

Short-Rotation Woody Crops Program

at

State University of New York
College of Environmental Science & Forestry

Biomass Power for Rural Development Technical Report:

CLONE-SITE TESTING AND SELECTIONS FOR SCALE-UP PLANTINGS

Final Report

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EXECUTIVE SUMMARY

Since 1987, the State University of New York College of Environmental Science and Forestry (SUNY-ESF), in cooperation with numerous other agencies, has been studying the potential of shrub willows (*Salix* spp.) as woody biomass crops. Willows were selected because of their rapid juvenile growth rates, ease of breeding and propagation and ability to vigorously resprout after harvest. Impetus for the study of willows came from Sweden, where encouraging results with willow plantations and an expanding willow bioenergy industry suggested that similar efforts might prove feasible in the northeastern United States (US). The primary objective of SUNY-ESF's willow research program has been to develop a commercially viable production system that effectively maximizes biomass production for bioenergy and bioproducts at economically reasonable costs. Significant progress has been made towards addressing this objective. Concurrent with scale-up efforts towards commercialization, the willow research and development program is focused on optimizing the production system at an operational scale, developing new clones through traditional breeding and quantifying and valuing the environmental benefits associated with willow biomass crops.

As part of the research efforts at SUNY-ESF, 12 clone-site trials were established between 1993 and 1998 to determine which willow clones will produce the greatest aboveground biomass across a variety of sites. The locations of the trials ranged from northern New York and Vermont to central Delaware. Two highly productive hybrid poplar clones were included in 10 of the clone-site studies to allow comparison with other woody biomass studies. Each trial was a completely randomized block design (RCBD) with three or four replications. Between seven and 19 clones were tested at each site. The establishment year was followed by a winter cutback (coppice) to promote the growth of multiple stems. By the end of 2002, eight sites had reached the end of their first rotation. Harvests occurred after three years at all but one site (Massena), which had a four year rotation.

Site is defined to include inherent features associated with soil and climate, coupled with environmental changes created by previous cultural treatments. Soil pits were dug at six sites to assess soil conditions and local climate data were acquired for all eight sites that were harvested. Sites with marginal soil moisture holding capacity and high weed populations at pre-planting stage were included in the study as representative of conditions at sites often available for establishment of willow biomass crops. It was envisioned that these sites would be useful in determining the lower limit of site quality that can be used to economically produce willow biomass.

Survival and production varied across sites with different soil and climate conditions. While no specific drivers for this variability could be identified, some key factors may be climatic factors such as growing degree days (GDD) and precipitation as well as soil texture. However, there were no significant correlations between climate and soils data at any site.

Survival at each of 11 sites was evaluated after the first growing season and ranged from 64% at Leon to 99% at Somerset. At the eight sites, mean survival at the end of the first

rotation ranged from 73% to 97%, averaging 85%, but with considerable clonal variation. Survival among the top-five clones at the eight sites ranged from 68% at Massena to 96% at Delaware.

First-rotation production among all clones at each site ranged from 7 t ha⁻¹ to 27 t ha⁻¹, with a mean across sites of 19 t ha⁻¹. Production of the top-five clones at each site ranged from 8 t ha⁻¹ to 31 t ha⁻¹. However, with Lafayette, a site with poor weed control, removed, the production of the top-five willow clones ranges from 19 t ha⁻¹ at Sheridan to 31 t ha⁻¹ at Massena. The greatest biomass production of a single willow clone at one site was 37 t ha⁻¹ and 35 t ha⁻¹ for SX61 at Burlington, VT and Wolcott, NY, respectively. Biomass production among the top-five willow clones was not correlated with survival, and weakly correlated over all clones ($R^2=0.31$, $p=0.0007$), thus a revision of the currently accepted 80% survival rate for successful establishment may be warranted. Production was generally good at seven of the eight sites in this study, but these plantings need to be followed through subsequent rotations to determine long-term viability.

Canonical discriminant analysis was conducted on the willow data to establish the degree of variation in willow foliar nutrient concentration (N, P, K, Ca, Mg) and biomass between sites. This analysis indicated that foliar P and Mg concentrations, in addition to biomass, were the factors that accounted for the greatest percent of variation between sites. The same analysis was conducted on soils data. This analysis indicated that the factors most affecting variation between sites were soil texture, pH and Mg concentrations. Production was positively correlated to soil pH and P, Ca, and Mg concentrations

This study suggests that several of the clones tested are plastic in nature, meaning they can grow well across a range of conditions. The willow species that were found to be the most plastic included *Salix miyabeana* (SX64, SX67), *S. xdasyclados* (SV1) and *S. purpurea* (PUR12, PUR34). At several sites, some of these clones performed as well or better than the reference clone (SV1). The more site-specific clones include *S. discolor* (S365), which did well on some sites and poorly on others. Some clones did so poorly at many sites where they were planted that they are no longer considered viable for biomass production in this program. The site-specific clones may warrant further study to define the specific suite of edaphic and climatic characteristics under which they grow well. The results of these studies will help decision makers to better determine appropriate planting stock for scale-up operations, suggest clones appropriate for selective breeding programs and provide groundwork for further refined clone-site trials.

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1.0 INTRODUCTION

1.1 Willow Biomass Research at SUNY-ESF

In 1987, the State University of New York College of Environmental Science and Forestry (SUNY-ESF) began studying the potential of willow (*Salix* spp.) for use as a feedstock for bioenergy and bioproducts (White et al. 1991). Willows were selected because of their rapid juvenile growth rates, ease of breeding and propagation, and ability to vigorously resprout after coppicing. Further impetus for their study came from Sweden, where successful willow plantations supporting an expanding willow bioenergy industry (Sirén et al. 1984; Sirén et al. 1987; Lönner and Parikka 1989) indicated that similar efforts might prove feasible in the northeastern United States (US). The primary objective of SUNY-ESF's willow research program has been to develop a commercially viable biomass production system. Willow biomass can be used as a feedstock for the production of bioenergy and/or biobased products. Significant progress has been made towards addressing this objective over the last 15 years. Concurrent with scale-up efforts towards commercialization, the willow research and development program is focused on optimizing the production system at the operational scale, developing new clones through traditional breeding and valuing the environmental and rural development benefits associated with willow biomass crops.

Ongoing research indicates that reducing the cost of feedstock production and/or valuing the environmental and rural development benefits would be necessary for the long-term economic viability of a commercial willow bioenergy industry (Empire Biopower Consortium 1995; Tharakan et al. 2003a). Reducing feedstock cost can be achieved by reducing the cost of plantation establishment and management, increasing biomass production per unit area, and centralizing harvest operations.

The goal of reducing feedstock costs has been addressed by the development of new planting stock through breeding programs that result in higher yields and improved pest resistance. Continued screening of the relative performance of different willow clones across a range of site conditions, and continuing basic applied research aimed at ensuring the long-term productivity and sustainability of the production system while minimizing production costs further advance this goal.

In this report, results are presented from SUNY-ESF's extensive testing of willow clones over multiple sites including a broad range of climatic and edaphic factors. Clones were

obtained from wild collections across the northeastern US and from the breeding programs at the University of Toronto.

1.2 Clonal Selection Strategy

The general philosophy of the SUNY-ESF genetics program follows the convention described by Libby (1987) –

- Level 1 testing: Initial screening of 1000s of seedlings from various crosses.
- most of this work for the clones discussed in this report was done at the University of Toronto.
- Level 2 testing: Progeny testing, with large numbers of clones and a small number of ramets per clone.
- a trial with 300 clones was established in central New York and southern Ontario, Canada, in 1987. Results identified 19 clones for further testing (White et al. 1991).
- Level 3 testing: Clonal performance testing, more extensive testing of better candidate clones. The number of clones at this level of testing will be moderately small, and the number of ramets should be large. This would include both single-site genetic selection trials and multi-site clone-site trials.
-from 1993 – 2000, genetic selection trials and multiple clone-site trials were established in central NY and other regions in the northeast by SUNY-ESF.

Over the years, SUNY-ESF has been involved in research at all three levels mentioned above (Kopp et al. 1993; Kopp et al. 1997; Tharakan et al. 2001; Tharakan et al. 2003b). This report, dealing with level three testing, includes the 2000 interim report, which presents early-rotation survival results from clone-site trials established on eleven sites across the northeastern US, and survival and production data from eight clone-site trials harvested by 2002.

1.3 Clone-site Trials

Research with short-rotation woody crops in general, and willow in particular, has shown that substantial differences can exist in the yields of individual clones grown under different soil and climate conditions. Biomass production of *Salix viminalis* exceeded 30 odt ha⁻¹ yr⁻¹ at one site in southern Finland, but biomass production and survival varied greatly among the experimental plantations (Tahvanainen and Rytönen 1999). Previous work with willow in Sweden (Ledin and Willebrand 1996) and with hybrid poplar in the United States (Farmer

and Wilcox 1968; Lee et al. 1987; White 1985; Hansen 1992; Riemenschneider et al. 2001) and Canada (Barkley 1983) has shown that site conditions strongly influence crop development. Based on these results, reported from a wide range of ecosystems, we hypothesized that large variation in growth potential and site adaptability exists among the willow clones in the SUNY-ESF collection.

In order to assess the nature and extent of these differences, clones were initially evaluated in limited, single-site genetic selection trials (Tharakan et al. 2001). Clones with superior growth potential were planted in larger clone-site trials. The sites were selected to represent a range of climate and site factors found in the northeastern US. In these trials, clones were monitored for survival and biomass production, incidence of disease and pests, and major environmental variables such as temperature, precipitation, and soil physical and chemical attributes.

Clone-site trials are used to evaluate clone-by-site interactions. Based on site adaptability, clones can be classified as either “plastic” or “site specific.” Those that are capable of performing well in a variety of environments are termed “plastic” and those that do well only under certain conditions are called “site specific” (Hansen et al. 1992). Both types of clones can be useful in a woody crops program; their relative importance is dictated by the degree of heterogeneity in environmental factors at the sites available for planting.

Data from clone-site trials, in combination with knowledge of regional climatic and edaphic factors, can be used to guide site-specific management practices. These trials can provide managers with valuable information about which clones are most suitable for establishment on a given site, thereby minimizing the risk of crop failure.

1.4 Current Study

Willow clone-site trials were established on twelve sites across DE, NY, PA and VT, between 1993 and 1999 (Figure 1.1), to evaluate clonal performance and assess clone-by-environment interactions. The clones used in these trials were the top ranking clones in terms of survival, yield and low incidence of disease and pest problems, selected from prior genetic selection trials (level 2 testing) in Ontario, Canada and New York (Mosseler and Zsuffa 1989; White et al. 1991). This final report includes the interim report, delivered in 2000, which focuses on early rotation survival at the clone-site trials, as well as analyses of data

collected at the end of the first rotation. While many of the sites are the same in both reports, only eight of the sites reached the end of first rotation intact and were unaffected by concurrent fertilization research.

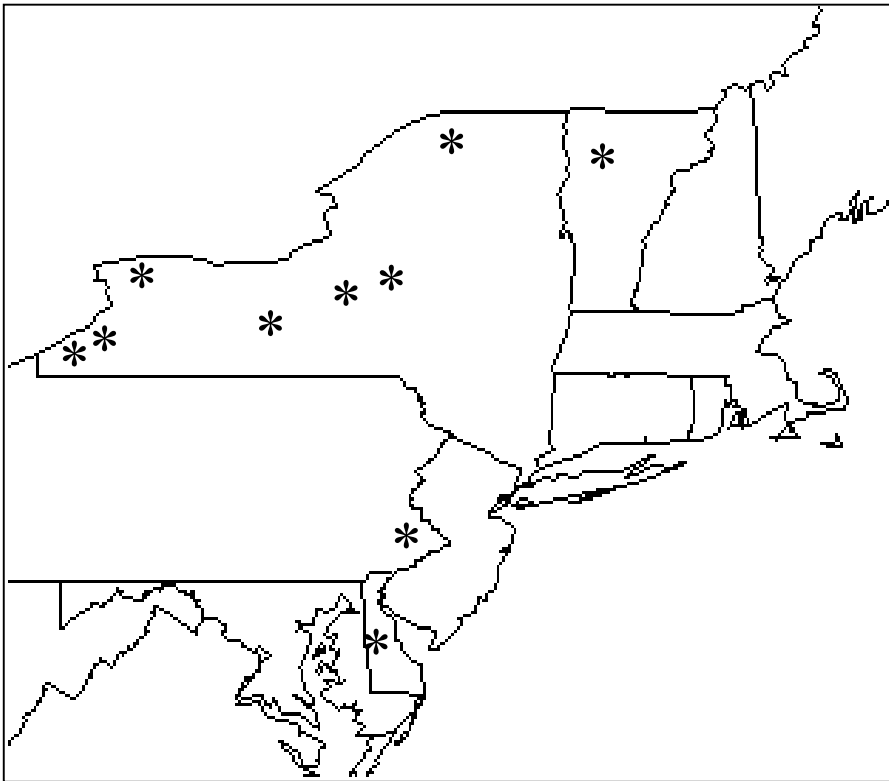


Figure 1.1. Locations of the clone-site trials in the northeastern US.

The primary objectives of this study were to:

- 1) establish clone-site trials that represent a wide range of soil and climate conditions in the northeastern United States;
- 2) collect information on willow clone survival, disease and pest problems (not reported), and biomass production on these sites;
- 3) collect information on individual site soil conditions including soil texture, pH, and organic matter and nutrient concentrations;
- 4) gain insight into which of the tested clones are plastic and which are site specific;
- 5) determine the nature and degree of influence of edaphic and climatic factors on biomass production among different clones

1.4.1 Interim report

While data on a range of growth, production and environmental factors were measured on these sites, the interim report focused on survival early in the first rotation. At that stage,

those data were available for a large number of sites. The effects of clone, site, and time on survival were examined in the interim report.

1.4.2 Final report

End-of-rotation data on survival, biomass production and foliar nutrient concentrations were collected and analyzed as detailed in section 2.3. These data were related to soil physical and chemical properties for six sites where soils data were available.

1.4.3 Study history

Site is defined to include inherent features associated with soil and geography, coupled with changes in the environment created by cultural treatments. Marginal sites with less than desirable soil moisture conditions and fallow land with well-established perennial weed populations were included in the study, representative of the type of land potentially available for establishment of willow crops. It was envisioned that these sites would be useful in identifying the minimum site quality required to economically produce willow biomass. The influence of time was viewed as important in understanding the effects of climate factors and weed competition as part of site influences on clonal performance.

As improved genetic clones are developed, matching them to actual field conditions throughout NY and the surrounding region and evaluating field performance will be critical. This study should be considered a preliminary step that will help develop new evaluation techniques and finalize protocols that will form the mainstay of continuing clone-site evaluation. These activities will continue to contribute towards a viable commercial willow biomass industry in the northeastern US.

2.0 METHODS AND MATERIALS

2.1 Establishment of Trials and Site Description

The experimental design at all sites was a completely randomized block design. Site preparation varied by site (Table 2.1) in response to the differences in previous land use, availability of local equipment, and local regulations. Generally, pre-trial vegetation on each site was killed with a postemergence herbicide, such as glyphosate, followed by plowing and disking. A preemergence herbicide (oxyflourfen and/or simazine) was applied on all of the sites, except Burlington, in the fall prior to planting, or during the spring following planting.

The number of clones planted at each site ranged from seven to 19 (Tables 2.2 and 2.3). In addition to willow clones, some sites included one or two highly productive hybrid poplar clones, which were intended to serve as a means of comparing relative performance between willow and poplars and a reference to other biomass research. All sites were hand planted with unrooted, 25 cm long dormant cuttings in a double row configuration with 15,200 plants per ha (Figure 2.1). Plants on all sites were coppiced mechanically at a height of 2-5 cm the winter after planting. Most sites were subsequently fertilized with N at the start of the next growing season (Table 2.1).

2.1.1 Site descriptions for end of rotation analyses

Eight clone-site trial locations had been through the first harvest and were selected for biomass production analysis after one harvest rotation. Sites were planted from 1996 to 1998 with 11 to 19 willow and one or two hybrid poplar clones (Tables 2.3 and 2.4). All sites were coppiced at a height of 2-5 cm during the winter after the first growing season and most were harvested after the fourth growing season (three-year aboveground growth). Massena was harvested after the fifth growing season due to deer browse early in the rotation. Climate characteristics varied among the sites. Normal (30-year average) growing season precipitation varied from 694 mm at Delaware to 589 mm at Burlington, VT. Normal (30-year average) growing season growing degree days (base 10° C) ranged from 2102 at Delaware to 1172 at Burlington. Further information is presented in Table 2.4.

Table 2.1. Information for eleven clone-site trails in the northeastern US.

