Short-Rotation Woody Crops Program
at
State University of New York
College of Environmental Science & Forestry

Three Willow to Energy Clone-Site Trials for Pennsylvania

FINAL REPORT

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Executive Summary

Willow biomass is a clean, versatile, renewable carbon source that has great potential as a feedstock for both bioproducts and bioenergy. To produce bioenergy it can be burned directly, co-fired with coal, gasified for use in gas turbines, or converted into liquid fuels. Increased effort is being focused on the fabrication of biobased materials and chemicals from willow biomass as an alternative to products currently derived from non-renewable fossil fuels.

The goal of this project was to establish research and demonstration (R & D) clone-site trials of high density, hybrid willow and poplar clones at three locations in Pennsylvania. Standardizing the experimental design and data collection will allow comparisons to be made among the trials in Pennsylvania and elsewhere. Future yield and survival data will be compared to similar trials that State University of New York College of Environmental Science and Forestry (SUNY-ESF) is managing and/or collaborating on in eight other states and one province. Ongoing participation in this clone-site trial network will allow Pennsylvania to remain a part of the regional database on interactions between site conditions and the survival, growth, and production of different willow and poplar clones. The Pennsylvania sites will also serve as demonstration areas for outreach and education efforts. To date, R & D trials have been established in Easton (1998; 14 clones), Roaring Branch (1999; 14 clones), and Montour Preserve (2000; 26 clones), PA. Unfortunately, changes in Lafayette College's development plans resulted in the destruction of the Easton trial in August 2000.

First-year survival and foliar nutrient concentration data was collected for clones growing at Easton in 1998 and at Roaring Branch in 1999. Both sites were coppiced, Easton in November 1998 and Roaring Branch in November 1999. First-year biomass data was collected at Roaring Branch at the time of coppicing. Survival data for Montour Preserve was collected in August 2000, as was foliage for nutrient analyses that will be that will be stored until funding can be secured to continue the analyses. Survival was excellent at all three sites. Mean survival was 98% at Easton, 97% at Roaring Branch and 87.6% at Montour Preserve. Foliar nutrient analysis indicated that the Easton was a fertile site for clone growth. Foliar N concentrations averaged 3.2% at Easton and 2.0% at Roaring Branch. Biomass estimates were within expectations, when the drought year of 1999 was considered. First year after coppice biomass ranged from 2.7 odt ac^{-1} (1.2 Mg ha^{-1}) to 16.0 odt ac^{-1} (7.1 Mg ha^{-1}) at Easton. Establishment year biomass at Roaring Branch ranged from 0.007 odt ac^{-1} (0.003 Mg ha^{-1}) to 1.4 odt ac^{-1} (0.61 Mg ha^{-1}). Future work on these trials is dependent on the availability of funding. Results from a clone-site trial established in central New York in 1993 and harvested in 1996 and 1999 indicate that clone-site trials should be followed for two rotations (seven years) in order to provide more information on clone-site interactions. Regular monitoring and measurement of the two remaining R & D trials in Pennsylvania should be carried out through two rotations (winter of 2004/5 for Roaring Branch and 2005/6 for Montour Preserve). Data from the Pennsylvania trials would be a beneficial addition to efforts already underway at SUNY-ESF to develop a model that can be used to predict growth and yield of different clones across a wide range of soils and climatic conditions.

