,422.31	572.02	321.65	3,353.09
				(11.98)	(75.24)	(42.69)	(23.28)	(318.06)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	70.77	1,453.01	566.39	290.98	3,127.04
				(2.69)	(51.25)	(30.82)	(9.002)	(56.45)
2	SV1	1x3	1991	N/A	N/A	N/A	N/A	N/A
			1992	224.46	1,444.56	593.31	343.37	3,648.11
				(5.69)	(4.45)	(29.76)	(10.47)	(167.31)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	78.61	1,562.8	605.84	292.17	3,309.92
				(7.66)	(110.49)	(41.4)	(26.29)	(276.10)
2	SV1	2x3.5	1991	N/A	N/A	N/A	N/A	N/A
			1992	229.28	1,496.92	596.43	306.83	3,742.58
				(26.21)	(111.51)	(19.95)	(28.66)	(188.72)
			1993	N/A	N/A	N/A	N/A	N/A
			1994	84.82	1,549.54	674.38	310.98	3,161.44
				(11.71)	(157.86)	(87.40)	(38.57)	(231.75)
3	SV1	1x1	1993	272.46	1,883.27	675.85	281.17	4,258.24
				(15.47)	(345.42)	(47.19)	(12.05)	(268.29)
3	SV1	1x3	1993	253.52	2,191.43	638.41	263.14	3,952.99
				(10.08)	(42.78)	(5.94)	(7.64)	(106.84)
3	SV1	2x3.5	1993	258.86	2,295.22	698.19	273.54	4,064.66
				(11.88)	(77.35)	(13.5)	(18.68)	(148.38)

APPENDIX D
SPACING/CUTTING CYCLE STUDY FOLIAGE NUTRIENT DATA FROM 1990 TO 1994.

APPENDIX D

Table D-1. Mean and standard error (in parentheses) of foliage nutrient concentrations of two Salix clones sampled in early fall 1991-1994 harvested on one-, two-, or three-year cycles at three spacings (1x1, 1x3, or 2x3.5 ft). The experiment was established and coppiced in 1990 and fertilized and irrigated in 1991-1994.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
1	SA22	1x1	1991	3.1	0.23	2.04	1.18	0.22
				(0.07)	(0.005)	(0.10)	(0.15)	(0.04)
			1992	3.11	0.42	1.41	1.27	0.17
				(0.07)	(0.02)	(0.23)	(0.07)	(0.004)
			1993	3.29	0.26	1.89	1.05	0.25
				(0.11)	(0.01)	(0.13)	(0.05)	(0.007)
			1994	Clone SA22 was eliminated in 1994				
1	SA22	1x3	1991	3.51	0.25	1.98	1.26	0.22
				(0.09)	(0.002)	(0.13)	(0.02)	(0.01)
			1992	3.25	0.42	1.98	1.21	0.19
				(0.09)	(0.03)	(0.005)	(0.10)	(0.0008)
			1993	3.28	0.24	1.66	1.06	0.26
				(0.08)	(0.01)	(0.09)	(0.14)	(0.006)
			1994	Clone SA22 was eliminated in 1994				
1	SA22	2x3.5	1991	3.74	0.27	2.07	1.13	0.23
				(0.04)	(0.01)	(0.05)	(0.07)	(0.01)
			1992	3.32	0.48	1.81	1.1	0.24
				(0.03)	(0.01)	(0.13)	(0.08)	(0.02)
			1993	3.22	0.24	1.47	1.05	0.27
				(0.09)	(0.01)	(0.11)	(0.05)	(0.004)
			1994	Clone SA22 was eliminated in 1994				

continued

Table D-1 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
1	SV1	1x1	1991	3.55	0.27	2.25	1.09	0.16
				(0.15)	(0.01)	(0.10)	(0.07)	(0.01)
			1992	3.17	0.51	1.93	1.02	0.15
				(0.17)	(0.01)	(0.04)	(0.03)	(0.009)
			1993	3.38	0.25	1.45	1.15	0.23
				(0.14)	(0.01)	(0.15)	(0.07)	(0.006)
			1994	3.33	0.29	1.49	1.07	0.18
				(0.07)	(0.02)	(0.07)	(0.1)	(0.01)
1	SV1	1x3	1991	3.39	0.26	2.08	1.15	0.17
				(0.11)	(0.02)	(0.20)	(0.05)	(0.01)
			1992	3.33	0.44	1.97	1.12	0.15
				(0.03)	(0.02)	(0.08)	(0.08)	(0.01)
			1993	3.46	0.24	1.4	1.09	0.23
				(0.03)	(0.01)	(0.12)	(0.06)	(0.01)
			1994	3.56	0.29	1.54	0.99	0.2
				(0.06)	(0.03)	(0.05)	(0.15)	(0.004)
1	SV1	2x3.5	1991	3.81	0.27	2.06	1.06	0.18
				(0.09)	(0.01)	(0.12)	(0.04)	(0.02)
			1992	3.47	0.49	1.81	1.2	0.14
				(0.03)	(0.01)	(0.14)	(0.12)	(0.01)
			1993	3.57	0.23	1.14	1.28	0.25
				(0.11)	(0.01)	(0.14)	(0.07)	(0.003)
			1994	3.47	0.29	1.41	1.11	0.21
				(0.13)	(0.01)	(0.05)	(0.14)	(0.01)

continued

Table D-1 continued

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
2	SA22	1x1	1991	3.87	0.35	2.31	1.04	0.25
				(0.22)	(0.02)	(0.05)	(0.04)	(0.01)
			1992	3.41	0.47	1.97	1.5	0.19
				(0.02)	(0.03)	(0.13)	(0.04)	(0.003)
			1993	3.78	0.32	1.82	1.1	0.26
				(0.12)	(0.02)	(0.16)	(0.08)	(0.009)
			1994	Clone SA22 was eliminated in 1994				
2	SA22	1x3	1991	4.29	0.35	2.19	0.89	0.24
				(0.09)	(0.01)	(0.13)	(0.05)	(0.01)
			1992	3.47	0.53	2.17	1.28	0.2
				(0.11)	(0.02)	(0.03)	(0.06)	(0.008)
			1993	3.64	0.3	1.8	1.03	0.25
				(0.07)	(0.02)	(0.17)	(0.07)	(0.003)
			1994	Clone SA22 was eliminated in 1994				
2	SA22	2x3.5	1991	4.13	0.34	2.02	0.88	0.23
				(0.02)	(0.008)	(0.03)	(0.05)	(0.01)
			1992	3.49	0.49	1.94	1.18	0.19
				(0.03)	(0.02)	(0.15)	(0.06)	(0.005)
			1993	3.47	0.29	1.51	1.05	0.27
				(0.08)	(0.02)	(0.02)	(0.04)	(0.007)
			1994	Clone SA22 was eliminated in 1994				