Site	Year Planted	Number of Clones	Site preparations activities	Preemergence herbicide/ mechanical weed control	Crop prior to willow (fertilization rate ¹)
Burlington, VT	1997	6 willow 1 poplar	Fall Glyphosate ² Fall plow and disk	Mechanical cultivation following planting.	Fallow (100 kg N ha ⁻¹)
Canastota, NY	1998	13 willow 1 poplar	Spring plow and cultumulcher.	Oxyfluorfen (Spring) (2.24 kg ai ha ⁻¹)	Soybeans (100 kg N ha ⁻¹)
Peter's Tract, DE	1998	12 willow 2 poplar	Spring plow and disk	Oxyfluorfen (Spring) (2.24 kg ai ha ⁻¹) Fusilade (2.3 kg ai ha ⁻¹)	Soybeans (100 kg N ha ⁻¹)
Easton, PA	1998	13 willow 1 poplar	Fall plow and disk. Spring disk.	Oxyfluorfen (Spring) (2.24 kg ai ha ⁻¹)	No-till corn (100 kg N ha ⁻¹)
King Ferry, NY	1995	13 willow 1 poplar	Fall Glyphosate Fall plow and disk	Simazine (Fall) (4.5 kg ai ha ⁻¹)	Fallow (112 kg N ha ⁻¹)
Lafayette, NY	1997	14 willow 2 poplar	Fall Glyphosate Fall plow and disk. Spring disk.	Oxyfluorfen (Spring) (2.24 kg ai ha ⁻¹)	Fallow (100 kg N ha ⁻¹)
Leon, NY	1998	15 willow 1 poplar	Fall Glyphosate Dicamba 12.1 kg ai ha ⁻¹ . Fall plow and disk. Spring disk.	Simazine (Spring) (4.5 kg ai ha ⁻¹)	Fallow (None)
Massena, NY	1993	14 willow	Fall Glyphosate No-till	Oxyfluorfen (Fall) (2.24 kg ai ha ⁻¹)	Abandoned field (112 kg N ha ⁻¹)
Sheridan, NY	1998	11 willow 1 poplar	Fall Glyphosate Fall plow and disk. Spring disk.	Oxyfluorfen (Spring) (2.24 kg ai ha ⁻¹)	Fallow (100 kg N ha ⁻¹)
Somerset, NY	1995	6 willow 1 poplar	Fall Glyphosate Fall plow and disk	Simazine (Fall) (4.5 kg ai ha ⁻¹)	Cereal crop (112 kg N/ha)
Tully, NY	1993	19 willow	Fall Glyphosate. Fall plow and disk	Oxyfluorfen (Fall) (2.24 kg ai ha ⁻¹)	Poplar (112 kg N ha ⁻¹)
Wolcott, NY	1998	11 willow 1 poplar	Spring plow and disk	Oxyfluorfen (Spring) (2.24 kg ai ha ⁻¹)	Winter wheat (wet chicken manure compost, 20.2 odt ha ⁻¹) ³

¹ – Fertilizer applied in the beginning of the second growing season following winter coppice.

² – Glyphosate was applied at 2.2 kg ai ha⁻¹.

³ – Chicken manure was applied in the spring prior to planting and incorporated with a chisel plow.

Table 2.2. Parentage of willow and poplar clones used in clone-site trials established in New York, Vermont, Pennsylvania and Delaware, between 1993 and 1998.

Clone	No. sites	Species	Origin ^a
S19	6	<i>Salix eriocephala</i>	U of T
S25	10	<i>S. eriocephala</i>	U of T
S34	1	<i>S. eriocephala</i>	U of T
S71	2	<i>S. petiolaris</i> x <i>eriocephala</i>	U of T
S185	2	<i>S. eriocephala</i>	U of T
S287	2	<i>S. eriocephala</i>	U of T
S301	11	<i>S. interior</i> x <i>eriocephala</i>	U of T
S365	10	<i>S. discolor</i>	U of T
S546	5	<i>S. eriocephala</i>	U of T
S557	2	<i>S. eriocephala</i>	U of T
S566	3	<i>S. eriocephala</i>	U of T
S599	2	<i>S. eriocephala</i> x <i>petiolaris</i>	U of T
S625	5	<i>S. eriocephala</i> x <i>interior</i>	U of T
S646	5	<i>S. eriocephala</i>	U of T
S652	3	<i>S. eriocephala</i>	U of T
SA2	7	<i>S. alba</i>	OMNR
SH3	6	<i>S. purpurea</i>	OMNR
SP3	1	<i>S. purpurea</i>	OMNR
SV1	11	<i>S. dasyclados</i>	OMNR
SX61	7	<i>S. sachalinensis</i>	U of T
SX64	5	<i>S. miyabeana</i>	U of T
SX67	5	<i>S. miyabeana</i>	U of T
NM6	9	<i>Populus maximowiczii</i> x <i>nigra</i>	OMNR
NM5	1	<i>P. maximowiczii</i> x <i>nigra</i>	OMNR
PUR12	3	<i>S. purpurea</i>	U of T
PUR34	5	<i>S. purpurea</i>	U of T
94001 (FC185)	3	<i>S. purpurea</i>	SUNY-ESF
94004 (FC188)	3	<i>S. purpurea</i>	SUNY-ESF
94005 (FC189)	2	<i>S. purpurea</i>	SUNY-ESF
94006 (FC190)	4	<i>S. purpurea</i>	SUNY-ESF
94009 (B193)	3	<i>S. purpurea</i>	SUNY-ESF
94011 (B195)	2	<i>S. purpurea</i>	SUNY-ESF

^a ‘U of T’ indicates the University of Toronto, ‘OMNR’ indicates the Ontario Ministry of Natural Resources, ‘SUNY-ESF’ indicates the State University of New York College of Environmental Science and Forestry.

Table 2.3. List of clones planted at the twelve clone-site trial locations.

Clone	Burlington	Canastota	Delaware	Easton ¹	King Ferry	Lafayette	Leon	Massena	Sheridan	Somerset	Tully	Wolcott
94001		X	X	X			X					
94004				X			X					X
94005			X						X			X
94006		X		X			X		X			
94009			X	X			X					X
94011									X			X
PUR12			X	X		X			X			
PUR34		X		X		X			X			X
SH3					X	X		X		X	X	
S185					X						X	
S19	X				X	X	X	X			X	
S25	X	X	X	X	X	X	X	X		X	X	X
S34											X	
S287					X						X	
S301	X	X	X	X	X	X	X	X	X	X	X	X
S546		X	X		X			X		X	X	
S557								X			X	
S566								X			X	
S599								X			X	
S625					X	X	X	X			X	
S646		X	X		X		X	X			X	
S652		X				X					X	
S71								X			X	
SA2		X			X	X	X	X		X	X	
S365	X	X		X	X	X	X	X	X		X	X
SV1	X	X	X	X	X	X	X	X	X	X	X	X
SX61	X	X	X	X		X	X		X			X
SX64		X	X	X		X	X		X			
SX67			X	X		X	X		X			X
SP3											X	
NM5			X			X						
NM6	X	X	X	X	X	X	X		X	X		X

¹ – Plowed under after two years.

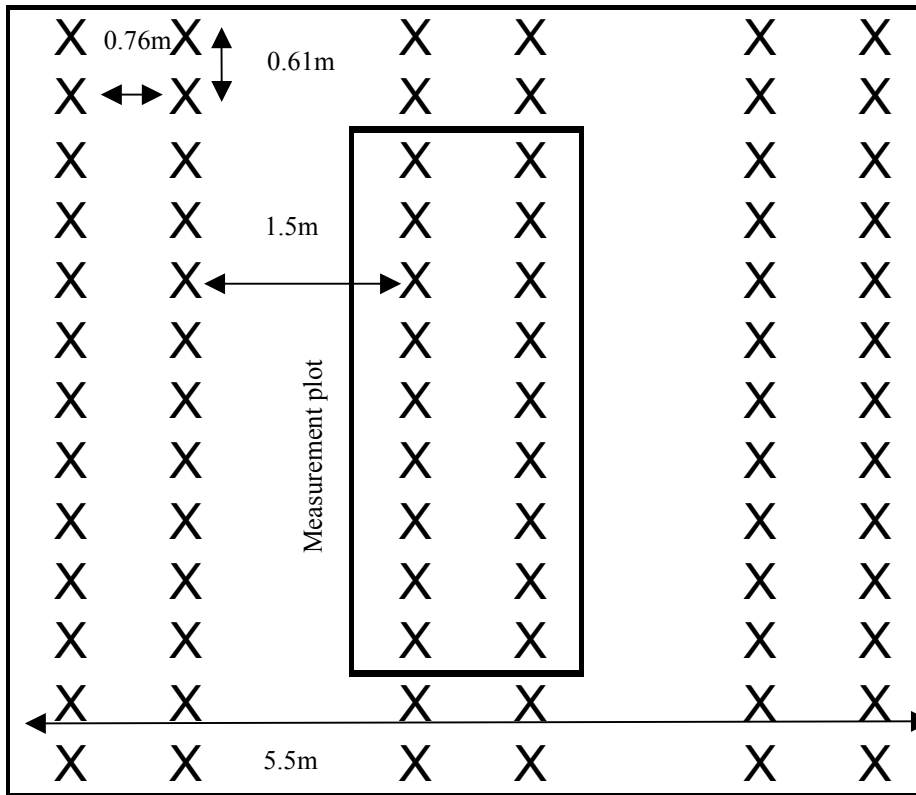


Figure 2.1. Diagram of the double-row planting design used for the 11 clone-site trials established between 1993-1998. Length of the individual plots differed among sites (not to scale).

Table 2.4. Elevation (Elev; m), 30 yr normal growing degree days (GDD; base 10° C) and 30 yr normal precipitation (PPT; mm) for the eight clone-site trials. GDD and PPT are for the growing season (April – October).

Site	Elev	GDD ¹	PPT ¹	Planted	Coppiced	Harvested
Burlington	101	1171.8	589.03	1996	1997	1999/00
Canastota	665	1306.7	676.66	1998	1999	2001/02
Delaware	70	2101.6	694.44	1998	1999	2001/02
Lafayette	980	1325.2	628.90	1997	1998	2000/01
Massena	177	1114.8	591.82	1993	1994	1997/98
Sheridan	713	1433.3	687.83	1998	1999	2001/02
Tully	1286	1210.8	616.71	1993	1994	1996/97
Wolcott	400	1457.8	598.93	1998	1999	2001/02

(¹Northeast Regional Climate Center 2002)

2.2 Early Rotation Survival Data Collection and Analysis (Interim Report)

Census surveys to assess survival were conducted at the end of every growing season during 1993-1998 in all clone-site trials. Clone and site effects on percent survival were tested using analysis of variance (ANOVA). Tukey's mean studentized range test was used to determine significant mean separations. In order to test site effects it was necessary that the same clones had been planted on each of the sites. While the analysis of clonal and site related factors on survival was carried out using first year data, the effect of time was evaluated using multi-year data. Five clones; NM6, S25, S301, S365, and SV1 had been planted on seven sites and thus an analysis across seven sites was done using data from these clones. Of these, S301 and SV1 had been planted on all eleven sites and hence the analysis across all sites was done only for these two clones.

Time effects on percent survival were tested on the four older trials-- King Ferry, Massena, Somerset, and Tully, using a repeated measures analysis approach (Meredith and Stehman 1991). This approach has been shown to be effective in longitudinal studies. The term "repeated" is used here to describe measurements that are made of the same characteristic on the same observational unit, but on more than one occasion. One method of analyzing longitudinal data would be to assume that data from each measurement period for each of the clones are observations from independent samples that conform to a normal distribution. We could then conduct a traditional one-way ANOVA on differences among clones and separate the means. However this method leads to erroneous results as there is dependence between the observations at different times and therefore the *F*-tests at different points in time are not independent. The alternative, repeated measures analysis, is to treat the specific well-defined variable, such as survival percent over time, as a single response from each clone. The individual survival curves (response curves over time) can then be described and compared with one another in a univariate fashion, using far fewer parameters. For instance if there are five clones and four time periods, instead of the 20 parameter values that we would have to use in the one way ANOVA method, the five clonal survival responses overtime are treated as individual curves. The slope of the curve and the intercept are then estimated using linear and higher order polynomial curves, by individually testing each term if it is statistically significant. In this study, measured survival data was used to interpret trends of survival over

time as a function of clone and site. Statistical analyses were carried out using SAS v.8.0 (SAS 1999). Differences were assessed at a critical level (α) of 0.05.

2.3 End-of-Rotation Analyses

2.3.1 Measurements and laboratory analysis

End-of-rotation survival for each clone was attained from the trees in the measurement plot in each block as in the previous section. Weight of the trees in the measurement plot was measured in the field. A subsample of the harvested willow was taken from each measurement plot and weighed to the nearest 0.1 gram, then dried in an oven at 65°C to a constant weight (about a week). The dry weights of the subsamples were then taken. Percent moisture of the woody biomass was defined as:

$$\frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} * 100\%$$

Oven dry biomass estimates for the measurement plots were then calculated using percent moisture estimates using the following equation:

$$\text{wet weight} - (\text{percent moisture} * \text{wet weight}) = \text{oven dry weight}$$

Foliage samples were obtained from each plot to assess foliar N, P, K, Ca, and Mg concentrations following SUNY-ESF's standard procedure (Appendix 1). The foliar samples were oven dried and ground using a Wylie® mill. Percent foliar N was determined using the Kjeldahl method (Bickelhaupt and White 1982). Percent N was calculated using the following equation:

$$\%N = \frac{(T-B)*(N)*1.4}{\text{sample wt.}}$$

where: T = volume titrated for sample
 B = volume titrated for blank
 N = normality of the acid

Phosphorus concentration of sample (in ppm) was determined by spectroscopic comparison to known standards (Bickelhaupt and White 1982). Percent P in sample was calculated as follows:

$$\%P = \frac{(\text{ppm P}) * (\text{dilution factor}) * (\text{volume}) * 0.001}{\text{sample wt.}}$$

Atomic absorption spectroscopy relative to known standards was used to determine K, Mg, Ca and Na concentrations (Bickelhaupt and White 1982).

2.3.2 Statistical analyses

Mean survival and biomass production was calculated across all clones and with the hybrid poplar clones excluded. While hybrid poplar was planted at several clone-site trials, the focus of this report is on willow. The mean biomass production of the top five willow clones at each site was calculated. The top five biomass producers from each site were compared to SV1 by calculating the percent biomass of each clone relative to SV1. SV1 has been the most consistent top biomass producer to date and used as our standard for research purposes (Kopp et al. 2001). Pearson correlation coefficients between foliar nutrients and survival and biomass were calculated. Canonical discriminant analysis, which derives linear combinations of the variables summarizing between-class variation (SAS 1999), was performed on measured willow parameters. This analysis provides insight into the factors driving the differences between willow characteristics by site. Graphical representation of these differences was made using the canonical coefficients from the linear combinations for each site. Only the two linear combinations accounting for the greatest variation (>90%) were used in graphing. Statistical analyses were performed using SAS v.8.0 (SAS 1999).

2.4 Soils

Two soil pits were dug at six of the clone-site trial locations. The soils were sampled by horizon. Determination of characteristics was done following the methods in Bickelhaupt and White (1982). An electronic meter was used to determine pH in the lab using a soil sample in suspension. Organic matter was determined using the loss-on-ignition method. Cation exchange capacity was determined using the ammonium-saturated method. Sand, silt and clay fractions for each sample were determined hydrometrically. N concentrations were determined by the Kjeldahl method (see section 2.4). P was determined from samples extracted in 0.002 N sulfuric acid and following the steps detailed in section 2.3, K, Ca, Mg and Na were determined colorimetrically from samples extracted in 2N ammonium acetate.

Canonical discriminant analysis, as describe in section 2.3, was performed using soil physical and chemical properties measured at each site. This analysis provides insight into the factors causing differences between soil characteristics among sites. The analyses were performed using SAS v8.0 (SAS 1999).

2.5 Soil by Willow Correlations

Correlations between soil characteristics and biomass and survival were examined at the six sites where soils data was collected. However, the low biomass at Lafayette is thought to be due to weed competition rather than edaphic properties, thus the site is excluded from the data considered here. Analyses including Lafayette are presented in Appendix 4. Correlations between biomass production and soil characteristics were examined across all clones, among the top five biomass producers at each site and for the three willow clones grown at all sites. Mean soils data, by horizon, was used in the analyses, which were performed using SAS v8.0 (SAS 1999).

3.0 RESULTS

3.1 Early-Rotation Survival (Interim Report)

3.1.1 Clone effects

Initial survival varied by clone on eight of the 11 sites (Tables 3.1-3.11). At each of these eight sites, statistically significant breaks in mean clonal survival generally occurred around 70-85%. The Burlington and Easton trials did not show significant clone effects due to the high survival of all clones at these sites, ranging from 95 to 100% (Tables 3.1 and 3.3). While there were clonal differences in survival, only two clones (S646 and S652) had consistently poor survival (<75%).

3.1.2 Site effects

Initial survival varied by site. Rankings of sites varied as a function of clone, as evidenced by statistically significant, clone by site interactions (Tables 3.12 and 3.13; Figure 3.1 and 3.2). With the sites generally ordered from “highest” to “lowest” in terms of initial survival, the lines representing each clone are not parallel (parallel lines would be indicative of no clone by site interaction) and in fact, cross each other from one site to another, particularly as

survival decreased. Across 11 sites, at overall high survival percentage, both clones S301 and SV1 performed similarly; on the other hand, as overall survival decreased, there was greater relative difference in the survival percentages of the clones and neither clone was consistently ranked above the other.