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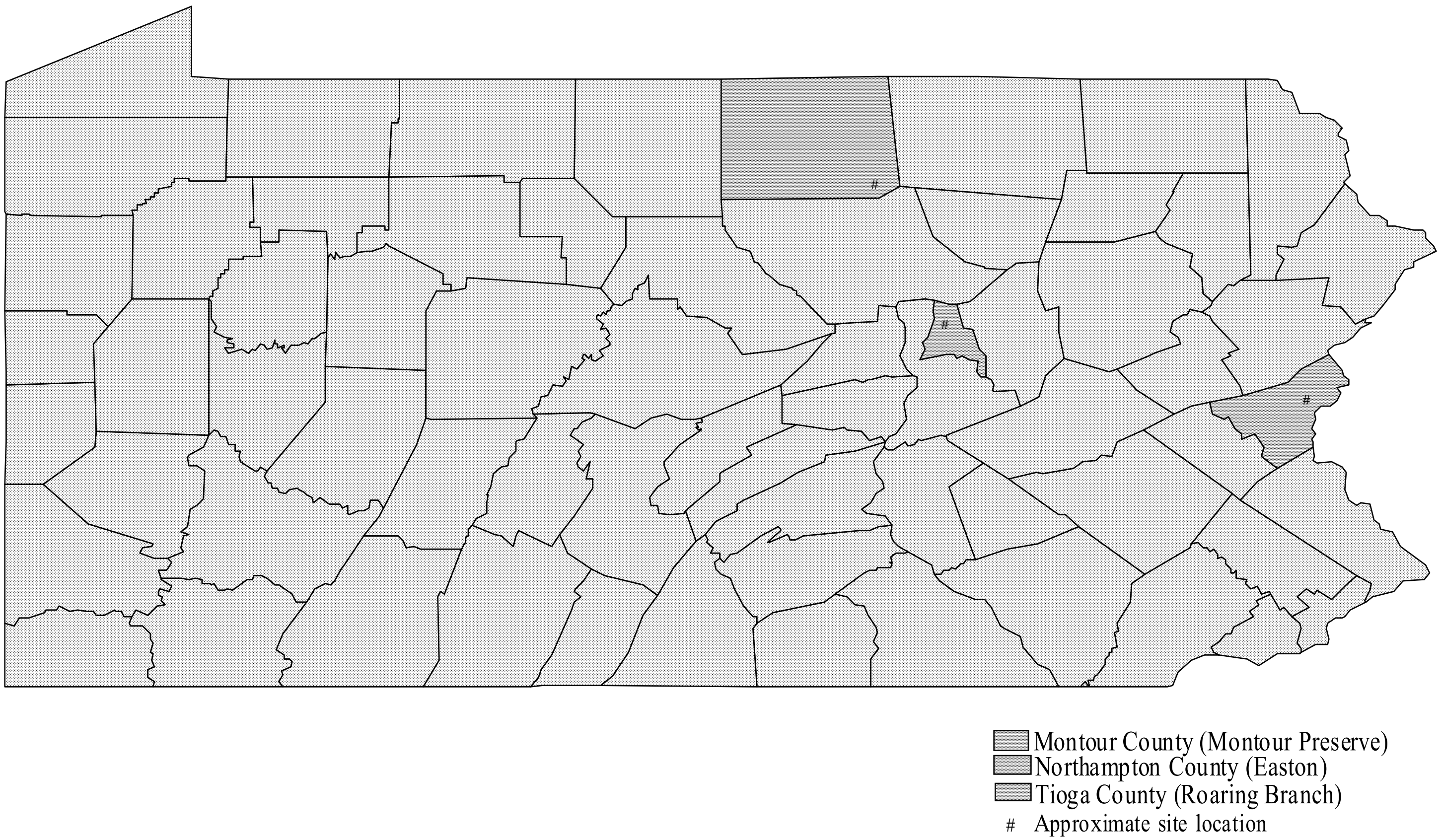
Introduction

Willow and poplar biomass is a clean, versatile, renewable carbon source that has high potential as a feedstock for both bioproducts and bioenergy. To produce bioenergy it can be burned directly, co-fired with coal, gasified for use in gas turbines, or converted into liquid fuels. Increased effort is being focused on the fabrication of biobased materials and chemicals from willow biomass as an alternative to products currently derived from non-renewable fossil fuels. Sixteen to 30 units of energy can be produced for every unit of energy invested in the production and conversion of willow biomass to electricity (Borjesson, 1996; Mann and Spath, 1997). Willow's ability to effectively capture and store the sun's energy as biomass is the main factor in this positive energy balance. This positive energy balance could increase in the future as yields rise and the production system is optimized. Co-firing willow biomass with coal results in consistently reduced SO_x emissions, and reduced NO_x emissions under certain conditions. Both of these compounds are precursors of acid rain. Willow is also a CO_2 neutral energy source (Mann and Spath, 1997). The amount of CO_2 taken up by plants during photosynthesis is equivalent to the amount released when the wood is burned plus that produced during crop production. Hence, willow biomass crops can make an immediate contribution to reducing the threat of global warming.