continued

Table D-1 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
2	SV1	1x1	1991	3.89	0.3	2.02	0.96	0.18
				(0.16)	(0.02)	(0.12)	(0.03)	(0.01)
			1992	3.27	0.4	1.92	1.23	0.14
				(0.06)	(0.03)	(0.13)	(0.19)	(0.01)
			1993	3.76	0.29	1.58	1.09	0.23
				(0.18)	(0.03)	(0.15)	(0.04)	(0.008)
			1994	3.41	0.26	1.52	1.32	0.22
				(0.12)	(0.01)	(0.04)	(0.13)	(0.01)
2	SV1	1x3	1991	3.88	0.29	1.96	1.04	0.23
				(0.08)	(0.01)	(0.03)	(0.13)	(0.02)
			1992	3.18	0.39	1.69	1.1	0.13
				(0.07)	(0.01)	(0.07)	(0.12)	(0.007)
			1993	3.63	0.29	1.61	1.06	0.23
				(0.16)	(0.01)	(0.03)	(0.03)	(0.002)
			1994	3.87	0.29	1.37	0.91	0.21
				(0.46)	(0.005)	(0.05)	(0.03)	(0.004)
2	SV1	2x3.5	1991	3.92	0.28	2.1	0.83	0.18
				(0.11)	(0.03)	(0.07)	(0.02)	(0.01)
			1992	3.16	0.41	1.74	1.21	0.13
				(0.03)	(0.02)	(0.06)	(0.11)	(0.007)
			1993	3.6	0.29	1.58	1.1	0.23
				(0.10)	(0.02)	(0.03)	(0.05)	(0.001)
			1994	3.42	0.3	1.53	0.93	0.23
				(0.12)	(0.01)	(0.07)	(0.03)	(0.01)

continued

Table D-1 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
3	SA22	1x1	1991	3.37	0.27	1.95	1.5	0.24
				(0.35)	(0.03)	(0.06)	(0.27)	(0.03)
			1992	3.15	0.44	2.03	1.3	0.16
				(0.02)	(0.02)	(0.09)	(0.02)	(0.003)
			1993	3.68	0.3	1.83	1.39	0.23
				(0.15)	(0.02)	(0.09)	(0.08)	(0.003)
			1994	Clone SA22 was eliminated in 1994				
3	SA22	1x3	1991	3.86	0.29	2.04	1.15	0.2
				(0.19)	(0.01)	(0.09)	(0.28)	(0.005)
			1992	3.41	0.48	1.94	1.17	0.16
				(0.14)	(0.004)	(0.16)	(0.04)	(0.006)
			1993	3.37	0.29	1.77	1.64	0.25
				(0.20)	(0.03)	(0.13)	(0.09)	(0.02)
			1994	Clone SA22 was eliminated in 1994				
3	SA22	2x3.5	1991	4.1	0.31	1.97	0.92	0.18
				(0.06)	(0.02)	(0.06)	(0.04)	(0.02)
			1992	3.4	0.56	1.99	1.38	0.17
				(0.22)	(0.01)	(0.02)	(0.11)	(0.01)
			1993	4.41	0.43	2.12	1.31	0.26
				(0.09)	(0.05)	(0.05)	(0.20)	(0.02)
			1994	Clone SA22 was eliminated in 1994				

continued

Table D.1 continued.

Cutting Cycle	Clone	Spacing (ft)	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
3	SV1	1x1	1991	3.6	0.27	2.1	0.95	0.14
				(0.18)	(0.01)	(0.18)	(0.04)	(0.01)
			1992	3.16	0.41	1.7	1.36	0.14
				(0.03)	(0.008)	(0.10)	(0.07)	(0.005)
			1993	3.28	0.26	1.4	1.42	0.23
				(0.06)	(0.01)	(0.05)	(0.11)	(0.007)
			1994	3.61	0.31	1.4	1.05	0.2
				(0.05)	(0.02)	(0.05)	(0.14)	(0.01)
3	SV1	1x3	1991	3.65	0.25	2.12	1.2	0.18
				(0.03)	(0.01)	(0.08)	(0.15)	(0.03)
			1992	3.14	0.41	1.43	1.21	0.14
				(0.07)	(0.03)	(0.12)	(0.05)	(0.007)
			1993	3.38	0.27	1.25	1.2	0.21
				(0.10)	(0.01)	(0.18)	(0.10)	(0.02)
			1994	3.42	0.31	1.36	1.15	0.2
				(0.12)	(0.02)	(0.08)	(0.14)	(0.008)
3	SV1	2x3.5	1991	3.54	0.27	2.01	1.23	0.18
				(0.04)	(0.02)	(0.07)	(0.24)	(0.02)
			1992	3.26	0.42	1.52	1.2	0.15
				(0.11)	(0.03)	(0.14)	(0.08)	(0.02)
			1993	3.31	0.27	1.46	1.33	0.23
				(0.04)	(0.004)	(0.08)	(0.04)	(0.007)
			1994	3.55	0.3	1.49	1.06	0.21
				(0.07)	(0.02)	(0.06)	(0.14)	(0.01)

APPENDIX E
IRRIGATION STUDY FOLIAGE NUTRIENT DATA FROM 1991 TO 1994.

APPENDIX E

Table E-1. Mean and standard error (in parentheses) of foliage nutrient concentrations of two *Salix* clones sampled in early fall 1991-1994 with or without irrigation (IR or NI), in a fertilized energy plantation established in 1990 and coppiced after the 1990 growing season.

Clone	Irrigation Treatment	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
SV1	NI	1991	3.46	0.29	0.86	1.43	0.25
			(0.20)	(0.03)	(0.13)	(0.26)	(0.03)
		1992	3.24	0.43	1.85	1.37	0.21
			(0.04)	(0.003)	(0.06)	(0.08)	(0.005)
		1993	2.91	0.21	0.99	1.43	0.23
			(0.06)	(0.004)	(0.16)	(0.13)	(0.01)
		1994	3.51	0.28	1.07	1.44	0.26
			(0.07)	(0.02)	(0.09)	(0.14)	(0.02)
SV1	IR	1991	3.52	0.25	1.46	0.98	0.17
			(0.05)	(0.005)	(0.15)	(0.10)	(0.02)
		1992	3.1	0.37	1.56	1.63	0.16
			(0.04)	(0.02)	(0.11)	(0.12)	(0.007)
		1993	3.35	0.28	1.49	1.35	0.24
			(0.15)	(0.01)	(0.10)	(0.12)	(0.004)
		1994	3.44	0.31	1.31	0.98	0.2
			(0.06)	(0.02)	(0.03)	(0.02)	(0.01)

continued

Table E.1 continued.