A similar trend of greater relative difference in clonal survival percentages was repeated among clones S25, S301, S365 and SV1 planted across seven sites. Other than clone NM6 that had the highest survival percentage across all sites, site rankings varied as a function of clone.

While willow clones S301, SV1 and hybrid poplar clone NM6, which had initial survivals above 75% for the three sites considered to have the poorest growing condition; King Ferry, Wolcott and Leon, clones S25 and S365 had low survival on at least one of these sites; (Tables 3.14 through 3.20).

3.1.3 Time effects

The following section summarizes the results for each site. Detailed explanation of the statistical results is provided in the footnote with each related table.

King Ferry: The overall intercept term (Z) for all the clones was statistically significant (Figure 3.3, Table 3.21). Analysis of the individual response curves indicated that the linear (B) and quadratic (Q) interaction terms were not statistically significant. Thus, there were no differences among the clones with respect to the linear and quadratic components of their response curves. The cubic term was significant implying that at least two of the clones differed in the cubic component of their response curves. Means separation analysis of the clones for the intercept term (Z) and cubic term (C) indicated that several clonal means were significantly different both in terms of the intercept term (Z) and the cubic term (C) at $\alpha = 0.05$ (Tables 3.22 and 3.23).

Massena: The main effects including the intercept term (Z) were not statistically significant (Figure 3.4, Table 3.24). The linear term (B) of the individual response curves was also not significant. The cubic term (C) and quadratic term (Q) was barely significant at $\alpha = 0.05$,

suggesting that at least two of the clones may differ in their response curves with respect to these two components. A mean separation analysis on the C and Q term, however, indicated that none of the clonal means were significantly different at $\alpha = 0.05$. Thus the extent of interaction was not sufficient to produce statistically different response curves. Therefore, at Massena, the response curves of all the clones had the same shape and intercept.

Somerset: The overall intercept term (Z) and the linear (B), quadratic (Q) and cubic (C) terms of the response curve were not different, implying that the response curves had the same intercept and shape (Figure 3.5, Table 3.25). Redoing the analysis after eliminating the quadratic term (as it was not statistically significant) did not result in any change in the *p*-values or in the coefficient of the intercept, linear and cubic components. Thus in Somerset, over time, all the clones behaved similarly.

Tully: While the overall intercept term (Z) was statistically significant, none of the interaction terms (B, Q or C) were significant, implying that all the clones had the same shape (Figure 3.6, Table 3.26). Since the intercept term was significant, there was a difference among the intercepts of the clones and the quadratic term was not significant. Thus, we dropped the quadratic term and redid the analysis. This analysis however did not result in a change in the coefficients or *p*-values for any of the terms. A means separation exercise performed on clonal means for the Z term indicated that there were significant differences among clones (Table 3.27).

Table 3.1. First year (1997) survival percentages for seven clones at Burlington, VT.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
NM6	99.7 a	0.5
S19	99.1 a	0.9
SX61	98.5 a	1.9
SV1	98.2 a	1.8
S25	98.2 a	0.0
S301	97.6 a	1.9
S365	95.5 a	2.3

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of 0.10. Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 3 for each clone in each year. The minimum significant difference was 4.3 percent.

Table 3.2. First year (1998) survival percentages for 14 clones at Canastota, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
NM6	100.0 a	0.0
94006	100.0 a	0.0
SV1	100.0 a	0.0
SA2	99.6 a	0.9
S301	99.6 a	0.9
S546	99.6 a	0.9
PUR34	98.8 a	1.6
SX64	98.7 a	0.9
SX61	98.3 a	2.4
FC185	97.9 a	0.8
S646	95.8 a	4.0
S25	95.8 a	7.3
S365	84.6 a b	14.6
S652	75.0 b	22.9

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of <0.01 . Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 4 for each clone. The minimum significant difference was 19.2 percent.

Table 3.3. First year (1998) survival percentages for 14 clones in Easton, PA.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
S301	100.0 a	0.0
PUR12	100.0 a	0.0
NM6	100.0 a	0.0
S25	100.0 a	0.0
SX64	100.0 a	0.0
94001	99.6 a	0.9
94004	99.6 a	0.9
94006	99.2 a	1.7
SV1	99.2 a	1.7
SX61	99.2 a	1.7
PUR34	99.2 a	1.0
S365	98.3 a	1.3
SX67	95.9 a	3.5
94009	95.4 a	7.1

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of 0.11. Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 4 for each clone. The minimum significant difference was 5.8 percent.

Table 3.4. First year (1995) survival percentages for 14 clones at King Ferry, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
S365	94.6 a	2.7
NM6	94.0 a	4.3
SV1	93.1 a	3.9
S25	83.5 a b	5.9
S185	82.5 a b	6.1
SA2	77.7 a b	4.7
S646	76.1 a b	2.1
S301	76.1 a b	2.7
S287	74.8 a b	5.5
S19	74.3 a b c	8.6
S546	73.6 a b c	6.8
S625	69.1 b c	17.6
SH3	52.7 c	18.7

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of <0.01 . Means with the same letter are not significantly different using Tukey's HSD. Sample size is 4 for each clone in each year. The minimum significant difference was 21.6 percent.

Table 3.5. First year (1997) survival percentages for 16 clones at Lafayette, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
SA2	99.6 a	0.8
NM6	98.8 a	0.8
PUR34	98.5 a	3.1
NM5	97.7 a	3.0
PUR12	97.7 a	2.7
S365	97.7 a	2.7
S301	97.3 a	2.6
SX61	94.6 a	2.0
SV1	94.6 a	2.0
S625	94.2 a	1.5
SX67	94.1 a	2.4
SX64	94.1 a	3.5
SH3	86.7 a	4.7
S25	83.6 a b	17.4
S19	70.0 b	14.5
S652	68.0 b	8.1

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value value of <0.01 . Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 4 for each clone in each year. The minimum significant difference was 16.7 percent.

Table 3.6. First year (1998) survival percentages for 16 willow clones at Leon, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
NM6	94.2 a	3.4
SV1	91.2 a b	3.9
S301	85.3 a b	11.1
S625	83.9 a b	14.3
SA2	78.6 a b	36.9
94006	75.4 a b	17.6
94001	67.0 a b	19.2
S365	65.7 a b	19.5
S646	58.0 a b	28.5
SX64	53.2 a b	34.0
94004	52.7 a b	21.0
SX67	50.0 a b	30.1
94009	46.9 a b	9.9
SX61	41.5 a b	24.3
S19	40.6 a b	21.6
S25	33.1 b	35.7

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of <0.01 . Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 4 for each clone. The minimum significant difference for was 58.9 percent.

Table 3.7. First year (1993) survival percentage for 14 clones at Massena, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
S25	97.9 a	3.6
S301	93.7 a	6.3
S365	93.7 a	6.3
SA2	93.7 a	6.3
SV1	91.7 a	7.2
S625	91.6 a	9.6
S71	91.6 a	3.6
S19	89.5 a	7.2
S566	85.4 a	3.6
S599	85.4 a	7.2
S546	83.3 a	13.0
S557	81.2 a	16.5
SH3	81.2 a	12.5
S646	77.1 a	23.6

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value value of 0.48. Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 3 for each clone. The minimum significant difference was 31.6 percent.

Table 3.8. First year (1998) survival percentages for 12 clones at Sheridan, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
NM6	99.6 a	0.9
PUR12	98.8 a	1.6
SV1	97.9 a	1.6
94011	96.7 a	5.6
PUR34	96.3 a	3.7
S301	94.6 a b	3.4
94006	94.2 a b	10.6
94005	91.7 a b	7.2
SX64	89.6 a b	9.2
SX61	79.7 b	9.4
S365	79.2 b	6.1
SX67	60.0 c	9.3

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of <0.01 . Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 4 for each clone. The minimum significant difference was 16.3 percent.

Table 3.9. First year (1995) survival percentages for seven clones at Somerset, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
SA2	100.0 a	0.0
SV1	100.0 a	0.0
SH3	99.7 a b	0.4
S546	98.9 a b	1.0
S25	98.7 a b	0.7
NM6	98.6 a b	0.9
S301	98.0 b	1.6

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value value of 0.02. Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size was 4 for each clone. The minimum significant difference was 1.9 percent.

Table 3.10. First year (1993) survival percentages for 19 clones at Tully, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
S25	100.0 a	0.0
SP3	100.0 a	0.0
SA2	100.0 a	0.0
S287	98.9 a	1.9
S301	97.8 a	1.9
S365	97.8 a	1.9
SV1	93.3 a b	6.7
S652	92.2 a b	3.9
SH3	92.2 a b	6.9
S185	91.1 a b	9.6
S19	90.0 a b	3.3
S546	78.9 a b	10.7
S34	76.7 a b	20.3
S625	72.2 a b c	18.3
S599	70.0 a b c	11.5
S646	65.6 a b c	22.2
S557	60.0 b c	20.2
S566	58.9 b c	20.4
S71	36.7 c	10.0

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of <0.01 . Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size is 3 for each clone. The minimum significant difference was 36.2 percent.

Table 3.11. First year (1998) survival percentages for 12 clones at Wolcott, NY.

<u>Clone</u>	<u>Mean</u>	<u>Standard deviation</u>
NM6	99.2 a	1.0
S301	90.8 a	4.0
S25	89.2 a	8.9
94005	88.4 a	9.6
PUR34	84.2 a	13.7
94009	81.7 a	6.4
94011	81.3 a	4.4
SV1	75.0 a b	17.9
SX61	71.3 a b	18.8
94004	69.6 a b	16.4
S365	67.5 a b	27.7
SX67	39.6 b	18.0

Notes: The clone effect is in a completely randomized design. The overall F-test had a p -value of <0.01 . Means with the same letter are not significantly different using Tukey's HSD controlling the experimentwise error rate at $\alpha = 0.05$. Sample size was four for each clone. The minimum significant difference was 35.4 percent.

Table 3.12. ANOVA for the two willow clones (SV1, S301) planted across 11 sites.

<u>Source of Variation</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>
Model	21	4090.8	<0.01
Clone	1	1.8	0.81
Site	10	2860.0	<0.01
Clone*Site	10	1226.3	<0.01
Error	60	1869.4	
Total	81	5960.2	

Note: Type III sums of squares were used for both experiments as the replications were different for some clones (3 or 4).

Table 3.13. ANOVA for the five clones (NM6, SV1, S301, S365, S25) planted on 7 sites.

<u>Source of Variation</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>
Model	34	25087.9	<0.01
Clone	4	3603.0	<0.01
Site	6	9739.6	<0.01
Clone*Site	24	11478.1	<0.01
Error	100	11006.7	
Total	134	36094.6	

Note: Type III sums of squares were used for both experiments as the replications were different for some clones (3 or 4).

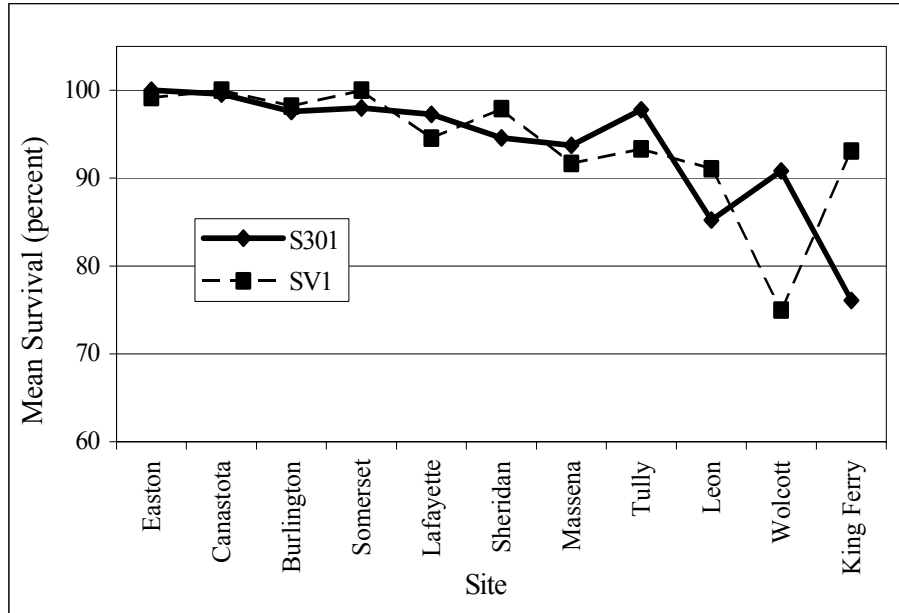


Figure 3.1. First year mean survival for willow clones S301 and SV1 across 11 sites.

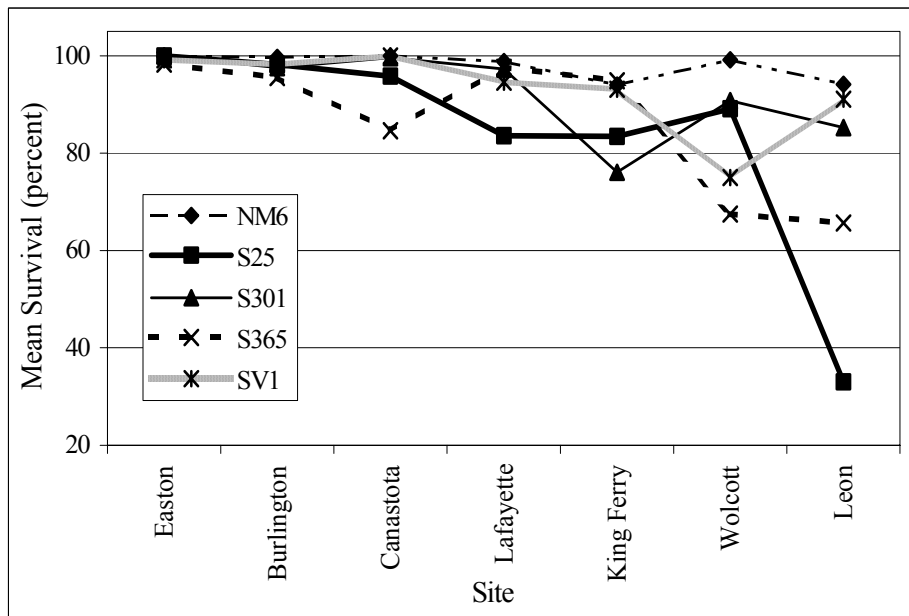


Figure 3.2. First year mean survival for hybrid poplar clone NM6 and willow clones S25, S301, S365 and SV1 at seven sites.

Table 3.14. Percent survival at the end of the establishment year for willow clone S301 planted between 1993-1998 in 11 clone site trials in NY, VT, and PA.

<u>Site</u>	<u>n</u>	<u>Mean</u>	<u>Standard deviation</u>
Easton	4	100.0 a	0.00
Canastota	4	99.6 a	0.85
Somerset	4	98.0 a	1.63
Tully	3	97.8 a	1.91
Burlington	3	97.6 a	1.87
Lafayette	4	97.3 a	2.64
Sheridan	4	94.6 a	3.42
Massena	3	93.7 a	6.25
Wolcott	4	90.8 a b	3.96
Leon	4	85.3 a b c	11.05
King Ferry	4	76.1 b c	2.71

Note: Means with the same letter are not significantly different. Tukey's HSD was used with $\alpha = 0.05$ to control the experimentwise error rate. The minimum significant difference was 15.5 percent.

Table 3.15. Percent survival at the end of the establishment year for willow clone SV1 planted between 1993-1998 in 11 clone site trials in NY, VT, and PA.

<u>Site</u>	<u>n</u>	<u>Mean</u>	<u>Standard deviation</u>
Canastota	4	100.0 a	0.00
Somerset	4	100.0 a	0.00
Easton	4	99.2 a	1.65
Burlington	3	98.2 a	1.80
Sheridan	4	97.9 a	1.58
Lafayette	4	94.6 a	2.01
Tully	3	93.3 a	6.65
King Ferry	4	93.1 a	3.92
Massena	3	91.7 a	7.22
Leon	4	91.2 ab	3.86
Wolcott	4	75.0 c	17.87

Note: Means with the same letter are not significantly different. Tukey's HSD was used with $\alpha = 0.05$ to control the experimentwise error rate. The minimum significant difference was 15.5 percent.

Table 3.16. Percent survival at the end of establishment year for willow clone SV1 planted between 1993-1998 across seven sites in NY, VT, and PA.

<u>Site</u>	<u>n</u>	<u>Mean</u>	<u>Standard deviation</u>
Canastota	4	100.0 a	0.00
Easton	4	99.2 a	1.65
Burlington	3	98.2 a	1.80
Lafayette	4	94.6 a	2.01
King Ferry	4	93.1 a	3.92
Leon	4	91.2 a	3.86
Wolcott	4	75.0 a	17.87

Note: Means with the same letter are not significantly different. Tukey's HSD was used with $\alpha = 0.05$ to control the experimentwise error rate. The minimum significant difference was 29.9 percent.

Table 3.17. Percent survival at the end of establishment year for poplar clone NM6 planted between 1993-1998 across seven sites in NY, VT, and PA.