The willow bioenergy system being developed in the United States is based on over 15 years of research at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) and experience from operational systems in Sweden and the United Kingdom. The system consists of a double-row planting of approximately 6,200 trees/acre (15,300 trees/ha), following complete site preparation, including herbicide application, plowing, and disking. Initial results using conservation tillage practices also show promise. Trees are planted in spring as 7.9" to 9.8" (20-25 cm) long, dormant, unrooted cuttings using machines developed in Sweden and modified for local conditions. Weed control, using a combination of mechanical and chemical techniques, is essential during the first year of establishment. Trees are coppiced (cut back) after the first year during the winter to promote vigorous sprouting. Harvesting occurs every three to four years in the dormant season after leaves fall from the trees. Specially designed harvesters mounted on agricultural equipment or modified corn harvesters are used to cut and chip the clones in one process. The willow and poplar resprout from stump following each harvest for six to seven rotations for a crop lifespan of 20 years or more.

The plantation would then be plowed under and replanted with new, improved clones of willow, or returned to traditional agricultural production.

Research with willow and poplar short-rotation woody crops indicates that yield is strongly influenced by the clones used and site conditions. First rotation yields of the five most productive willow clones from two locations in central and northern New York varied by 3 to 29% (Volk, unpublished data). Yield has a significant impact on the economic return from willow bioenergy systems. Because of the strong effect of clone-site interactions on yield, it is essential to assess the production potential of different clones in areas where large plantings of willow bioenergy crops may be established. The goal of this project, “Three Willow to Energy Clone-Site Trials for Pennsylvania” (NA-98-0176), was to establish research and demonstration plots of high density, hybrid willow and poplar at three locations in Pennsylvania. Standardizing the experimental design and data collection from these trials will allow comparisons to be made among the trials. Future yield and survival data will be compared to similar trials that SUNY-ESF is managing and/or collaborating on in eight other states and one Canadian province (Volk et al. 2000). Ongoing participation in this network will allow Pennsylvania to remain a part of the regional database on interactions between site conditions and the survival, growth, and production of different willow and poplar clones. The Pennsylvania sites will serve as demonstration areas for outreach and education efforts. They will provide opportunities for Pennsylvania’s agricultural, environmental, and natural resources communities; industrial and utility power businesses; and policy makers to learn about and gain experience with willow bioenergy crops. Trials were established in Easton, Roaring Branch, and Montour Preserve, PA (Figure 1). A timeline of activities at each site is presented in Figure 2. Unfortunately, changes in Lafayette College’s development plans resulted in the destruction of three of the four replications at the Easton trial in August 2000 (Figure 3). The support and participation of local, regional, and national organizations and individuals made the establishment and maintenance of the three trials possible (Table 1).



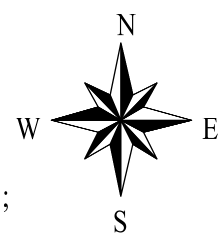


Figure 1. Counties in Pennsylvania where willow and poplar clone-site trials were established; 1998 (Northampton), 1999 (Tioga) and 2000 (Montour).

	1998 Spring	Summer	Fall	Winter	1999 Spring	Summer	Fall	Winter	2000 Spring	Summer	Fall	Winter
2a. **Easton**												
Site preparation	----------											
Planting	----------										**destroyed**	
Monitoring & weed control	----------	----------	----------		----------	----------	----------		----------	----------		
Foliage collection			----------				----------					
Cutback				----------								
Fertilizer application					----------							
End of season data collection			----------				----------					
Analysis & report writing			----------	----------			----------	----------		----------		
2b. **Roaring Branch**												
Site preparation			----------									
Planting					----------				----------			
Monitoring & weed control					----------	----------	----------		----------	----------	----------	
Foliage collection							----------				----------	
Cutback								----------				
Fertilizer application									----------			
End of season data collection							----------				----------	
Analysis & report writing							----------	----------			----------	----------
2c. **Montour Preserve**												
Site preparation							----------					
Planting									----------			
Monitoring & weed control									----------	----------	----------	
Foliage collection											----------	
Cutback												----------
Fertilizer application												
End of season data collection											----------	
Analysis & report writing											----------	----------