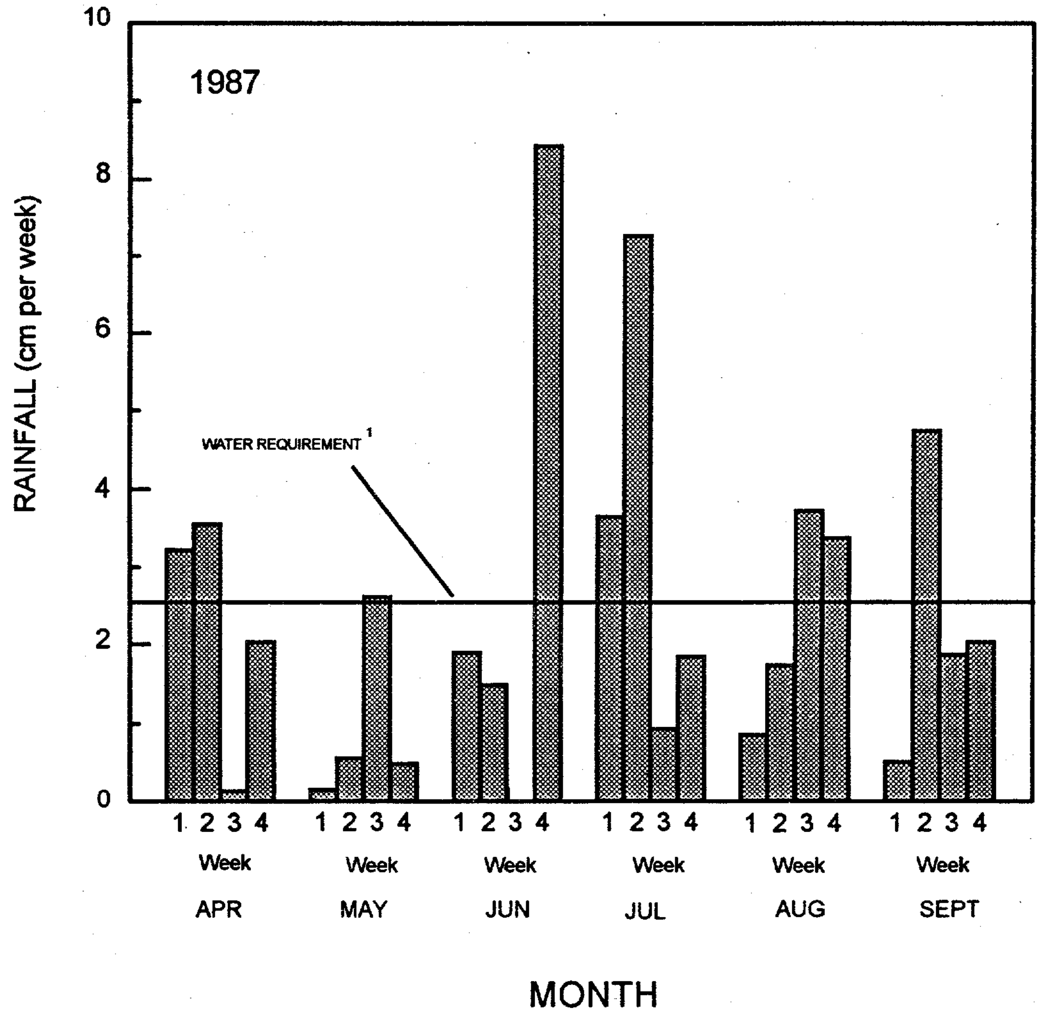
Clone	Irrigation Treatment	Year	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
SA22	NI	1991	3.37	0.25	0.81	1.23	0.31
			(0.17)	(0.03)	(0.20)	(0.18)	(0.07)
		1992	3.46	0.47	1.72	1.36	0.25
			(0.07)	(0.04)	(0.09)	(0.02)	(0.01)
		1993	3.24	0.23	1.25	1.46	0.28
			(0.15)	(0.02)	(0.14)	(0.03)	(0.004)
		1994	3.7	0.24	0.91	1.46	0.33
			(0.46)	(0.005)	(0.03)	(0.04)	(0.01)
SA22	IR	1991	3.55	0.28	1.65	1.2	0.2
			(0.27)	(0.03)	(0.14)	(0.10)	(0.005)
		1992	2.98	0.44	1.89	1.67	0.19
			(0.02)	(0.01)	(0.04)	(0.12)	(0.009)
		1993	3.73	0.31	1.55	1.51	0.25
			(0.12)	(0.02)	(0.24)	(0.01)	(0.01)
		1994	3.2	0.25	1.15	1.29	0.22
			(0.12)	(0.01)	(0.04)	(0.06)	(0.003)

APPENDIX F

WEEKLY GROWING SEASON PRECIPITATION AT SUNY GENETICS FIELD STATION, TULLY, NY FROM 1987 TO 1995.