<u>Site</u>	<u>n</u>	<u>Mean</u>	<u>Standard deviation</u>
Canastota	4	100.0 a	0.00
Easton	4	100.0 a	0.00
Burlington	3	99.7 a	0.52
Wolcott	4	99.2 a	0.98
Lafayette	4	98.8 a	0.80
Leon	4	94.2 a	3.36
King Ferry	4	94.0 a	4.26

Note: Means with the same letter are not significantly different. Tukey's HSD was used with $\alpha = 0.05$ to control the experimentwise error rate. The minimum significant difference was 29.9 percent.

Table 3.18. Percent survival at the end of the establishment year for willow clone S25 planted between 1993-1998 across seven sites in NY, VT, and PA.

<u>Site</u>	<u>n</u>	<u>Mean</u>	<u>Standard deviation</u>
Easton	4	100.0 a	0.00
Burlington	3	98.2 a	0.00
Canastota	4	95.8 a	7.26
Wolcott	4	89.2 a	8.87
Lafayette	4	83.6 a	17.39
King Ferry	4	83.5 a	5.92
Leon	4	33.1	35.66

Note: Means with the same letter are not significantly different. Tukey's HSD was used with $\alpha = 0.05$ to control the experimentwise error rate. The minimum significant difference was 29.9 percent.

Table 3.19. Percent survival at the end of the establishment year for willow clone S301 planted between 1993-1998 across seven sites in NY, VT, and PA.

<u>Site</u>	<u>n</u>	<u>Mean</u>	<u>Standard deviation</u>
Easton	4	100.0 a	0.00
Canastota	4	99.6 a	0.85
Burlington	3	97.6 a	1.87
Lafayette	4	97.3 a	2.64
Wolcott	4	90.8 a	3.96
Leon	4	85.3 a	11.05
King Ferry	4	76.1 a	2.71

Note: Means with the same letter are not significantly different. Tukey's HSD was used with $\alpha = 0.05$ to control the experimentwise error rate. The minimum significant difference was 29.9 percent.

Table 3.20. Percent survival at the end of establishment year for willow clone S365 planted between 1993-1998 across seven sites in NY, VT, and PA.

<u>Site</u>	<u><i>n</i></u>	<u>Mean</u>	<u>Standard deviation</u>
Easton	4	98.3 a	1.35
Lafayette	4	97.7 a	2.68
Burlington	3	95.5 a	2.32
King Ferry	4	94.9 a	2.72
Canastota	4	84.6 a	14.64
Wolcott	4	67.5 b	27.75
Leon	4	65.7 b	19.49

Note: Means with the same letter are not significantly different. Tukey's HSD was used with $\alpha = 0.05$ to control the experimentwise error rate. The minimum significant difference was 29.9 percent.

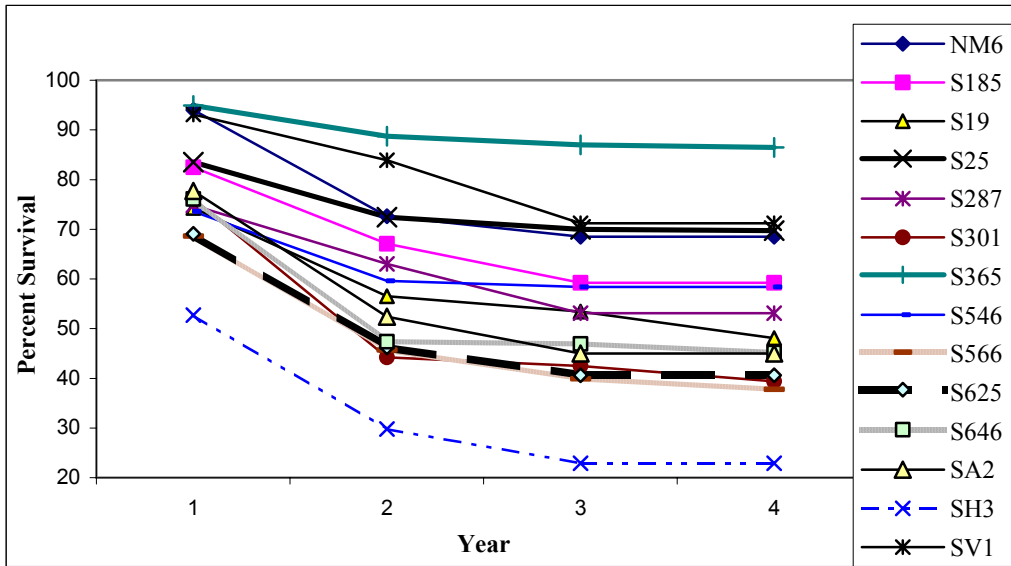


Figure 3.3. Mean survival for all clones at King Ferry, NY.

Table 3.21. Results of repeated measures analysis of the clonal survival curves for all 14 clones at King Ferry, NY. (A) whole unit analysis and (B) repeated measures factor.

(A)		<u>Whole-unit analysis (Z)</u>			
		<u>Source</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>
		Mean	1	209,347.0	<0.01
		Clone	13	902.4	<0.01
		Residual	42	203.0	

Analysis of RM factor

(B)		<u>Contrast</u>					
		<u>Linear (B)</u>		<u>Quadratic (Q)</u>		<u>Cubic (C)</u>	
<u>Source</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>
Mean	1	3504.1	<0.01	1104.1	<0.01	139.7	<0.01
Contrast X clone	13	24.2	0.52	13.2	0.27	17.9	0.04
Residual	42	25.7		10.5		8.9	

Interpretation

The linear and quadratic interaction terms are not significant ($p = 0.52$ and 0.27 respectively). Thus, there are no differences by clone in the linear and quadratic parts of the response curves. There are significant intercept and cubic interactions ($p < 0.01$ and $p = 0.04$ respectively). Therefore, the intercepts and cubic components of the response curves do differ for some clones.

Since all of the main effects are significant (even those with interaction are very low), we do not redo the RM with fewer components. We do however run a means separation on intercept (Z) and cubic factor (C) to see which clones have different intercept and cubic components to their response curves. Tables 23 and 24 show the results of a means separation using Tukey's LSD with a 0.05 significance level.

Table 3.22. Means separation of the intercept term (Z) term in the whole unit analysis for the King Ferry data

<u>Clone</u>	<u>Mean</u>
S365	89.3 a
SV1	79.8 a b
NM6	75.9 a b
S25	73.9 a b
S185	67.0 a b c
S546	62.5 a b c
S287	61.0 a b c
S19	58.1 a b c
SA2	55.0 a b c
S646	53.9 a b c
S301	50.6 b c
S625	49.1 b c
S566	48.0 b c
SH3	32.0 c

Note: Tukey's HSD was employed with a significance level of 0.05. The minimum significant difference was 35.8. Means with the same letter are not different. Tukey's method controls the experimentwise error rate. All clones had $n = 4$ replications. The standard error for each clone was 7.12.

Table 3.23. Means separation of the C term in the cubic analysis for the King Ferry data.

<u>Clone</u>	<u>Mean</u>
SV1	2.7 a
S287	1.3 ab
S185	0.1 ab
S365	-0.5 ab
S25	-1.1 ab
SH3	-1.5 ab
SA2	-1.7 ab
S546	-1.9 ab
S625	-2.0 ab
NM6	-2.2 ab
S566	-2.3 ab
S19	-2.8 ab
S646	-4.9 b
S301	-5.3 b

Note: Tukey's HSD was employed with a significance level of 0.05. The minimum significant difference was 7.5. Means with the same letter are not different. All clones had $n = 4$ replications. The standard error for each clone was 1.49.

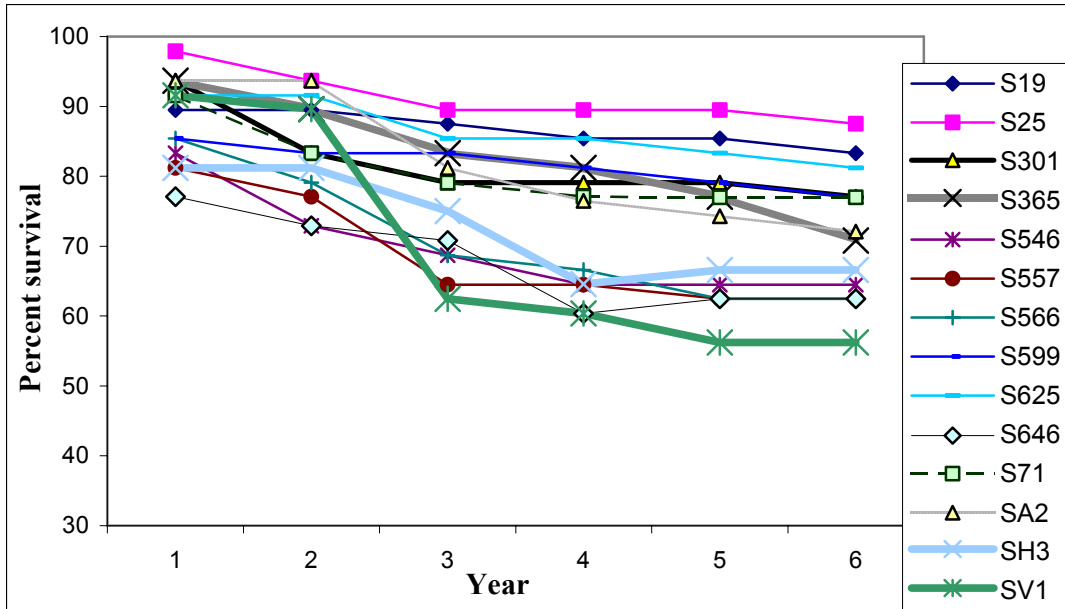


Figure 3.4. Mean survival for all clones at Massena, NY.

Table 3.24. Statistical analysis of estimated coefficients of a cubic polynomial response curve for clone site trials in Massena, NY.

		<u>Whole-unit analysis (Z)</u>							
(A)	<u>Source</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>					
	Mean	1	255,665.8	<0.01					
	Clone	13	187.6	0.26					
	Residual	28	142.2						
		<u>Analysis of RM factor</u>							
		<u>Contrast</u>							
		<u>Linear (B)</u>				<u>Quadratic (Q)</u>		<u>Cubic (C)</u>	
<u>Source</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>
Mean	1	509.7	<0.01	19.1	<0.01	0.24	0.22		
Contrast X clone	13	8.9	0.14	1.0	0.046	0.34	0.04		
Residual	28	5.5		0.5		0.15			

Interpretation

The interaction for the intercept (Z) and linear effects (B) are not significant ($p = 0.26$ and 0.14 respectively). Therefore, all of the clone's response curves have the same intercept and linear components. The quadratic (Q) and cubic (C) terms have a slightly significant interaction ($p = 0.046$ and 0.04 respectively). They imply that at least two of the clone's response curves have different quadratic and cubic components. Thus, a means separation exercise is conducted on these two coefficients.

After running the means separation for the quadratic and cubic components, there were NO coefficients significantly different for either component at the 0.05 significance level. The minimum significant difference was 2.04 and 1.17 for the quadratic and cubic components respectively. Thus, since the interaction values were close to 0.05, they were not significant enough to produce significantly different response curves.

Therefore all of the clones have the same shape and intercept to their response curves at the Massena site.

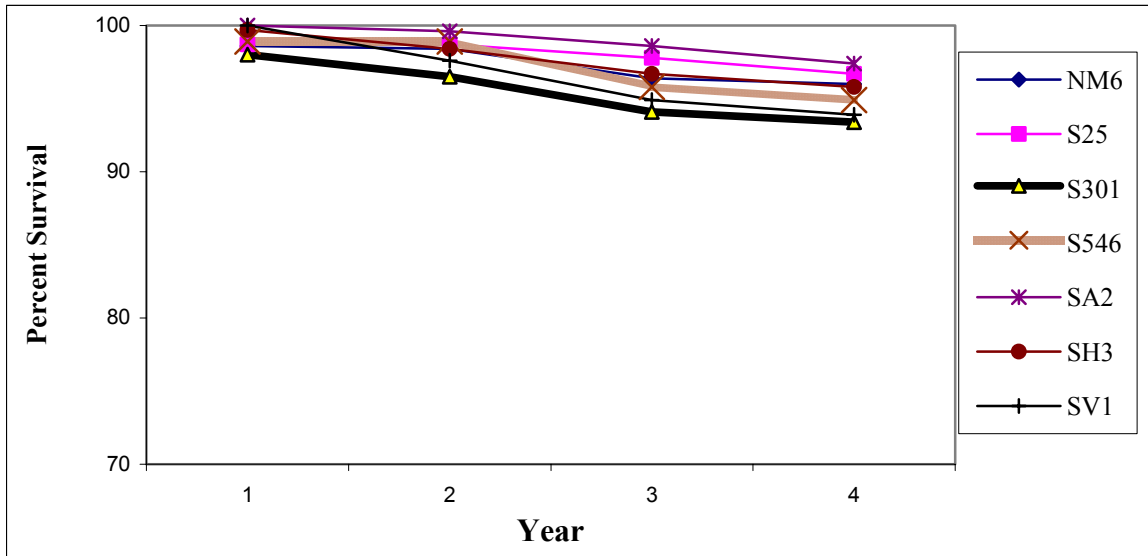


Figure 3.5. Mean survival for all clones at Somerset, NY.

Table 3.25. Statistical analysis of estimated coefficients of a cubic polynomial response curve for clone site trials in Somerset, NY.

(A)		<u>Whole-unit analysis (Z)</u>		
<u>Source</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>	
Mean	1	265,025.7	<0.01	
Clone	6	4.6	0.28	
Residual	21	3.4		

(B)		<u>Analysis of RM factor</u>					
		<u>Contrast</u>					
		<u>Linear (B)</u>		<u>Quadratic (Q)</u>		<u>Cubic (C)</u>	
<u>Source</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>
Mean	1	47.5	<0.01	0.0057	0.81	4.1	<0.01
Contrast X clone	6	1.0	0.43	0.23	0.06	0.3	0.53
Residual	21	0.9		0.095		0.4	

Interpretation

None of the interaction terms are significant (p -values of $p = 0.28$, $p = 0.43$, $p = 0.06$, and $p = 0.53$). Thus, regardless of the clone type, the intercept (Z), linear (B), quadratic (Q), and cubic (C) parts of the response curves are not different (i.e. the response curves have the same shape and intercept).

Since the p -value of the quadratic main effect isn't significant ($p = 0.81$), we can drop the quadratic part of the response curve. Upon doing this and repeating the RM analysis, there were NO changes in the p -values OR in any of the coefficients for the intercept, linear, and cubic components.

Therefore, all of the clones have the same response curves and behave similarly at the Somerset site.

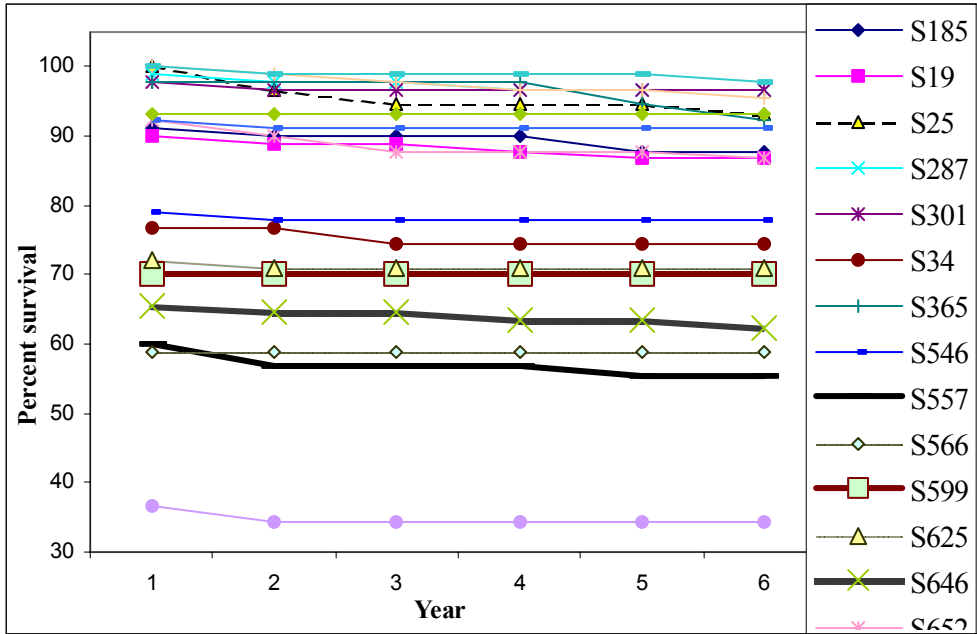


Figure 3.6. Mean survival for all clones at Tully, NY.

Table 3.26. Statistical analysis of estimated coefficients of a cubic polynomial response curve for clone site trials in Tully, NY.