Figure 2. Three-year time line of activities at the three Pennsylvania clone-site trials.
(a) Easton, PA (b) Roaring Branch, PA (c) Montour Preserve, PA

(a) (b)

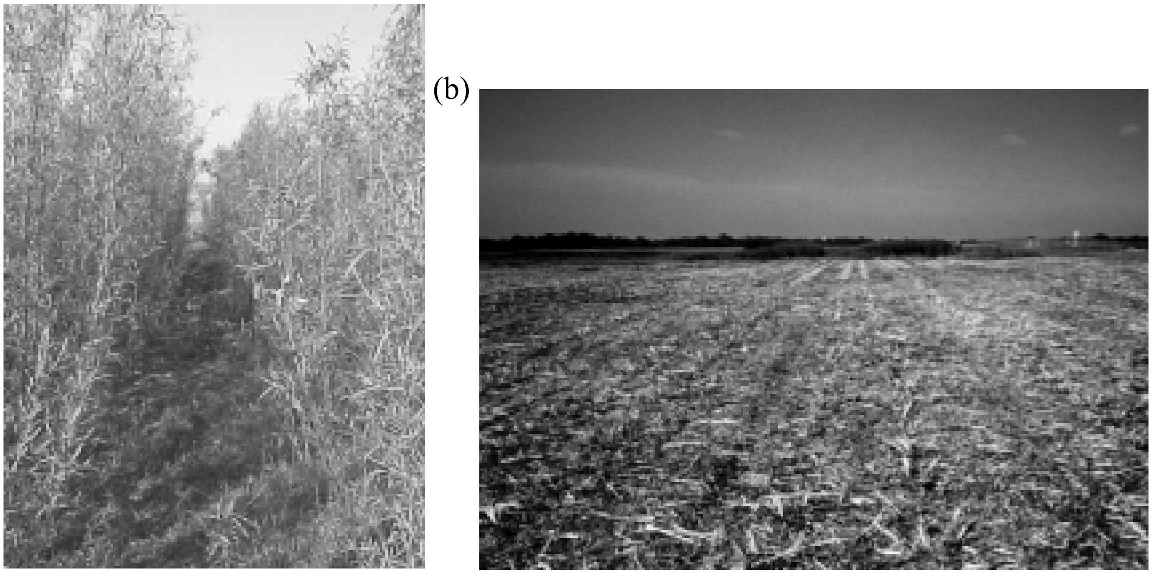


Figure 3. Willow biomass trial at Easton, PA
(a) early in the second growing season after coppice
(b) after three of the four replications were destroyed.
(Photos taken by Dwayne Breger, Lafayette College (a) and Mark Appleby, SUNY-ESF (b))

Site-trial regional climate

Clone trial sites in Pennsylvania are in three different physiographic regions, as defined by Cadman (1999). Easton is located in the Coastal Plain/Piedmont region, Roaring Branch is in the Allegheny Plateau region and Montour Preserve is in the Ridge and Valley Province.

Easton

In the Coastal Plain/Piedmont region, summers are long and hot. Daily temperatures reach 90° F (32° C) or above an average of 25 days during the summer. In general, the winters are mild, with an average of less than 100 days with minimum temperatures below freezing. Average annual precipitation is between 30" (762 mm) and 46" (1,168 mm) in the region. The average seasonal snowfall is about 30" (762 mm). Fields are usually snow covered about 30 days during winter.

Roaring Branch

The Allegheny Plateau has a continental-type climate, experiencing variable temperatures and an increased frequency of precipitation relative to the rest of the state. The coldest region of the state, the average daily temperature of the Allegheny Plateau ranges from 20° F (-7° C) in midwinter to 66° F (19° C) in midsummer. The growing season ranges from 130 days in the upper latitudes to 175 days in the lower latitudes.