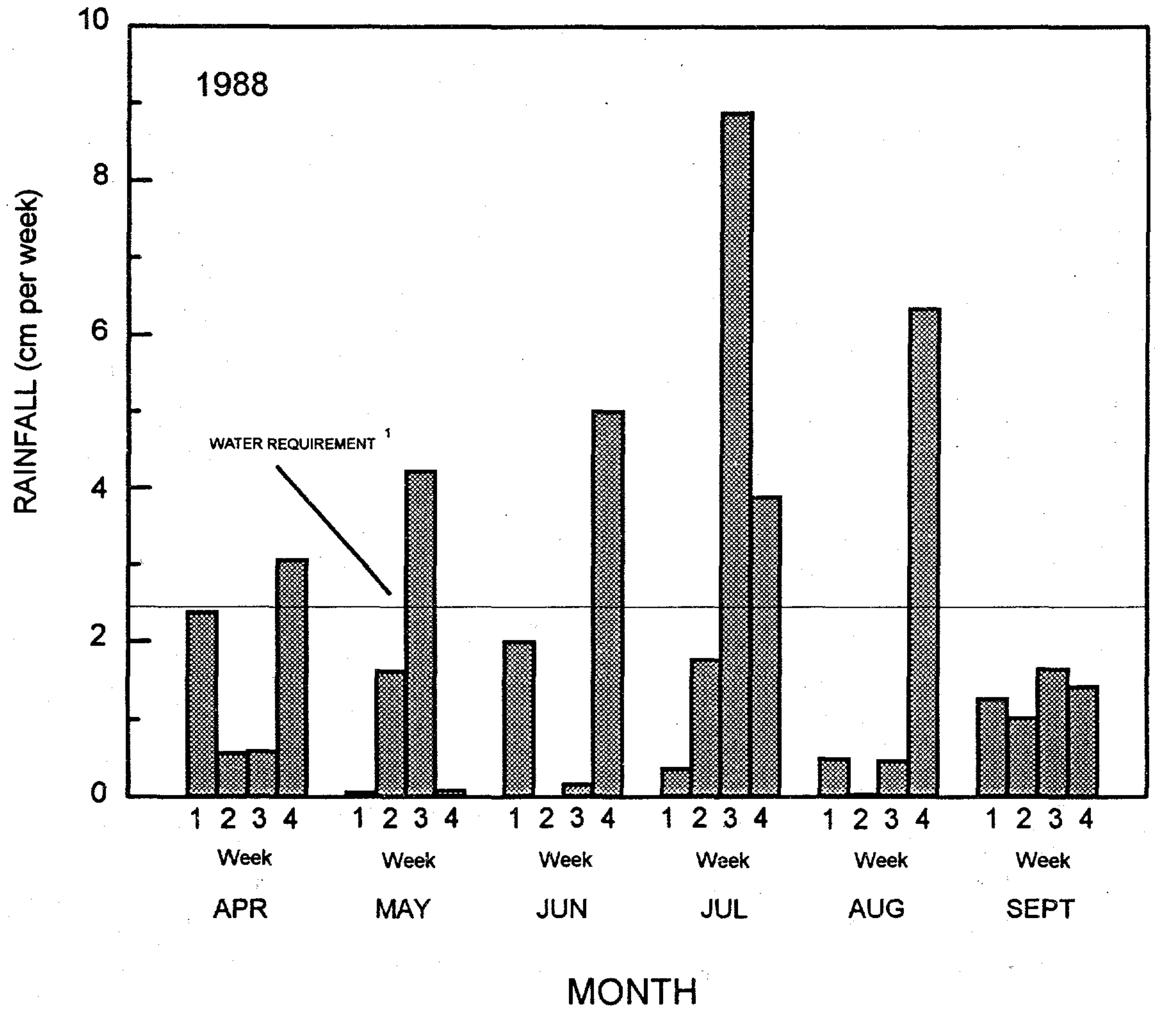
APPENDIX F

Figure F-1. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1987.



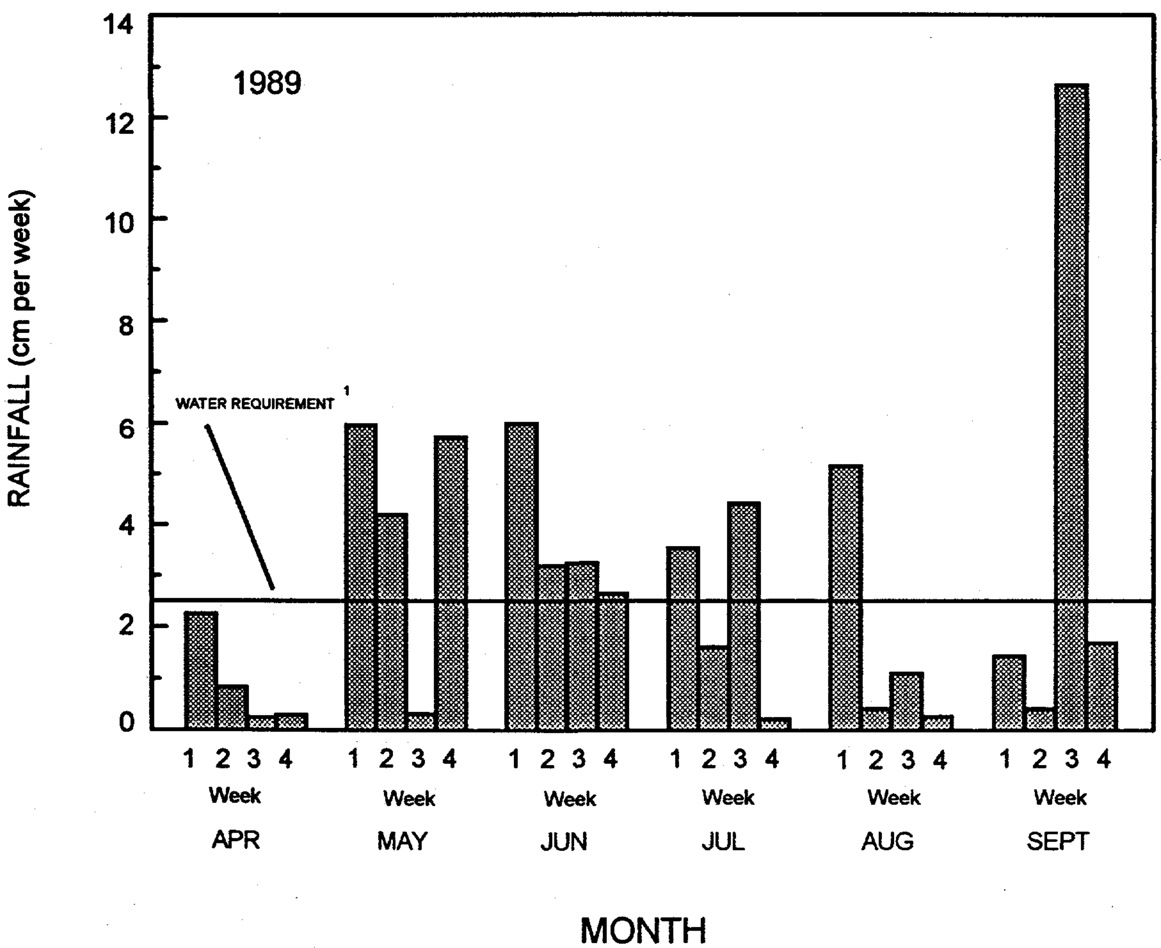
[1] Minimum weekly precipitation necessary to maintain maximum growth.

Figure F-2. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1988.