		<u>Whole-unit analysis (Z)</u>		
(A)	<u>Source</u>	<u>df</u>	<u>MS</u>	<u>p-value</u>
	Mean	1	375,679.9	<0.01
	Clone	18	959.7	<0.01
	Residual	38	146.1	

		<u>Analysis of RM factor</u>					
		<u>Contrast</u>					
(B)		<u>Linear (B)</u>		<u>Quadratic (Q)</u>		<u>Cubic (C)</u>	
Source	<u>df</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>	<u>MS</u>	<u>p-value</u>
Mean	1	12.8	<0.01	0.26	0.08	0.12	<0.01
Contrast X clone	18	0.4	0.42	0.078	0.52	0.0095	0.87
Residual	38	0.4		0.081		0.16	

Interpretation

In this case, none of the interaction terms for the linear, quadratic, and cubic parts are significant (p -values of 0.42, 0.52, 0.87). The interaction term for the intercept (Z) is significant with $p < 0.01$. Thus, all of the response curves have the same linear, quadratic, and cubic components (i.e. they have the same shape).

Since the intercept term has a significant interaction, there is a difference for the intercepts among clones. We also note that the quadratic main effect is not significant ($p = 0.08$). Thus, we can drop the quadratic term and redo the RM. When this was carried out, there was no change in the coefficients or p -values for any of the terms.

To determine which clones have a significantly differing intercept a means separation is performed on Z. Tables 29 shows the results of a means separation using Tukey's LSD at the 0.05 significance level.

Table 3.27. Means separation of intercept term (Z) in the whole unit analysis for the Tully data.

<u>Clone</u>	<u>Mean</u>
SP3	98.9 a
SA2	97.6 a
S287	97.4 a
S301	96.9 a
S365	96.3 a
S25	95.6 a b
SV1	93.3 a b c
SH3	91.3 a b c
S185	89.4 a b c
S652	88.7 a b c
S19	88.1 a b c
S546	78.0 a b c
S34	75.2 a b c
S625	71.3 a b c d
S599	70.0 a b c d
S646	63.9 a b c d
S566	58.9 b c d
S557	56.8 c d
S71	34.8 d

Note: Tukey's Honest Significant Difference was employed with a significance level of 0.05. The minimum significant difference was 37.2%. Means with the same letter are not significantly different. Tukey's method controls the experimentwise error rate to 0.05. All clones had $n = 3$ replications. The standard error for each clone was 6.98.

3.2 First-rotation Survival and Production (Final Report)

3.2.1 Survival and mean biomass by site

End-of-rotation survival across all clones at each site equaled or exceeded 80% at all but two sites (Table 3.28). Survival was 73% at Massena (Mas) and 78% at Wolcott (Wol). Across all clones, mean biomass production over the three-year rotation varied from 8-24 odt ha⁻¹. Burlington (Bur) was the highest, at almost 27 odt ha⁻¹ but over a four-year rotation. Lafayette (Laf) had the lowest mean biomass production, and both Sheridan (Sher) and Tully (Tul) averaged less than 20 odt ha⁻¹. Included in Table 3.28 are the minimum and maximum biomass productions on an individual replicate basis. These maximums show that production potential for some clones, under good conditions, can exceed 30 odt ha⁻¹. It should be noted that the maximum at Laf was a hybrid poplar clone (NM6). No willow clone at that site exceeded 10 odt ha⁻¹. Excluding the poplar clones NM6 and NM5 (where planted) reduced the mean biomass production, but only Delaware (Del) and Laf were greatly affected, with the mean biomass falling to 12.4 odt ha⁻¹ and 4.9 odt ha⁻¹, respectively. Mean survival and biomass production by clone for each site are presented in Appendix 2.

When only the five best-producing willow clones at each site are considered, the ranking of the sites in terms of biomass production changes (Table 3.29). Mas had the best biomass production (but over a 4 year rotation) and Sher and Laf are the only sites to produce less than 20 odt ha⁻¹. Biomass production of the top five willow clones relative to SV1 is shown in Table 3.30. At sites where they were planted, SX61 and SX64 consistently out-produced SV1. Mean biomass and survival for the individual top-producing clones at each site are presented in Table 3.31.

Table 3.28. Mean biomass production and survival across all clones after one rotation at eight clone site trial locations.

Site	N ¹	Biomass production (odt ha ⁻¹)				Survival (%)
		Mean	Std Err	Minimum	Maximum	
Bur ²	21	26.6	1.5	8.0	41.2	91.3
Can	56	23.9	1.0	10.9	44.2	95.4
Wol	48	21.5	1.7	4.1	48.8	77.8
Del	55	20.6	3.2	0.1	78.3	96.8
Mas	42	20.3	1.9	5.2	68.0	73.0
Tul	57	17.7	0.7	7.7	28.7	79.7
Sher	48	14.8	0.9	4.2	29.6	86.1
Laf	64	7.8	1.1	0.1	32.9	82.4

¹ – N is the

number of clones time the number of replications at each site.

² – Bur had a four-year rotation. All others were three-year rotations.

Table 3.29. Mean biomass production of the top five willow clones at eight clone site trial locations. Annual production is the mean divided by the years in the rotation at each site.

	N	Biomass Production (odt ha ⁻¹)		Annual Production (odt ha ⁻¹ yr ⁻¹)
		Mean	Std Err	
Mas	15	31.1	3.6	7.8
Can	20	29.9	1.3	10.0
Bur	15	27.1	1.5	9.0
Wol	20	25.9	2.7	8.6
Del	20	24.8	3.0	8.3
Tul	15	21.0	1.3	7.0
Sher	20	18.7	1.4	6.2
Laf	20	7.9	1.0	2.6

Table 3.30. Relative biomass production over one rotation of the top five willow clones at each site with SV1 used as a reference clone.

Bur		Can		Del		Laf	
Clone	Relative Production (%)	Clone	Relative Production (%)	Clone	Relative Production (%)	Clone	Relative Production (%)
SX61	45.3	SX64	12.2	SX64	1746	SX61	37.3
SV1	0.0	SX61	8.7	SX67	1370	S301	36.5
S25	-3.4	SV1	0.0	SX61	1297	PUR34	23.2
S19	-3.9	FC185	-1.6	S25	1111	SX64	3.0
S301	-5.5	S365	-18.5	S301	570	SV1	0.0
S365	-24.6	S646	-27.4	SV1	0.0	PUR12	-4.9
Mas		Sher		Tul		Wol	
Clone	Relative Production (%)	Clone	Relative Production (%)	Clone	Relative Production (%)	Clone	Relative Production (%)
SV1	0.0	SX64	27.3	SV1	0.0	SX61	37.8
S365	-3.7	SX61	10.1	S287	-17.9	S25	1.5
S301	-17.2	SV1	0.0	S365	-23.1	SV1	0.0
S625	-25.0	PUR34	-19.5	S301	-31.5	S365	-11.7
S25	-32.5	SX67	-22.6	S34	-35.4	SX67	-17.2
S19	-47.1	PUR12	-28.1	S25	-36.9	S301	-19.6

Table 3.31. Mean biomass and survival of the top five biomass-producing clones in addition to SV1 at each site. SE is standard error.

Site	Clone	Biomass Production (odt ha ⁻¹)		Survival (%)	
		Mean	SE	Mean	SE
Burlington	SX61	37.0	2.95	97.3	1.55
	SV1	25.4	3.08	79.1	21.5
	S25	24.6	1.14	93.7	3.89
	S19	24.4	1.45	98.5	0.52
	S301	24.0	0.24	96.4	2.36
Canastota	SX64	33.5	1.75	99.1	1.67
	SX61	32.4	4.08	99.1	1.67
	SV1	29.8	2.84	100	0
	FC185	29.4	1.37	98.3	1.92
	S365	24.3	3.23	83.3	22.9
Delaware	SX64	34.7	5.08	97.5	1.67
	SX67	27.6	9.83	96.2	3.7
	SX61	26.3	4.46	97.0	2.85
	S25	22.8	5.94	96.6	3.33
	S301	12.6	3.89	95.4	4.17
Lafayette	SX61	9.0	2.55	81.6	6.68
	S301	8.9	1.42	94.5	3.72
	PUR34	8.1	2.3	96.4	5
	SX64	6.8	3.42	83.2	15.9
	SV1	6.6	1.61	87.1	8.21
Massena	SV1	36.8	16.18	56.2	6.25
	S365	35.5	6.06	77.0	23.6
	S301	30.5	8.19	79.1	3.58
	S625	27.6	4.93	83.3	9.52
	S25	24.9	4.48	89.5	7.22
Sheridan	SX64	24.0	2.8	89.1	8.66
	SX61	20.8	1.39	75.8	11.3
	SV1	18.8	0.95	96.6	3.85
	PUR34	15.2	1.26	98.7	2.5
	SX67	14.6	5.03	62.0	7.25
Tully	SV1	26.8	0.32	93.3	6.51
	S287	22.0	3.64	96.6	3.51
	S365	20.6	1.56	98.0	1.73
	S301	18.4	1.49	97.0	0
	S34	17.3	4.2	74.3	18.6
Wolcott	SX61	35.0	7.63	80.8	25.4
	S25	25.8	3.69	93.3	6.67
	SV1	25.8	8.38	65.0	28.4
	S365	22.4	6.05	63.3	34.8
	SX67	21.0	3.33	40.0	19.4

3.2.2 Within-site correlations

The correlation between survival and biomass production among all clones across all sites was 0.31 with a p-value of 0.0007. Biomass of the top five willow producers was not correlated with survival or foliar nutrient concentrations across all sites. However, significant correlations were found at some individual sites. Biomass yield was negatively correlated with Mg at Bur and Can (Table 3.32). At Del, biomass was positively correlated with Ca and survival. At Laf, biomass was positively correlated with all nutrient concentrations except Mg, as well as survival. Biomass at Tul was positively correlated with P, while at Wol biomass was positively correlated with Ca and survival.

Table 3.32. Pearson correlation coefficients (and p-values) for foliar nutrient concentrations and survival with biomass production at each site.

Site	N	P	K	Ca	Mg	Survival
Bur	-0.05	-0.28	-0.43	0.35	-0.55 ¹	0.34
	0.8543	0.3079	0.1098	0.1993	0.0336	0.2142
Can	-0.10	-0.10	0.16	0.16	-0.46	-0.02
	0.6697	0.6963	0.5190	0.5087	0.0468	0.9356
Del	0.08	0.12	-0.05	0.48	0.23	0.43
	0.7450	0.6313	0.8546	0.0373	0.3384	0.0586
Laf	0.66	0.54	0.35	0.54	0.06	0.62
	0.0001	0.0028	0.0644	0.0029	0.7684	0.0005
Mas	0.12	0.46	-0.28	-0.16	0.02	-0.04
	0.6621	0.0852	0.3058	0.5641	0.9428	0.8897
Sher	0.28	0.01	0.30	0.44	-0.42	0.34
	0.2289	0.9978	0.1929	0.0551	0.0679	0.1484
Tul	0.52	0.59	-0.04	0.32	-0.07	0.43
	0.0570	0.0265	0.8890	0.2586	0.8137	0.1060
Wol	0.02	0.11	0.38	0.53	-0.27	0.69
	0.9206	0.6470	0.1129	0.0205	0.2566	0.0008

¹ – Bold denotes significant at $\alpha = 0.05$.

3.2.3 Canonical discriminant analysis

The five willow clones at each site with the best biomass production were used in a canonical discriminant analysis on total biomass production and foliar nutrients. Analysis revealed that sites were differentiated by foliar P and Mg concentrations as well as biomass (Table 3.33). Wol and Bur are highly positive on the first canonical axis (Axis1),

strongly associated positively with P concentration and negatively with Mg concentration. Del and Mas were highly positive on the second canonical axis (Axis2), associated positively with Mg concentration and biomass production (Figure 3.7). The Mahalanobis distances, testing the hypothesis that the canonical coefficients of the linear combinations equal zero, were significant for all sites.

3.2.4 Soils

Canonical discriminant analysis using the measured chemical and physical properties of the soil at each site confirmed differences among sites. The x-axis (Axis1) (Figure 3.8) was positively influenced by Mg, pH and the silt fraction, and negatively by the sand and clay fractions. The y-axis (Axis2) was most strongly negatively influenced by the silt fraction (Table 3.34). Interpretation of the results reveals Can and Laf have the highest pH, Mg concentration and silt fractions. Bur has high pH and the greatest proportion of silt of all sites. Wol, Sher and Tul are more acidic sites, but Wol has a high sand fraction and is lower in Mg than any other site. The Mahalanobis distances, testing the hypothesis that the canonical coefficients equal zero, were significant in all cases. Soil data by horizon by site is presented in Appendix 3.

Table 3.33. Pooled within-class standardized canonical coefficients (loadings) for total biomass production and foliar nutrient concentrations.

Variable	Axis1	Axis2
Biomass	-0.19	0.56
N	0.26	-0.04
P	0.75	0.26
K	0.21	0.53
Ca	0.37	0.23
Mg	-0.69	0.70

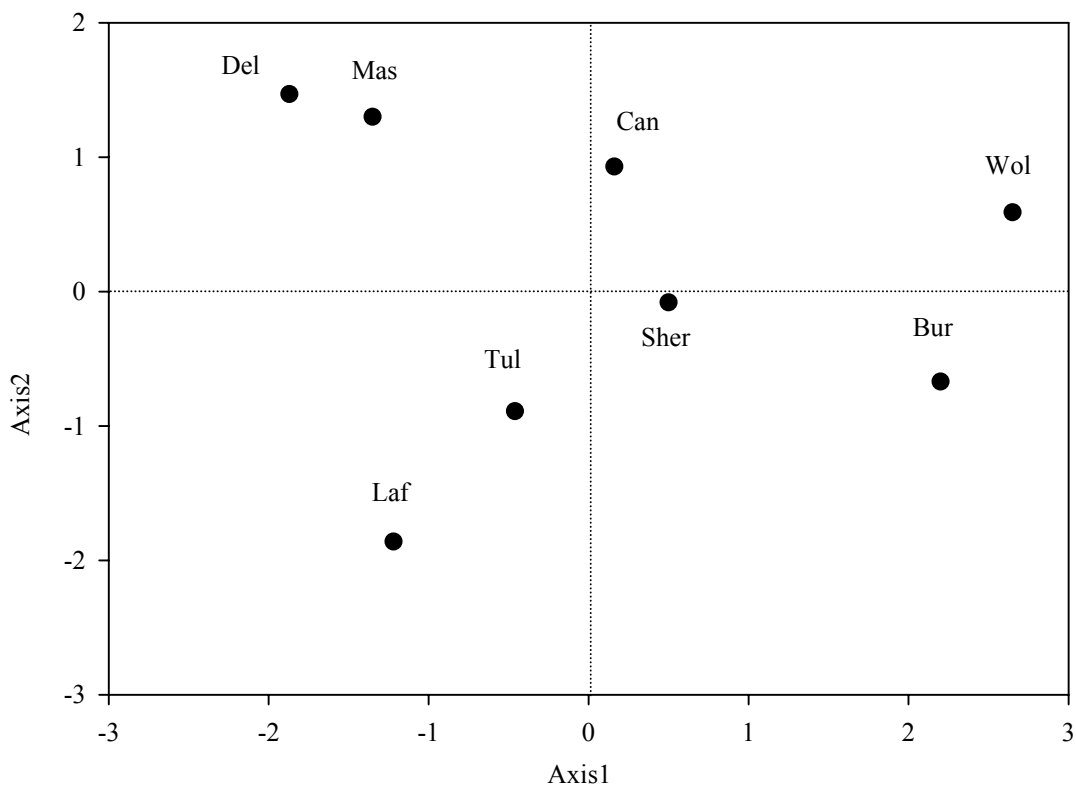


Figure 3.7. Distribution of sites, by mean canonical discriminant coefficients, by total biomass production and foliar nutrient concentrations. Loadings are in Table 3.33.

Table 3.34. Pooled within-class standardized canonical coefficients (loadings) for axes in Figure 3.7.