Mean annual precipitation is 41” (1,041 mm) and seasonal snowfall varies with latitude, averaging 54” (1,371 mm) northern areas, less in the south. During the winter season, snow usually covers fields for about 67 days.

Montour Preserve

The Ridge and Valley Province has many characteristics of a mountain climate. Due to the elevational influence on the air movements, this region experiences relatively large temperature extremes. The growing season averages between 130 and 165 days. Annual precipitation in the region is 33”-50” (838-1,270 mm) and snowfall averages 37”-88” (940-2,235 mm) in the Ridge and Valley Province.

Weather Data

Weather stations proximal to the trial locations were used to represent conditions for the Easton site in 1998 and 1999 and Roaring Branch site in 1999 (Table 2; Northeast Regional Climate Center 2000). Growing degree days (GDD) presented are calculated at base 50° F and include the period between April 1 and October 31 of each year.

Easton

Weather at the Easton site is approximated from the Belvedere Bridge, NJ station, 9.1 miles (14.5 km) SE of Easton. The average annual GDD for Belvedere Bridge (1982-1999) is 2,740. Annual temperature averages 50° F (10° C), with a growing season (April 1-October 31) mean of 62° F (17° C). This site averages 44.9” (1,140 mm) of precipitation annually, 29.0” (737 mm) during the growing season. Belvedere Bridge had slightly warmer growing seasons in 1998 and 1999, with 3,026 GDD and 3,066 GDD respectively. The site received 31” (787 mm) of precipitation during the 1998 growing season. Only 20” (508 mm) of precipitation was received during the 1999 growing season, well below normal for the site.

Roaring Branch

Weather at Roaring Branch is approximated from a station 4.0 miles (6.4 km) SSE of Wellsboro. The Wellsboro site averages 1,553 GDD annually (1961-1990), 1,529 GDD during the growing season. Annual temperature averages 44.1° F (7° C), 56.2° F (13° C) during the growing season. Annual precipitation at Wellsboro averages 32” (831 mm), 22” (559 mm) during the growing season. During the growing season of 1999, Wellsboro had 1,821 GDD and averaged 57.6° F (14° C). The area received 19.5” (496 mm) of precipitation, which is not less than the long-term average.

Methods

Fourteen to 26 different clones of willow and poplar were planted at three sites in Pennsylvania. Planting stock for each site consisted of 9.8” (25 cm) long, dormant, hardwood cuttings made from one year old shoots. The clones at each site were planted in a randomized complete block design (RCBD) consisting of four blocks. Parentage and origin of the clones at each site are presented in Table 3.

Easton

SUNY-ESF collaborated with several organizations, including Lafayette College, the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry, the Pennsylvania Farm Bureau, and the Coalition of Northeast Governors (CONEG), to establish the first willow bioenergy crop clone-site trial in Pennsylvania. Lafayette College, Easton, PA, donated the land. Dr. Dwayne Breger of Lafayette College has provided ongoing monitoring and support of the trial.

The Easton site (Figure 4) had been in no-till corn for several years prior to the establishment of the trial. The site was plowed and disked in the spring prior to planting. The trial includes 13 willow clones and one hybrid poplar hand planted in the double-row configuration that is currently being used in large-scale demonstration areas in New York. Distance between the double rows is 4.9’ (1.5 m), within the double row is 2.0’ (0.60 m). Density of the plantings was 6,200 trees/ha (15,300 plants/ha). The trial was planted on April 30 and May 1, 1998 with personnel from SUNY-ESF, Lafayette College, and the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry. A pre- emergent herbicide cap of oxyfluorfen (Goal 1.6e at 1.0 lb ai ac^{-1}) was applied on May 5, 1998.

First year survival data and foliage samples were collected in August 1998. Percent survival for each clone was calculated using data from the 30 stools in the measurement plot (Figure 5). Foliage was sampled in accordance with SUNY-ESF’s Standard Operating Procedure (Appendix 1). The plants were coppiced in November 1998. Above-ground biomass production the first year after coppice was estimated for Easton utilizing allometric equations developed at SUNY-ESF (Ballard et al. 1999).