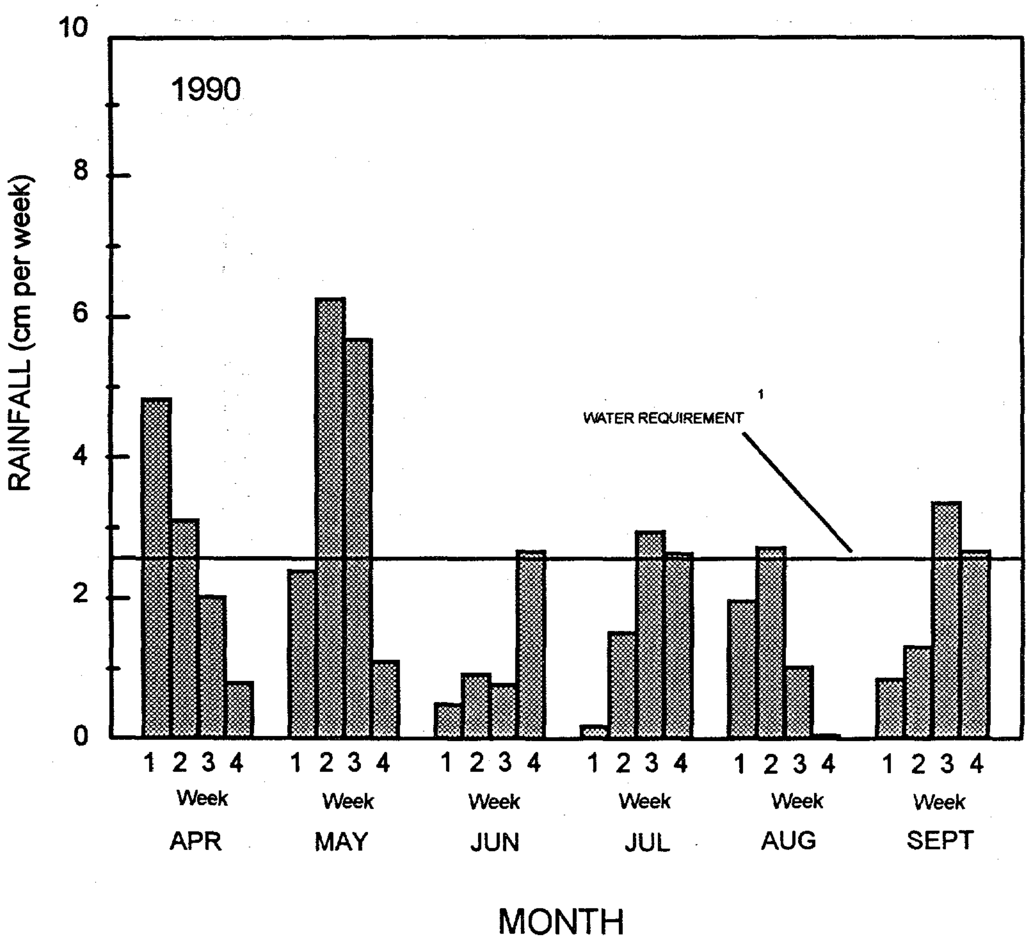
1 Minimum weekly precipitation necessary to maintain maximum growth.

Figure F-3. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1989.



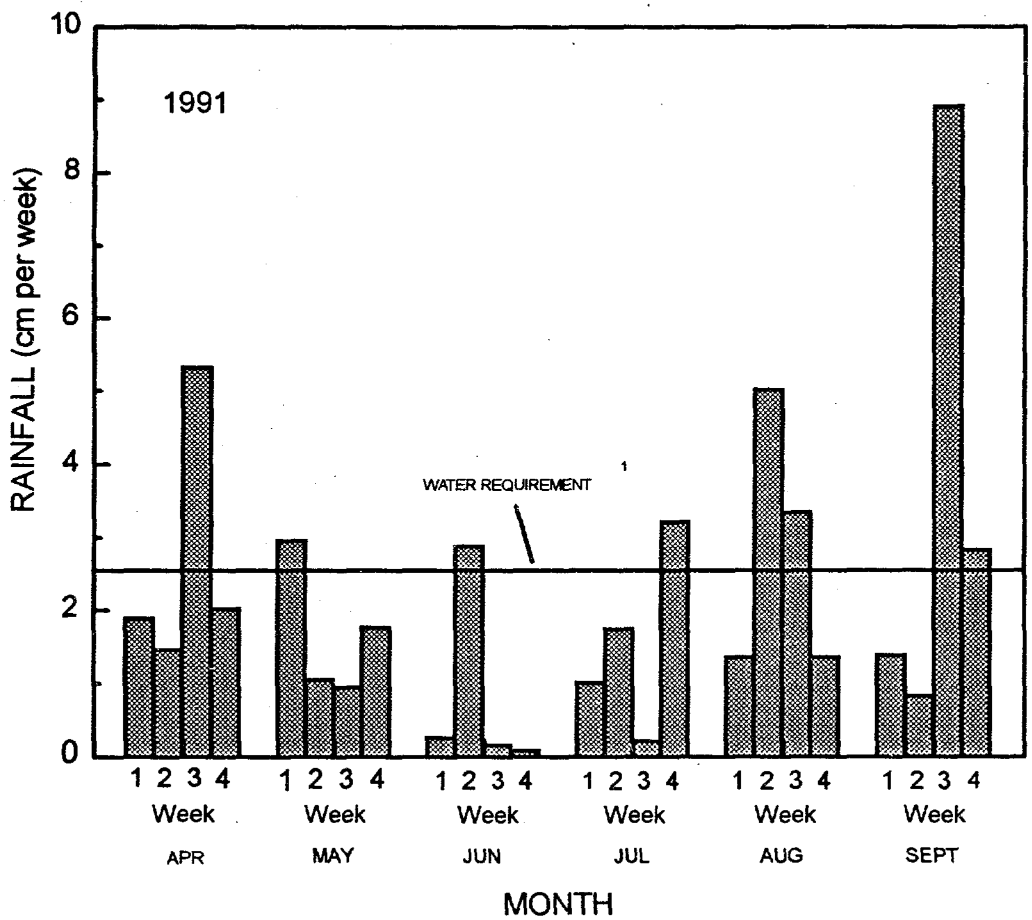
[1] Minimum weekly precipitation necessary to maintain maximum growth.

Figure F-4. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1990.