Variable	Axis1	Axis2
pH	1.153	0.333
Organic Matter	-0.511	-0.189
N	-0.103	-0.066
P	-0.337	-0.472
K	-0.164	0.231
Ca	-0.083	0.390
Mg	0.942	0.362
Na	-0.120	-0.427
Sand	-1.350	-0.080
Silt	0.946	-0.829
Clay	-0.735	-0.143

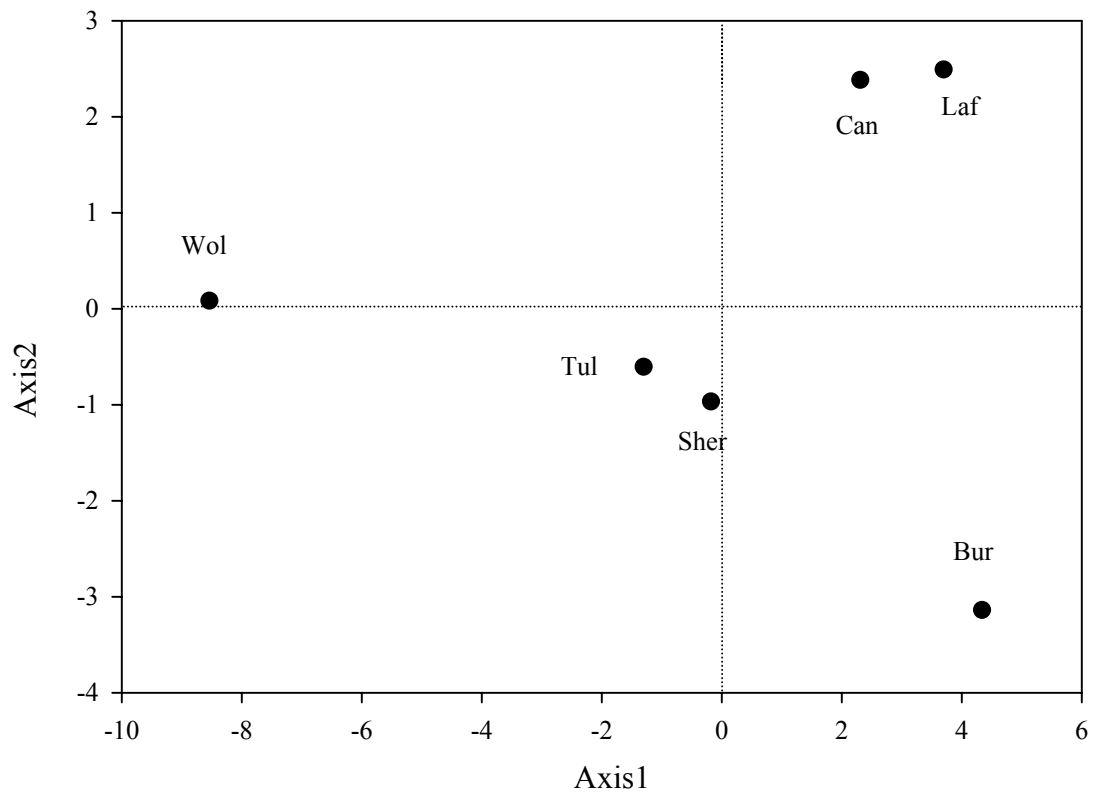


Figure 3.8. Mean canonical discriminant separation on soil data from each of the six sites where data was collected. Loadings for axes are presented in Table 3.34.

3.2.5 Soil by willow relationships

Across all five sites (Laf was excluded from this analysis, as the extremely low biomass production is thought to be due to inadequate weed control) and willow clones, there were significant correlations between mean soil parameters by horizon and willow characteristics (Table 3.35). Survival was correlated to all parameters in the A-horizon except pH and K. Survival was not correlated to organic matter, N or the silt fraction in the B-horizon. It was positively correlated to all other parameters except the sand fraction, which was negatively correlated. Biomass was correlated to pH, P, Ca, Mg and Na in the A-horizon. There was a positive correlation between pH, P, Ca, and Mg in the B-horizon, and a negative relationship with B-horizon organic matter, N concentrations and cation exchange capacity (CEC).

Considering only the top five willow clones at each site strengthens most of the stronger correlations and eliminates some of the weaker correlations found among all clones (Table 3.36). Of particular note is that survival becomes negatively correlated with K in the A-horizon, but the correlation disappears in the B-horizon. Survival also becomes significantly correlated with N in the B-horizon. Biomass was no longer correlated with P or Na in the A-horizon and the correlation with B-horizon CEC disappeared. Scatter plots (Figures 3.9 and 3.10) show the general correlation patterns.

Willow clones S301, S365 and SV1 were planted at each of the five sites included in this analysis. There were some significant correlations between biomass and soil characteristics (Table 3.37). Biomass of S301 was positively correlated to pH and negatively correlated to percent clay in the A-horizon. It was negatively correlated to organic matter, K, CEC and percent clay in the B-horizon. S365 biomass was positively correlated to A-horizon pH and negatively correlated to B-horizon organic matter. SV1 production was not correlated to soil characteristics of either horizon.

Table 3.35. Pearson correlation coefficients (and p-values) for biomass and survival with soil characteristics by horizon across all willow clones at five clone-site trial locations.

	pH	OM	N	P	K	Ca	Mg	Na	CEC	sand	silt	clay
A-horizon												
Biomass	0.41 ¹	0.12	-0.05	0.16	0.10	0.35	0.26	0.18	0.12	0.08	-0.07	-0.09
	<.0001	0.0792	0.4968	0.0225	0.1382	<.0001	0.0001	0.0074	0.0771	0.2195	0.3061	0.1693
Survival	0.11	0.30	0.19	-0.19	-0.04	0.25	0.30	0.32	0.30	-0.23	0.20	0.24
	0.1115	<.0001	0.0044	0.0050	0.5534	0.0002	<.0001	<.0001	<.0001	0.0006	0.0029	0.0003
B-horizon												
Biomass	0.38	-0.36	-0.24	0.37	0.11	0.19	0.25	0.10	-0.16	0.10	-0.11	-0.07
	<.0001	<.0001	0.0004	<.0001	0.1034	0.0064	0.0002	0.1274	0.0166	0.1264	0.0961	0.3310
Survival	0.28	0.02	0.06	0.33	0.24	0.32	0.32	0.28	0.20	-0.21	0.12	0.27
	<.0001	0.7374	0.4030	<.0001	0.0003	<.0001	<.0001	<.0001	0.0027	0.0021	0.0812	<.0001

¹ – Bold denotes significant at $\alpha = 0.05$.

Table 3.36. Pearson correlation coefficients (with p-values below) between biomass and survival of the top five willow clones and soil parameters at five clone-site trial locations.

	pH	OM	N	P	K	Ca	Mg	Na	CEC	sand	silt	clay
A-horizon												
Biomass	0.47¹	0.15	0.02	0.17	0.15	0.42	0.30	0.12	0.16	0.11	-0.11	-0.08
	<.0001	0.1453	0.8170	0.1017	0.1670	<.0001	0.0040	0.2717	0.1349	0.2931	0.2995	0.4323
Survival	-0.04	0.32	0.26	-0.43	-0.26	0.20	0.26	0.45	0.35	-0.46	0.43	0.38
	0.7408	0.0025	0.0139	<.0001	0.0145	0.0592	0.0125	<.0001	0.0006	<.0001	<.0001	0.0003
B-horizon												
Biomass	0.44	-0.39	-0.29	0.40	0.08	0.22	0.28	0.07	-0.16	0.15	-0.16	-0.07
	<.0001	0.0001	0.005	0.0001	0.4432	0.0352	0.0066	0.5049	0.1425	0.167	0.1219	0.5008
Survival	0.27	0.19	0.28	0.35	0.09	0.40	0.29	0.48	0.36	-0.43	0.34	0.39
	0.0089	0.0772	0.0064	0.0007	0.4168	0.0001	0.0049	<.0001	0.0005	<.0001	0.001	0.0001

¹ – Bold denotes significant at $\alpha = 0.05$.

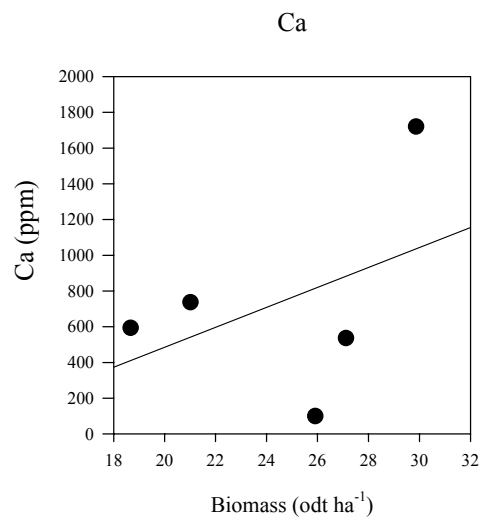
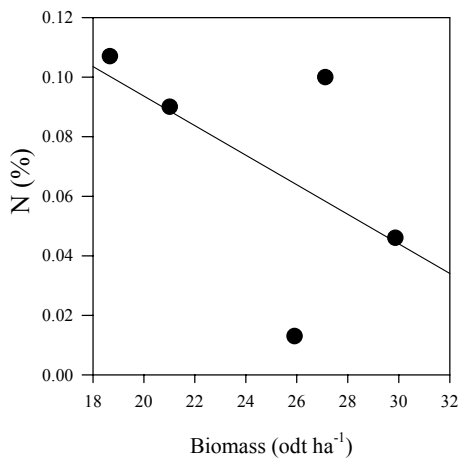
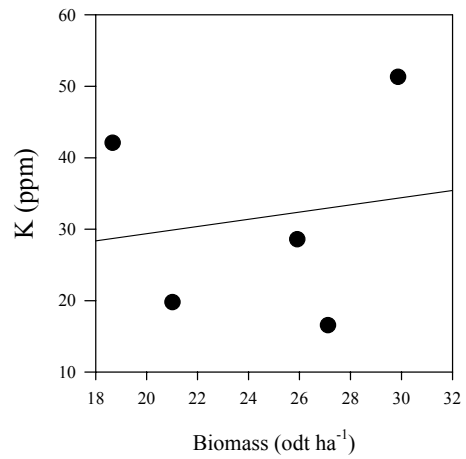
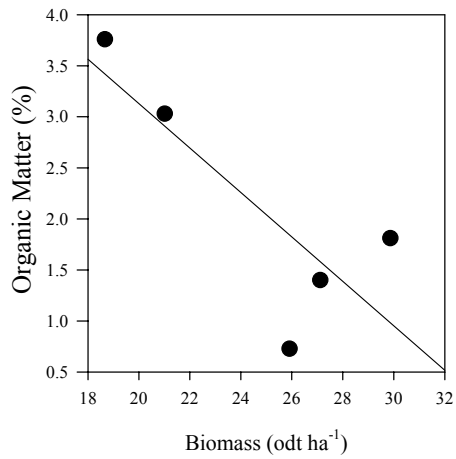
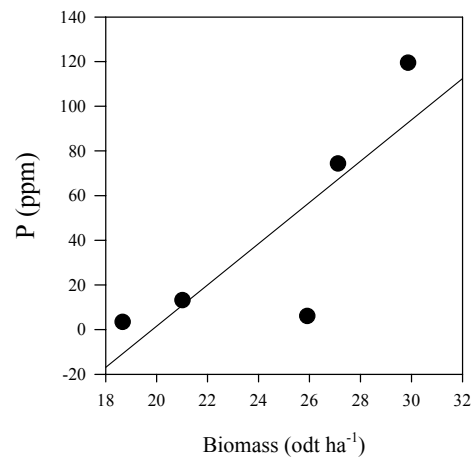
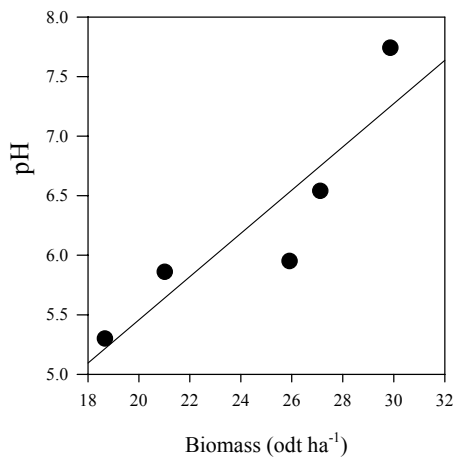


Figure 3.9. Scatter plots of A-horizon soil characteristics and biomass at five clone-site trial locations.

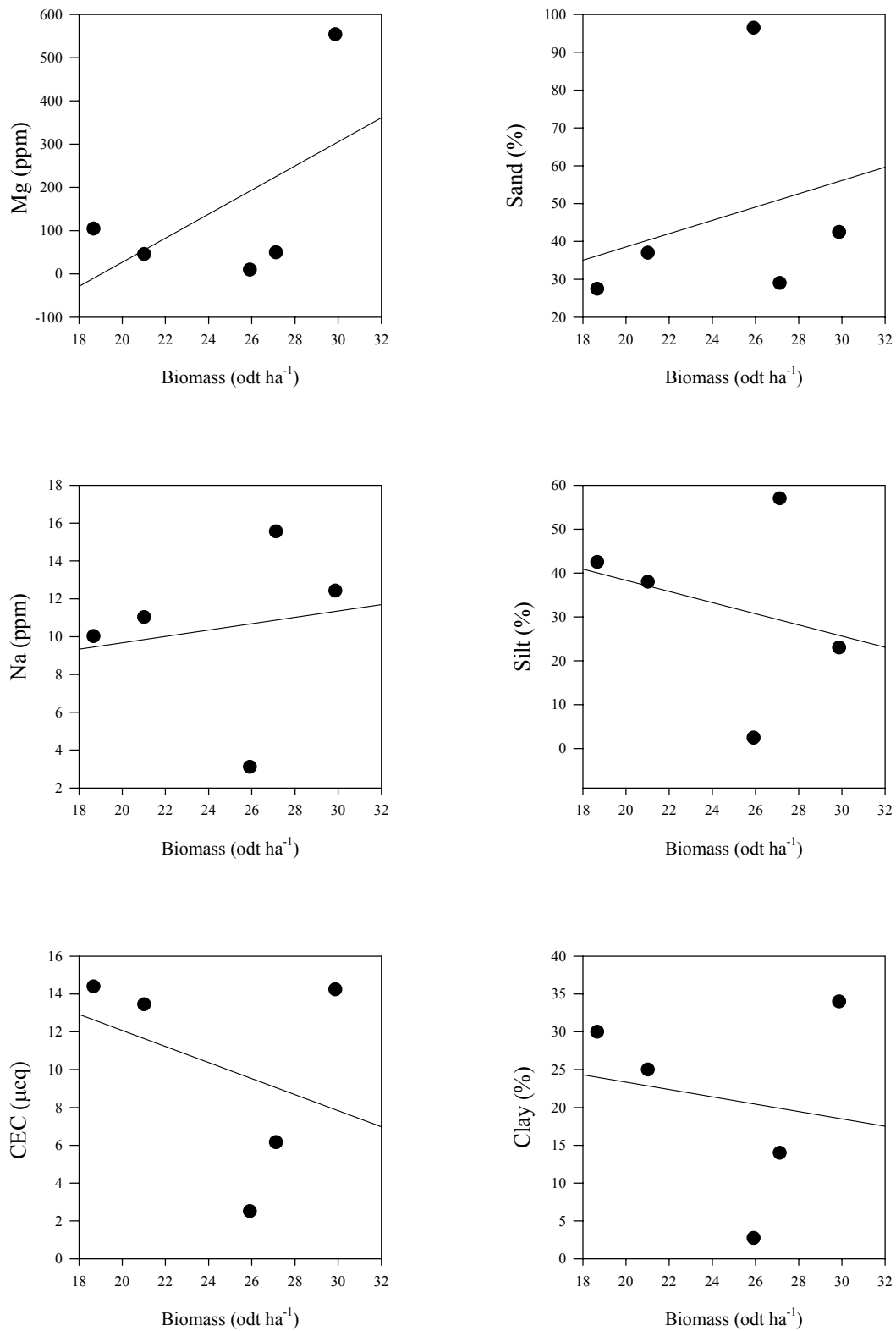


Figure 3.10. Scatter plots of A-horizon soil characteristics and biomass across 5 clone-site trial locations.

Table 3.37. Pearson correlation coefficients (with p-values below) for biomass of three willow clones with soil characteristics across five sites.

Horizon	Clone	pH	OM	N	P	K	Ca	Mg	Na	CEC	sand	silt	clay
A	S301	0.68¹	-0.23	-0.35	0.42	-0.07	0.36	-0.003	0.12	-0.19	0.31	-0.16	-0.51
		0.002	0.3524	0.1584	0.0865	0.7928	0.1471	0.9919	0.6435	0.4461	0.2140	0.5290	0.0314
	S365	0.57	0.15	0.11	0.28	0.29	0.48	0.28	-0.06	0.15	0.25	-0.27	-0.15
		0.0141	0.5588	0.6664	0.2627	0.2506	0.0425	0.2559	0.8035	0.5429	0.3184	0.2844	0.5623
	SV1	0.36	0.20	0.16	0.07	0.14	0.38	0.27	0.06	0.21	0.04	-0.07	0.02
		0.1399	0.4227	0.5131	0.7908	0.5685	0.1200	0.2742	0.8004	0.3950	0.8604	0.7752	0.9358
B	S301	0.46	-0.75	-0.36	0.38	-0.49	-0.05	-0.04	0.11	-0.57	0.31	-0.11	-0.50
		0.0573	0.0003	0.1416	0.1226	0.0381	0.8539	0.8892	0.6661	0.0126	0.2171	0.6698	0.034
	S365	0.47	-0.49	-0.45	0.34	-0.05	0.20	0.24	-0.05	-0.22	0.31	-0.33	-0.17
		0.0512	0.0391	0.0579	0.1637	0.8373	0.4264	0.3414	0.8297	0.3806	0.2083	0.1791	0.4991
	SV1	0.38	-0.26	-0.23	0.32	0.01	0.25	0.25	0.08	-0.03	0.10	-0.15	0.01
		0.1183	0.2926	0.3491	0.1997	0.9562	0.3173	0.3163	0.7587	0.8946	0.7018	0.5652	0.9793

¹ – Bold denotes significant at $\alpha = 0.05$.

4.0 DISCUSSION

4.1 *Early Rotation Survival (Interim Report)*

Preliminary results from the study demonstrate that willow clonal survival varies considerably across clones and across sites. The contributing factors probably include aspects related to site such as soil, climate and site history, and aspects related to the plantation itself such as establishment practices and maintenance.

Over 90% survival can be realized in the first year after planting with almost all the clones used in this study on at least a few of the sites. Four clones (S652, S19, S25, SX61) had <80% on at least one site, however, it should be noted that in these cases, the poor performance may have been caused by adverse site conditions resulting from inadequate weed competition control, rather than poor clonal vigor.

Minimizing weed competition is critical to the establishment of willow and other short-rotation woody crops (Ledin and Willebrand 1996; Bergkvist and Ledin 1997). Weed competition had not been explicitly measured in these trials and therefore it was not possible to quantify the specific extent of its influence on clonal survival. However, weed competition appeared to have been a major factor in several of the trials. Initial mechanical and chemical weed control efforts at Himrod were inadequate and subsequently, the intense weed competition resulted in the failure of the trial. Weed problems in the 1997 Wolcott trial may have been due to application of the pre-emergent herbicide at an inadequate rate or delayed application after the weeds had germinated. The problem was compounded by the application of poultry manure to the site in fall of the previous year. The manure may have contained large amounts of weed seed that grew vigorously due to the high fertility associated with the manure. A new planting at Wolcott was successfully established the next year (1998), however weed competition may have still affected willow survival as evidenced by relatively moderate survival percentages at this site (Table 3.14). Weeds also appeared to be a problem at the King Ferry trial.

Since the primary emphasis of this production system is to realize full site occupancy as rapidly as possible leading to maximum light interception and subsequent conversion to

biomass, efforts have to be dedicated to ensuring maximum clonal survival in a cost effective manner. This can be achieved by combining effective chemical and mechanical weed techniques with clones that are tolerant to weed competition.

First year survival was greater than 90% for all clones at Burlington, Easton, and Somerset. Relatively rigorous weed control using both chemical and mechanical means had been maintained on these sites. High rates of survival on these sites are indicative of the level of plantation establishment that is possible when proper cultural practices are applied on a good quality site.

Weed control, however, is an expensive management intervention. A cost effective alternative would be to use clones that compete well against weeds on sites where weed competition may be a problem. This study provides some initial evidence that a few of the clones tested may have the ability to withstand some weed competition. This ability however is moderated by site characteristics. Hybrid poplar clone NM6 (99.2%) and willow clone S301 (90.8%) at the Wolcott trial, and S365 (94.6%), NM6 (94.0%) and willow clone SV1 (93.1%) at the King Ferry trial, appeared to be able to tolerate weed competition without an associated loss in survival. Some of these clones, however, fared relatively poorly at other weed-infested sites; clone S365 (67.5%) and clone SV1 (75.0%) at Wolcott and clone S301 (76.1%) at King Ferry. Site related stress factors, such as low moisture, might have accentuated weed competition related loss in clonal survival.

High levels of weed competition may not affect survival, but may adversely affect biomass production. Thus, information on clonal biomass production rates at different levels of weed competition are essential for a more comprehensive evaluation of a clone's tolerance to weed competition. It is envisaged that the analysis of growth and biomass production data collected at these sites will provide insights into this issue.

Three sites were found to be relatively unsuitable for the establishment of hybrid poplar and willow as indicated by the first year site mean survival; Wolcott, King Ferry, and Leon. As described above, while the Wolcott and King Ferry sites had weed problems, the Leon site did not. Low survival at Leon may be related to the relatively shallow depth

to bedrock or other limiting soil condition. A detailed analysis of soil physical and chemical characteristics at all the sites was initiated. Even with the wide range of sites tested, only one site, Leon, seems to have suffered from soil associated limitations. This bodes well for the willow bioenergy program, however it should be noted that these inferences are still only preliminary and evaluations over multiple rotations are needed to make a more conclusive recommendation. The preliminary results of this study suggests that although clonal differences exist, willow in general is a robust plantation crop capable of high survival and potentially high biomass production on a wide range of sites.

The different patterns of survival as a function of time observed among the four trials may be indicative of site quality and cultural practices. The quadratic curve shape observed for Massena and King Ferry, wherein survival decreased rapidly during the early stages of plantation development, was most likely due to the effect of weeds or some other form of interference (e.g., browsing by white-tailed deer). The flat pattern of survival at Tully indicates a combination of favorable site and adequate cultural practices that minimized both weed and browsing damage. In Somerset, the cause of the S-shaped or cubic pattern is unclear. However, it should be noted that since survival was over 90% during the entire period, the effects of the factors that caused the cubic pattern were nominal. In general, it appears that effects of interference on survival, including weeds, would be exhibited early and tends to persist until the trees died or grew past the interference problem (e.g. browsing height). The three distinct patterns of survival over time observed on the different sites may be useful in the future for differentiating the sites into site-quality classes. For example, a flat pattern with uniformly high survival percentage from one year to another would indicate a good quality site and a curvilinear pattern, with large variation in year-to-year survival percentage, a poor quality site. It should be noted that a more comprehensive evaluation of site quality should involve an assessment of clonal biomass production rates over time on different sites. The planned analysis of biomass production data collected at these sites may provide insights into this issue.

Based on site adaptability, clones can be classified as either “plastic” or “site specific” (Hansen et al. 1992). Those performing equally well in a variety of environments are termed “plastic” and those that do well only under specific conditions are called “site specific”. Both types of clones have a place in the selection program; the relative importance of each is dependent on the diversity of the planting sites. Interim results indicate that some clones are plastic in nature: hybrid poplar clone NM6 and willow clone SV1 appear to be the most plastic, followed by willow clones S301 and S365. Across sites, these four clones had first year survival percentage averages of 98, 94, 94, and 87%, respectively. NM6 had over 90% survival in all the nine sites it had been planted on. Clones SV1, S301, and S365 had over 90% survival in 10 out of 11, 9 out of 11 and 6 out of 10 sites, respectively. They, however, fared only moderately on at least one of the three poor sites identified earlier; SV1 in Wolcott (75% first year survival), S301 in King Ferry (76%), and S365 in King Ferry and Leon (67%, and 68%). Clone SV1 have been the mainstay of the willow bioenergy program since its inception. Clones S301 and S365 are relatively new to the program. Hybrid poplar NM6 has historically served as a useful reference clone. Of the four, NM6 appears to be the most plastic, followed closely by SV1.

Site-specific clones are more difficult to judge in these clone-site trials since few other clones (other than the plastic clones) were planted across a wide range of sites. Willow clone S25, the only other clone to be planted on multiple sites can be considered less plastic. Survival percentages ranged from 33% in Leon to 100 % in Tully and the average survival percentage across sites was 83%. Upon excluding the Leon site, survival averaged 92% with 3 out of 6 sites having survival percentages over 90%.

This reports uses clonal survival percentages to present a preliminary analysis of the interaction between genotype and environment. Further analysis of end of rotation survival percentage and biomass production at harvest, will provide a more rigorous assessment of which clones are “plastic” and which are site-specific. This information, in conjunction with site-specific data on climate and soils, will help describe the nature and

extent of genotype X environment interactions and the environmental factors that are primarily responsible.

4.2 End-of-rotation survival and biomass production (Final Report)

4.2.1 End-of-rotation survival and mean biomass by site

Survival rates of 80% or greater have been considered acceptable for SRIC plantations (Volk et al. 1999). While three of the eight sites evaluated after first rotation had overall survival rates below this threshold, only Massena, at 73.0%, was appreciably lower. Wol and Tul, at 77.8% and 79.7% were very close to the 80% survival goal and should be considered successful by this measure. Overall, survival rates across all clones were not correlated with mean biomass production at these sites. While Bur and Can had the highest mean biomass production and survival greater than 90%, the third highest biomass production was at Wol, where survival was 78%. Additionally, the lowest biomass production sites, Laf and Sher, had survival rates over 82%.

Individually, survival among the top five biomass producing clones at each site was often below 80%. Indeed, 23% (9 of 40) of the clones that were top biomass producers at each site were below the 80% threshold. While there was a significant correlation between survival and biomass production among the top five clones, the correlation was relatively weak and explained only 31% of the variability. This suggests that survival cannot be solely used as an indicator of plantation success early in the rotation. This is further supported by the variable survival responses seen in the interim report, where survival remained steady over the rotation at some sites, and decreased annually at others.

These survival/biomass results are probably due to planting density accounting. These clone-site trials were planted at a density of 15,200 plants ha⁻¹. An 80% survival rate corresponds to 11,500 plants ha⁻¹. If the clones grow rapidly and weed control is sufficient, the willow can still attain excellent site capture and high leaf area development, compensating for mortality (McCracken and Dawson 1996). Successful willow biomass plantations in the UK and Sweden have planting densities as low as 10,000 plants ha⁻¹ (Willenbrand et al. 1993; Bullard et al. 2002), which corresponds to a 66% survival based on our densities. While generally yields are higher at higher densities

(Bullard et al. 2002), these results indicate that, at least with some clones, lower survival rates can be used in evaluating successful plantings. However, while biomass production may be compensated for by increased growth, this may lead to complications at harvest, as the stem diameters may become greater than the harvest machinery can handle.

When evaluating only the top five willow biomass producers at each site, the ranking of the sites changes somewhat. Mas (4-year rotation) had the highest biomass production site while Bur fell to third. The remaining sites remain in the same order. The production of these clones was greater than the expected long-term yield of 11.25 odt ha⁻¹ (Volk et al. 1999) at all sites except Laf. Yields across all clones were above or near this expectation, except Laf and some clones at Del, but the top five were two- or three times this value at most sites.

Early studies indicated that clone SV1 was the most consistent and highest willow biomass producer in the SUNY-ESF collection (Volk et al. 1999; Kopp et al. 2001). SV1 was among the top five willow producers at all sites except Del, where it had neither good survival nor growth. While it is difficult to fully assess the role of site because few of the same clones were planted across the sites, results suggest that the best biomass producing clones across all sites (SX61, SX64, PUR34, SV1) are “plastic” rather than “site specific”, as these clones performed well across a range of sites. Potentially site-specific clones include S365, which did well on some sites and poorly on others. However, even for plastic clones, limits related to climatic adaptations will affect performance. This is probably the case in Del, where SV1 did not perform well. The clone SV1 (the *Salix xdasyclados* ecotype) originated in Ontario, Canada, and therefore was likely not adapted for more southerly climates. Future research should focus on plastic clones that can be planted across a wide range of sites, and the soil and climate characteristics that affect the production of site-specific clones.

4.2.2 Biomass correlations

Across clones, percent survival was not consistently correlated with biomass over all sites. However, at Laf and Wol, sites with low survival percentages, overall biomass was correlated with survival. At most sites, overall survival was high enough not to affect

biomass production. However, when considering just the top five clones at each site, there was a 31% correlation between biomass and survival, since some clones were able to attain full site occupancy despite lower survival. While there were some site-specific correlations between biomass production and foliar nutrients, there was no overall pattern.

The exception was at Laf, where there were significant correlations between biomass and foliar concentrations of N and P. Weed populations, a severe problem at this site, may have competed with willow for nutrients and moisture. Research suggests that during the establishment year weeds generally out compete willow for light, leading to reduced biomass (Sage 1999). Since reduced biomass growth in the establishment year is coincident with reduced root development (CITE), strongly established weed populations may compete for nutrients in subsequent years. Alriksson (1997) found positive correlations between foliar N and biomass production at sites in Sweden, similar to the results at Laf. However, the ability of clones to utilize N is strongly influenced by site conditions (Alriksson 1997).

There was no correlation between foliar N and biomass at the other sites in this study, suggesting N is not normally limiting across our range of site conditions and fertilization regimes. Annual N uptake in highly productive poplar stands was as high as 92 kg ha⁻¹ (Berthelot et al. 2000), and is estimated to be 75-100 kg ha⁻¹ for our willow clones (Adegbidi 1999). These values are below our N fertilization rates. However, if only 60-80% of this uptake is returned to the soil through leaf litter (Berthelot et al. 2000), it is possible that N limitation will occur late in the rotation of some clones. Adegbidi (2000) found that the addition of organic soils amendments or slow-release fertilizers had a positive effect on biomass production.

4.2.3 Canonical discriminant analysis

Canonical discrimination separated sites along multivariate axes derived from foliar characteristics and biomass production. This analysis was useful to demonstrate the degree of variation in willow characteristics across sites. However, the influential parameters, primarily foliar concentrations of P and Mg, fell within normal ranges for

willow (Kopinga and van den Burg 1995; Ericsson et al. 1992) and so probably did not influence biomass.

4.2.4 Soils

Canonical discriminant analysis separated the sites by a combination of soil texture, Mg concentration and pH. This analysis illustrates the variation among sites included in this study. Mg concentrations varied widely in this study, hence was an influential parameter in site separation. However, because Mg is required in relatively large amounts (Hopkins 1995), its concentration in soils can be influential in biomass production, as discussed below.

4.2.5 Soil-willow interactions

Labrecque et al. (2001) and Alriksson (1997) found consistently higher biomass production from willow grown on soils with high clay concentrations. This result was ascribed to the greater water holding capacity of soils with a higher clay fraction. The clay fraction at sites in this study fell within a relatively narrow range compared to these studies and was therefore not a significant influence on biomass production. Only one site in this study (Wol) had greater than 40% sand, but biomass production was not reduced at this site. Alriksson (1997) found that willow would perform well on sandy sites with a perched water table. Depth-to-water at Wol was found to be quite shallow, thereby reducing the water stress often associated with sandy soils.

A survey of literature by Zasada et al. (2001) suggests that soil concentrations of K, P, Ca and cation exchange capacity were the most important site quality indicators for growth of *Populus* spp. Alriksson (1997) found biomass production was positively correlated with N availability. In our study, only soil pH, Mg and Ca were correlated to willow biomass production among the top five producers in both the A- and B-horizons. Concentrations of organic matter and N were negatively correlated to biomass in the B-horizon, and P was positively correlated. Mg and Ca, both base cations, influence pH, so it is difficult to interpret whether soil pH is influencing biomass production or whether the plant's utilization of Mg and Ca availability drives production. The negative influence of B-horizon N concentrations on biomass is unclear, but may be linked to

speciation of N. The N may not have been biologically available if it was bound in organic form. Unfortunately, only total N was measured in this study

Among the individual clones planted at all sites with soils data, there were few significant correlations between biomass and soil characteristics, the exceptions being A-horizon N and P with S301 and B-horizon N with S365. Differences with Zasada et al. (2001) may be due to the sites examined. This study was conducted on formerly cultivated lands, while the studies surveyed in Zasada et al. were conducted on lands without considerable human disturbance.

5.0 CONCLUSIONS

Survival and production varied across sites with different soil and climate conditions. While no specific drivers for this variability have been identified, some key factors may be climate and soil texture. Survival was not strongly correlated with biomass production, so a revision of the currently accepted 80% survival rate is warranted. Production was generally good in this study, but these sites should be followed through subsequent rotations.

This study suggests several of the clones tested are plastic in nature, meaning they can grow well across a range of conditions. The willow species that were found to be the most plastic included *Salix miyabeana* (SX64, SX67), *S. xdasyclados* (SV1) and *S. purpurea* (PUR12, PUR34). The more site-specific clones include *S. discolor* (S365), which did well on some sites and poorly on others. The site-specific clones may warrant further study to define the specific suite of edaphic and climatic characteristics under which they grow well. The results of this study will allow decision makers to better determine appropriate planting stock for scale-up operations, suggest clones appropriate for selective breeding programs and provide groundwork for further refined clone-site trials.

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Appendix 1. Standard Operating Procedures for Sampling Willow Foliage for Nutrient Concentration Measurements.

Purpose: to diagnose nutrition status of plantations as a basis for: (1) prescribing fertilizer amendments, and (2) relating nutrient status to wood production.

Sampling dates: sampling should occur late in the growing season, preferably between August 15 and September 15. Late season foliage should be green (photosynthetically active). If foliage has started to senesce, as indicated by a change in color (green to yellow), it should not be collected.

Sample location--programmatic: All research, demonstration, and commercial plantings will be sampled for foliage nutrient analysis at various times in plantation development. Demonstration and commercial plantings will be sampled the summer before dormant season harvest, e.g., at the end of the first growing season (before cut back), at the end of the fourth growing season (3-yr-old plants on 4-yr-old root systems), etc. All research plantings will, at minimum, be sampled using this schedule with additional samples taken as dictated by the study.

Sample location--within area (NOTE--an area may be a single rep in the case of a clone site trial, or a large planting block in the case of a commercial planting): A number of trees should be sampled across the area from as many trees as possible. For example, 10 leaves from each of ten "trees" of a single clone would be adequate for large-leaved clones. NOTE that the sample size of 10 trees is a minimum. Sampling of more trees, perhaps up to 30 per area, would be better.

Sample location--with a tree crown: Ten to 20 leaves from the top one third of a crown (sun-exposed portion of crown).

Sample quantity: Depends on the clone. A total of 200 leaves (10 leaves from 10 trees) of small-leaved clones (e.g., *Salix purpurea*) or 100 leaves from large-leaved clones (e.g., *Salix dasyclados*). The purpose here is to produce enough dry tissue to perform various nutrient analyses, including a reserve amount of material for reanalysis if necessary, perhaps as part of the Quality Assurance Program.