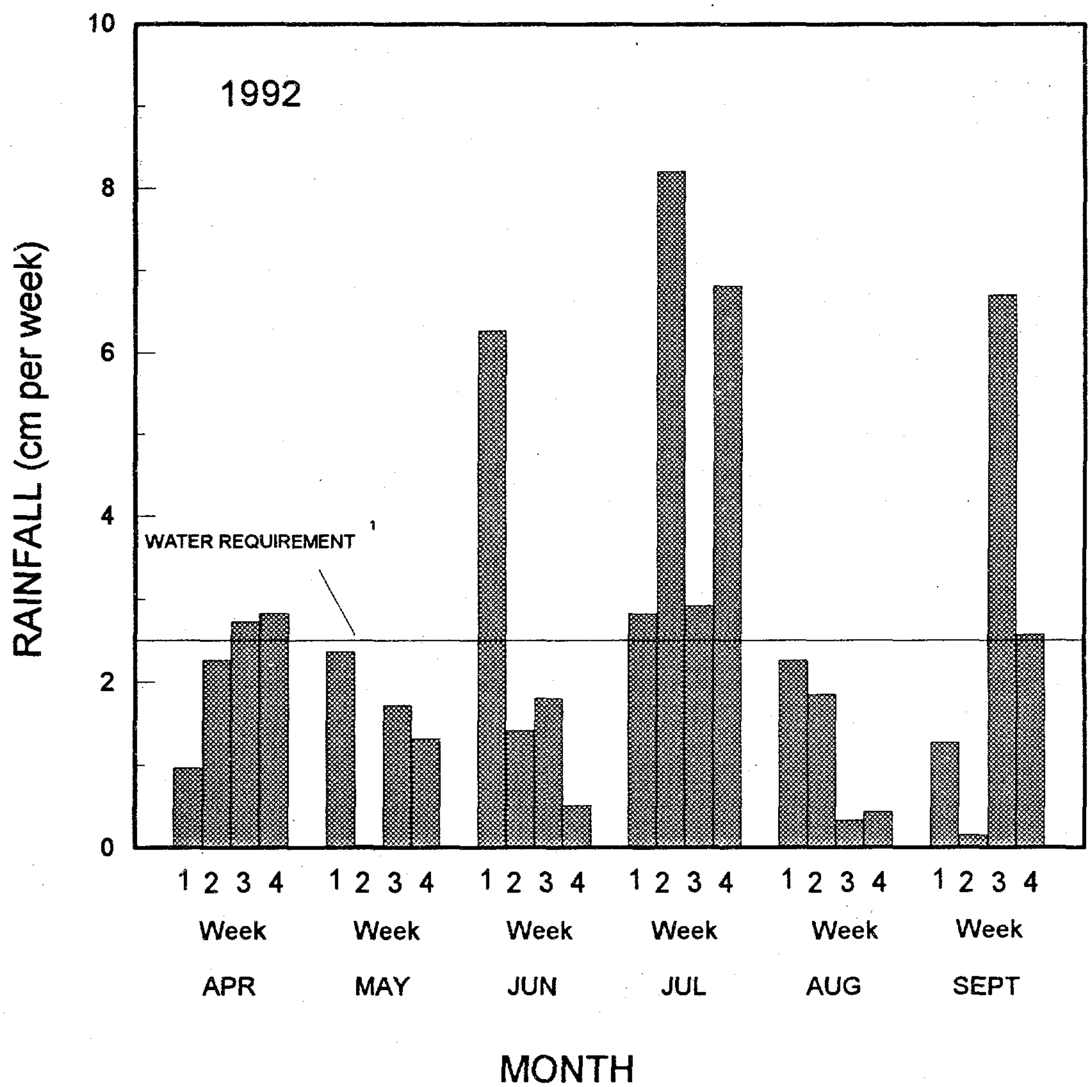
[1] Minimum weekly precipitation necessary to maintain maximum growth.

Figure F-5. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1991.



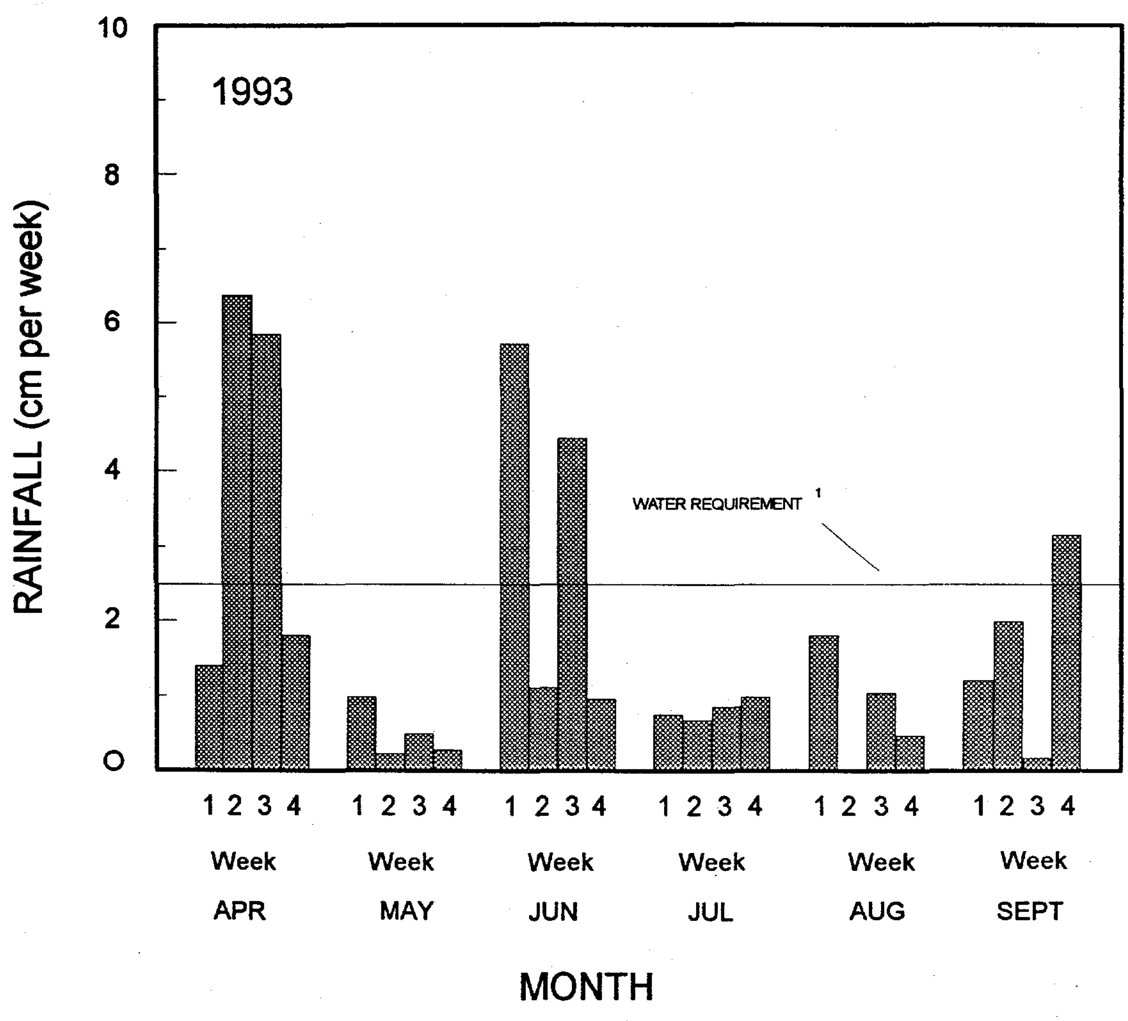
[1] Minimum weekly precipitation necessary to maintain maximum growth.