Sample quality: mature, "normal" leaves are to be collected. Mature connotes fully formed, normal sized leaves. Normal is a clone-specific; year-to-year condition defined by the general quality of foliage for all of the trees in the area. It may be that foliage is normally discolored by nutrient stress or disease, or partially missing due to insects. The description of "normal" condition should be included with sample information (see below), particularly if it deviates from green, whole, healthy tissue.

Sample information: each sample should be uniquely identified by date of sampling, sample I.D. number, area location, clone, rep, and any miscellaneous notes about condition. This information should be recorded with the field sample collection (brown bag) and study notebook.

Field and laboratory techniques: follow Bickelhaupt and White (1982). In particular, care should be given to either cooling (ice packs, refrigerator) or drying (preferable) samples the same day as collected.

Appendix 2. Mean biomass and survival by clone at each of the eight sites in the final report.

All sites were three-year rotations except Burlington, which had a four-year rotation.

* SE is standard error.

Site	Clone	Rep	Biomass (odt ha ⁻¹)	SE*	Survival (%)	SE*
Burlington	SX61	3	37.00	2.95	97.32	1.55
	NM6	3	31.43	0.77	95.83	2.87
	SV1	3	25.47	3.08	79.17	21.45
	S25	3	24.60	1.14	93.75	3.89
	S19	3	24.47	1.45	98.51	0.52
	S301	3	24.07	0.24	96.43	2.36
	S365	3	19.20	5.62	78.27	30.67
Canastota	NM6	4	34.20	1.00	100	0
	SX64	4	33.46	1.75	99.17	1.67
	SX61	4	32.42	4.08	99.17	1.67
	SV1	4	29.82	2.84	100	0
	FC185	4	29.35	1.37	98.33	1.92
	S365	4	24.30	3.23	83.33	22.93
	S646	4	21.64	1.60	95.83	4.19
	S25	4	21.56	1.16	96.67	6.67
	PUR34	4	20.73	3.15	98.33	1.92
	FC190	4	19.32	0.91	100	0
	S301	4	18.68	1.08	99.17	1.67
	S652	4	17.51	0.75	67.50	24.55
	S546	4	16.99	0.97	99.17	1.67
	SA2	4	14.73	1.62	99.17	1.67
Delaware	NM5	4	70.94	2.69	97.5	0.96
	NM6	4	66.71	2.87	98.75	1.60
	SX64	4	34.69	5.08	97.5	1.67
	SX67	4	27.62	9.83	96.25	3.70
	SX61	4	26.25	4.46	97.08	2.85
	S25	4	22.76	5.94	96.67	3.33
	S301	4	12.58	3.89	95.42	4.17
	S365	4	4.85	2.61	98.33	0
	PUR12	4	3.94	1.28	93.33	7.93
	FC185	4	3.58	1.38	93.33	5.93
	FC189	4	3.38	1.46	97.08	4.79

	S625	4	3.35	1.26	97.92	1.60
	SV1	4	1.88	1.60	98.33	3.33
	B193	3	1.33	0.55	97.08	3.44
Lafayette	NM5	4	29.18	1.26	97.27	3.22
	NM6	4	26.03	2.30	98.05	1.97
	SX61	4	9.03	2.55	81.64	6.68
	S301	4	8.98	1.42	94.53	3.72
	PUR34	4	8.10	2.30	96.48	5.00
	SX64	4	6.78	3.42	83.20	15.85
	SV1	4	6.58	1.61	87.11	8.21
	PUR12	4	6.25	2.14	94.14	2.96
	S365	4	5.70	1.79	95.70	4.49
	SX67	4	4.88	2.97	83.20	8.87
	SA2	4	4.20	1.95	89.06	10.13
	SH3	4	3.03	1.11	67.97	14.29
	S25	4	1.73	0.43	64.84	10.08
	S625	4	1.40	0.55	83.20	11.51
	S652	4	1.30	0.57	48.83	14.28
	S19	4	0.88	0.34	52.73	14.11
Massena	SV1	3	36.83	16.18	56.23	6.25
	S365	3	35.47	6.06	77.07	23.64
	S301	3	30.50	8.19	79.13	3.58
	S625	3	27.63	4.93	83.30	9.52
	S25	3	24.87	4.48	89.53	7.22
	S19	3	19.50	2.06	85.40	13.02
	SA2	3	18.77	3.63	74.30	7.28
	S71	3	18.63	1.37	77.03	19.09
	S557	3	13.53	3.68	62.47	16.55
	S546	3	13.20	4.90	64.53	14.43
	S646	3	12.93	1.64	62.47	18.75
	S566	3	10.77	0.82	62.50	12.50
	S599	3	10.57	2.95	81.23	62.25
	SH3	3	10.57	3.12	66.63	20.10
Sheridan	SX64	4	23.99	2.80	89.17	8.66
	SX61	4	20.75	1.39	75.83	11.26
	SV1	4	18.84	0.95	96.67	3.85
	NM6	4	17.69	3.25	97.92	0.83
	PUR34	4	15.17	1.26	98.75	2.50

	SX67	4	14.59	5.03	62.08	7.25
	PUR12	4	13.54	3.06	92.08	10.48
	FC189	4	12.43	3.20	80.83	20.66
	B195	4	11.29	1.16	92.92	6.29
	FC190	4	10.82	1.96	85.42	21.23
	S301	4	9.91	1.50	89.58	10.31
	S365	4	9.06	1.90	71.67	8.92
Tully	SV1	3	26.80	0.32	93.33	6.51
	S287	3	22.00	3.64	96.67	3.51
	S365	3	20.60	1.56	98.00	1.73
	S301	3	18.37	1.49	97.00	0
	S34	3	17.30	4.20	74.33	18.58
	S25	3	16.90	3.15	94.67	4.04
	S652	3	15.90	2.26	88.00	10.15
	S625	3	15.77	1.84	71.00	19.05
	S19	3	15.73	1.42	87.67	6.81
	S185	3	15.43	1.84	90.00	8.89
	S599	3	14.77	2.41	70.33	11.55
	SH3	3	14.67	1.68	87.67	4.04
	S546	3	14.17	1.42	77.67	9.24
	S646	3	13.17	1.96	63.67	20.82
	S566	3	12.60	1.82	59.00	20.30
	SP3	3	12.43	2.27	99.00	1.73
	SA2	3	10.23	0.90	96.67	3.51
	S71	3	9.13	0.78	34.33	10.26
	S557	3	8.37	0.43	56.67	23.71
Wolcott	NM6	4	38.14	2.64	97.50	1.67
	SX61	4	34.97	7.63	80.83	25.44
	S25	4	25.77	3.69	93.33	6.67
	SV1	4	25.38	8.38	65.00	28.35
	S365	4	22.42	6.05	63.33	34.75
	SX67	4	21.02	3.33	40.00	19.44
	S301	4	20.40	1.59	90.83	5.69
	B193	4	18.65	2.72	77.50	3.191
	PUR34	4	14.26	1.49	86.67	13.61
	FC189	4	13.99	3.30	90.83	10.67
	B195	4	13.09	2.67	79.17	13.71
	FC188	4	9.56	3.59	68.33	20.09

Appendix 3. Soils data, by horizon, for six clone-site trial locations.

Site	Pit	Horizon	pH	OM (%)	N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	CEC ($\mu\text{eq } 100\text{g}^{-1}$)	sand (%)	silt (%)	clay (%)
Burlington	1	Ap	6.89	3.56	0.044	73.29	18.25	1590	53.15	15.4	10.84	34	52	14
Burlington	1	Bw	6.48	1.27	0.043	72.74	17.5	452.5	48.15	13.1	5.42	30	56	14
Burlington	1	Bw1	6.6	1.37	0.043	76.33	13.75	445	39.8	19.2	5.02	34	56	10
Burlington	1	Bw2	6.33	1.66	0.053	63.89	23.25	622.5	72.75	15.3	8.14	22	58	20
Burlington	1	C	7.27	0.53	0.015	46.74	19.3	152.5	23.5	8.95	2.58	62	32	6
Burlington	2	Ap	6.28	3.35	0.134	72.74	19.15	1103	35.8	18.15	10.3	28	60	12
Burlington	2	Bw	6.74	1.29	0.262	84.36	11.7	621	38.6	14.65	6.08	30	58	12
Burlington	2	C1	6.36	1.53	0.05	89.06	19.7	668	63.8	13.1	8.22	16	64	20
Burlington	2	C2	6.34	0.78	0.027	82.7	12.85	306.5	38.85	13.45	3.86	36	56	8
Canastota	1	Ap	6.94	11.98	0.422	61.95	97.05	3660	1026	12.85	39.02	28	42	30
Canastota	1	Bg	7.46	2.89	0.07	187.8	91.6	2532	777.9	16.4	25.24	14	26	60
Canastota	1	Cg	7.84	1.18	0.027	186.7	56	1533	480.6	15.15	12.26	41	30	29
Canastota	2	A	7.42	3.9	0.083	45.63	66.6	2220	658.5	14.45	23.42	34	30	36
Canastota	2	Ap	7.24	7.43	0.132	22.96	71.85	2490	665.1	12.65	25.88	32	42	26
Canastota	2	IIBw	8.01	0.72	0.022	51.17	11	907.5	329.5	8.45	3.24	71	20	8
Canastota	2	IIC	8.22	0.59	0.006	35.95	11.35	1467	232.6	5.25	2.26	74	18	8
Lafayette	1	Ap	7.73	4.44	0.166	35.12	63.35	2007	290.4	7.75	16.02	31	40	28
Lafayette	1	B	7.81	2.77	0.078	16.04	36.5	1446	216.4	5.25	12.4	28	42	30
Lafayette	1	C1	8.11	1.46	0.052	3.04	29.9	3240	148.3	7.25	7.26	38	37	25
Lafayette	1	C2	8.41	0.9	0.028	6.36	32.6	3171	156.2	6.3	7.44	35	32	32
Lafayette	1	C2	8.19	1	0.028	9.96	17.8	2781	109.8	6.4	10.9	46	36	18
Lafayette	2	Ap	7.48	4.99	0.211	29.59	72.2	2148	384.9	4.8	17.74	31	40	29
Lafayette	2	Ap	7.56	5.72	0.209	27.38	75.65	2109	394.6	4.25	18.14	30	40	30
Lafayette	2	B	7.53	1.64	0.074	48.12	30.15	1980	252.4	9.1	9.62	39	36	25
Lafayette	2	Cd	8.53	1.09	0.035	10.51	25.5	2886	150	5.35	6.54	42	36	22
Sheridan	1	A	5.07	4.04	0.152	3.4	59.45	803	136	11.55	15.14	27	44	29
Sheridan	1	Bw	5.52	4.32	0.145	5.51	51.55	785	132.5	11.2	14.68	26	43	31
Sheridan	1	C	6.7	2.11	0.052	101.8	34.4	1329	173.7	13.65	9.42	36	40	24
Sheridan	2	A	5.32	5.98	0.161	4.91	42.35	720.5	108	9.65	17.12	26	49	25
Sheridan	2	Bw	5.08	3.19	0.07	1.41	32.6	402	76.35	8.85	14.12	29	42	29
Sheridan	2	C1	6.78	2.06	0.058	58.78	38.9	1189	252.2	15.75	10.82	42	36	22
Sheridan	2	C2	3.51	2.05	0.068	25.97	11.2	1189	286.7	3.1	6.36	41	42	17
Tully	1	A	5.91	5.12	0.202	11.34	64	1214	99.4	5.7	17.08	29	44	27
Tully	1	AB	6.04	4.49	0.158	6.48	22.4	1385	82.95	11.35	16.8	30	44	26
Tully	1	Bw1	6.06	3.27	0.092	13.77	23.4	855	59.35	10.65	13.32	34	40	26

Tully	1	Bw2	6.19	1.93	0.045	12.85	19.45	674	51.85	9.3	9.24	41	34	25
Tully	1	C	8.34	1.09	0.035	38.67	18.9	1959	306.7	7.15	9.32	73	8	19
Tully	2	Ap	5.34	5.52	0.191	6.71	66.25	950	71.65	10.65	18.62	33	44	23
Tully	2	Bw	5.34	3.89	0.137	12.85	16.45	680	26.15	13.15	17.78	36	40	24
Tully	2	C	5.23	1.55	0.041	19.84	22.2	327.5	19.2	17.15	9.42	49	34	17
Wolcott	1	Ap	7.2	3.29	0.118	279.9	81.25	1475	65.5	3.15	7.68	90	6.4	3.6
Wolcott	1	BC	6.33	0.62	0.01	6.71	38.75	86	10.65	3.05	2.72	96.4	2	1.6
Wolcott	1	Bs	6.14	1.22	0.017	0.81	52.6	202	20.55	3.3	4.24	96	2.4	1.6
Wolcott	1	C	5.76	0.43	0.008	4.75	33.6	41.5	4.3	3.3	1.74	97.2	2.2	0.6
Wolcott	2	Ap	6.8	3.75	0.116	266.1	94.81	1405	71.13	3.55	9.56	90.2	5.2	4.6
Wolcott	2	BC	5.63	0.34	0.007	10.64	10.3	30.5	2.6	4.05	1.08	96.4	3	0.6
Wolcott	2	Bs	5.71	0.73	0.017	6.12	12.6	77	4.65	2.05	2.02	96	2.4	1.6
Wolcott	2	C	5.29	0.21	0.006	6.99	8.4	9	1.3	2.3	0.86	97.4	1	1.6
Wolcott	2	E	5.71	1.1	0.026	5.59	13.9	146	7.8	2.5	3.24	95.2	3.2	1.6

Appendix 4. Correlation analyses with soil characteristic including Lafayette.

Table 1. Correlation coefficients between biomass and survival and soil characteristics across all willow clones at all six sites with available soils data.

	pH	OM	N	P	K	Ca	Mg	Na	CEC	sand	silt	clay
A-horizon												
Biomass	-0.15	0.11	-0.27	0.29	-0.04	0.03	0.07	0.39	0.08	0.24	-0.14	-0.32
	0.0993	0.2557	0.0028	0.0017	0.6403	0.7232	0.4347	<.0001	0.3604	0.0099	0.1196	0.0003
Survival	-0.01	0.30	0.23	-0.40	-0.24	0.19	0.25	0.37	0.34	-0.43	0.41	0.34
	0.8781	0.0009	0.0109	<.0001	0.0099	0.0431	0.0061	<.0001	0.0002	<.0001	<.0001	0.0002
B-horizon												
Biomass	-0.18	-0.29	-0.27	0.35	0.05	-0.32	0.09	0.27	-0.16	0.27	-0.25	-0.22
	0.0540	0.0013	0.0031	<.0001	0.5719	0.0004	0.3542	0.0031	0.079	0.0026	0.0056	0.0184
Survival	0.22	0.18	0.27	0.33	0.08	0.31	0.28	0.43	0.34	-0.40	0.32	0.37
	0.0163	0.0508	0.0026	0.0002	0.3699	0.0007	0.002	<.0001	0.0001	<.0001	0.0003	<.0001

Table 2. Correlation coefficients between biomass and survival and soil characteristics among clones planted at all six sites with soils data.

Horizon	Clone	pH	OM	N	P	K	Ca	Mg	Na	CEC	sand	silt	clay
A	S301	0.12	-0.19	-0.48	0.45	-0.16	0.08	-0.10	0.33	-0.17	0.36	-0.18	-0.58
		0.5862	0.4074	0.0254	0.0365	0.4773	0.7147	0.6520	0.1363	0.4476	0.1005	0.4340	0.0045
A	S365	0.09	0.12	-0.12	0.34	0.13	0.21	0.14	0.18	0.11	0.31	-0.27	-0.30
		0.6783	0.5919	0.5950	0.1177	0.5542	0.3487	0.5371	0.4304	0.6268	0.1544	0.2290	0.1688
A	SV1	-0.16	0.14	-0.15	0.20	-0.02	0.04	0.08	0.33	0.13	0.17	-0.11	-0.23
		0.4774	0.5244	0.5126	0.3820	0.9162	0.8430	0.7325	0.1384	0.5593	0.4420	0.6227	0.3097
B	S301	-0.03	-0.61	-0.33	0.36	-0.39	-0.38	-0.11	0.25	-0.49	0.37	-0.19	-0.51
		0.8902	0.0024	0.1285	0.1045	0.0707	0.0849	0.6262	0.2576	0.0194	0.0914	0.3957	0.0144
B	S365	0.02	-0.42	-0.42	0.34	-0.05	-0.19	0.12	0.11	-0.22	0.37	-0.37	-0.26
		0.9433	0.0509	0.0502	0.1251	0.8378	0.4098	0.5954	0.6169	0.3262	0.0860	0.0913	0.2519
B	SV1	-0.16	-0.21	-0.23	0.30	0.01	-0.26	0.08	0.25	-0.07	0.22	-0.23	-0.14
		0.4868	0.3530	0.3098	0.1814	0.9782	0.2470	0.7137	0.2591	0.7515	0.3180	0.3090	0.5245