Figure F-6. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1992.



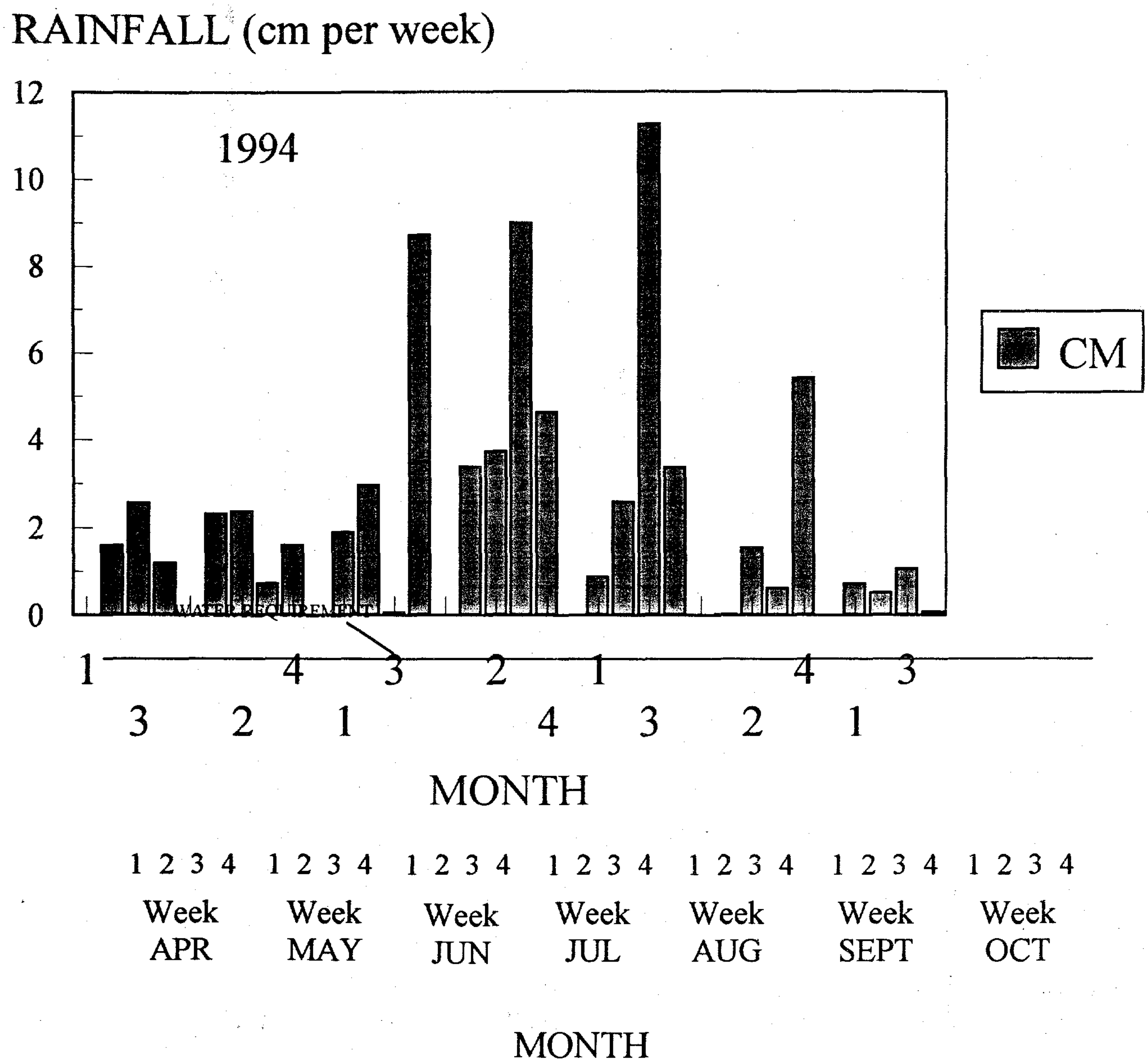
[1] Minimum weekly precipitation necessary to maintain maximum growth.

Figure F-7. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1993.



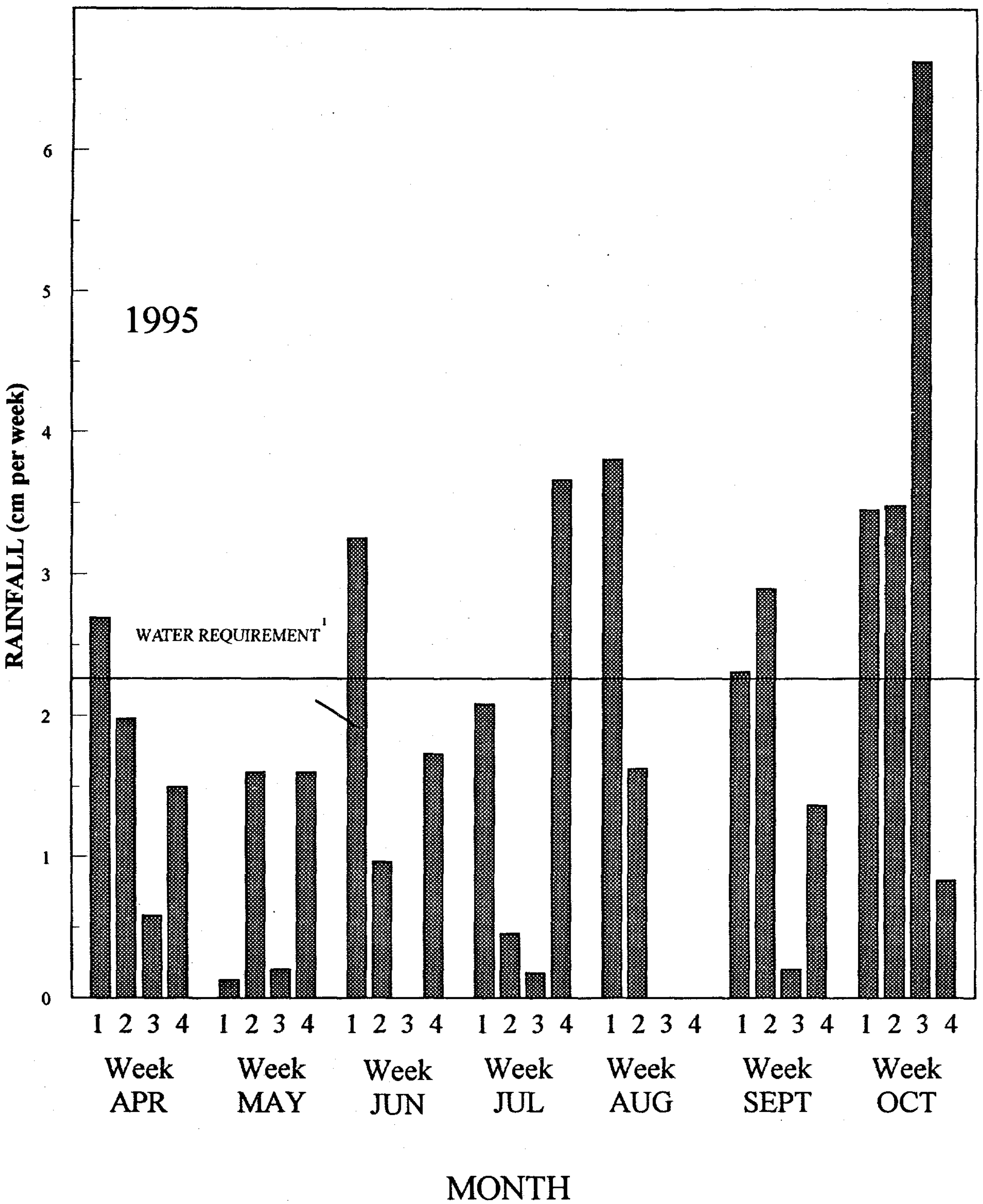
[1] Minimum weekly precipitation necessary to maintain maximum growth.

Figure F-8. Weekly growing season precipitation at SUNY Genetics Field Station, Tully, NY, during 1994.



[1] Minimum weekly precipitation necessary to maintain maximum growth.

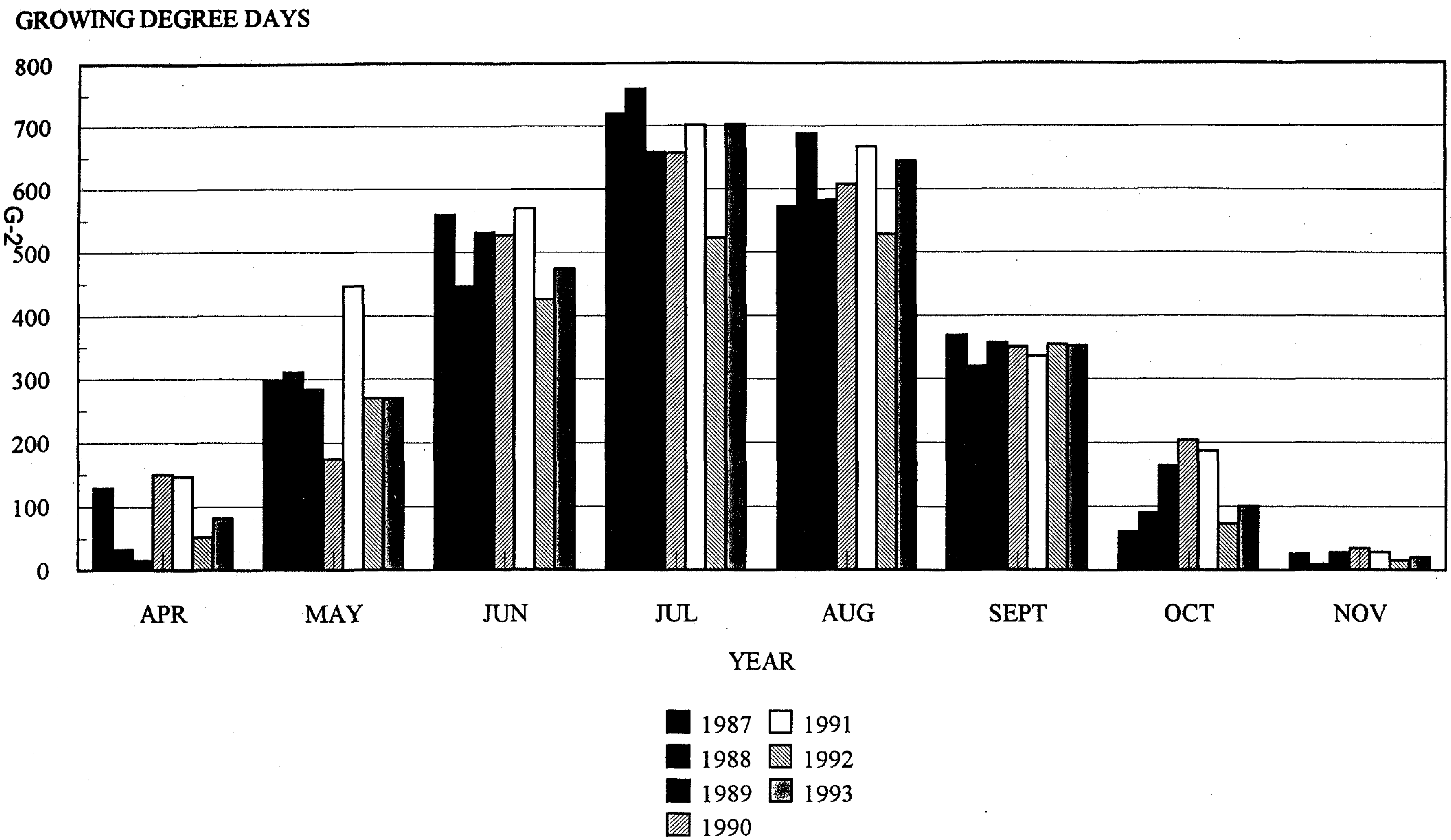
Figure F-9. Weekly growing season precipitation at SUNY Genetic Field Station, Tully, NY, during 1995.



[1] Minimum weekly precipitation necessary to maintain maximum growth.

APPENDIX G
GROWING DEGREE DAYS FROM 1987 TO 1995.

Table G-1. Monthly sum of growing degree days (base temperature = 45°F) at SUNY Genetics Field Station, Tully, NY from April to November during 1987 to 1995[1].



[1] 1995 Data was taken from the Tully Heiberg weather station #308627, as the Tully 4 NE station #308625 was unavailable during this time.