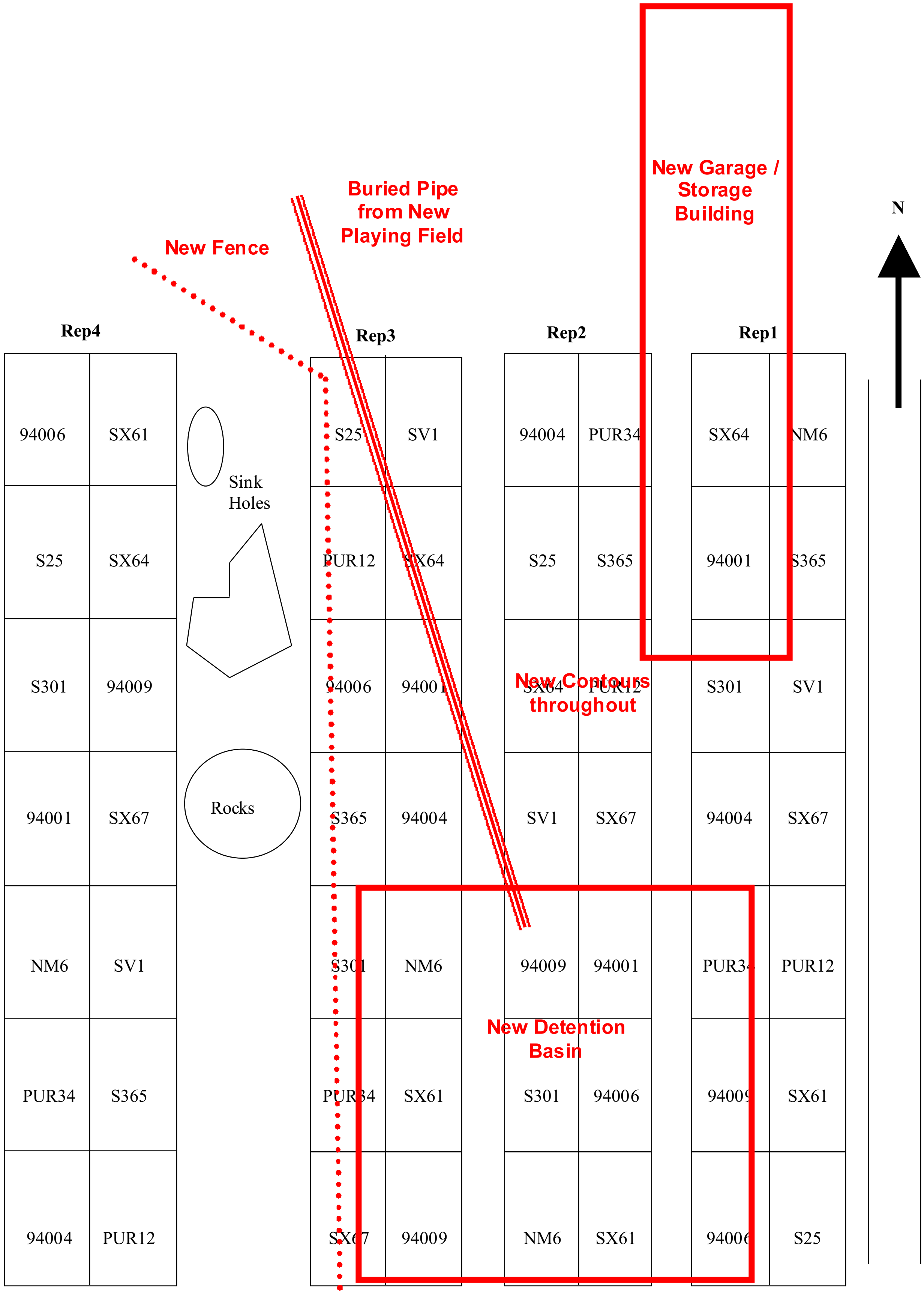


Figure 4. Site map of willow and poplar clones planted at Easton, PA in the spring of 1998, with proposed construction superimposed. Replications 1, 2 and 3 were destroyed in August 2000. See Table 3 for specific clone information. Diagram not to scale.

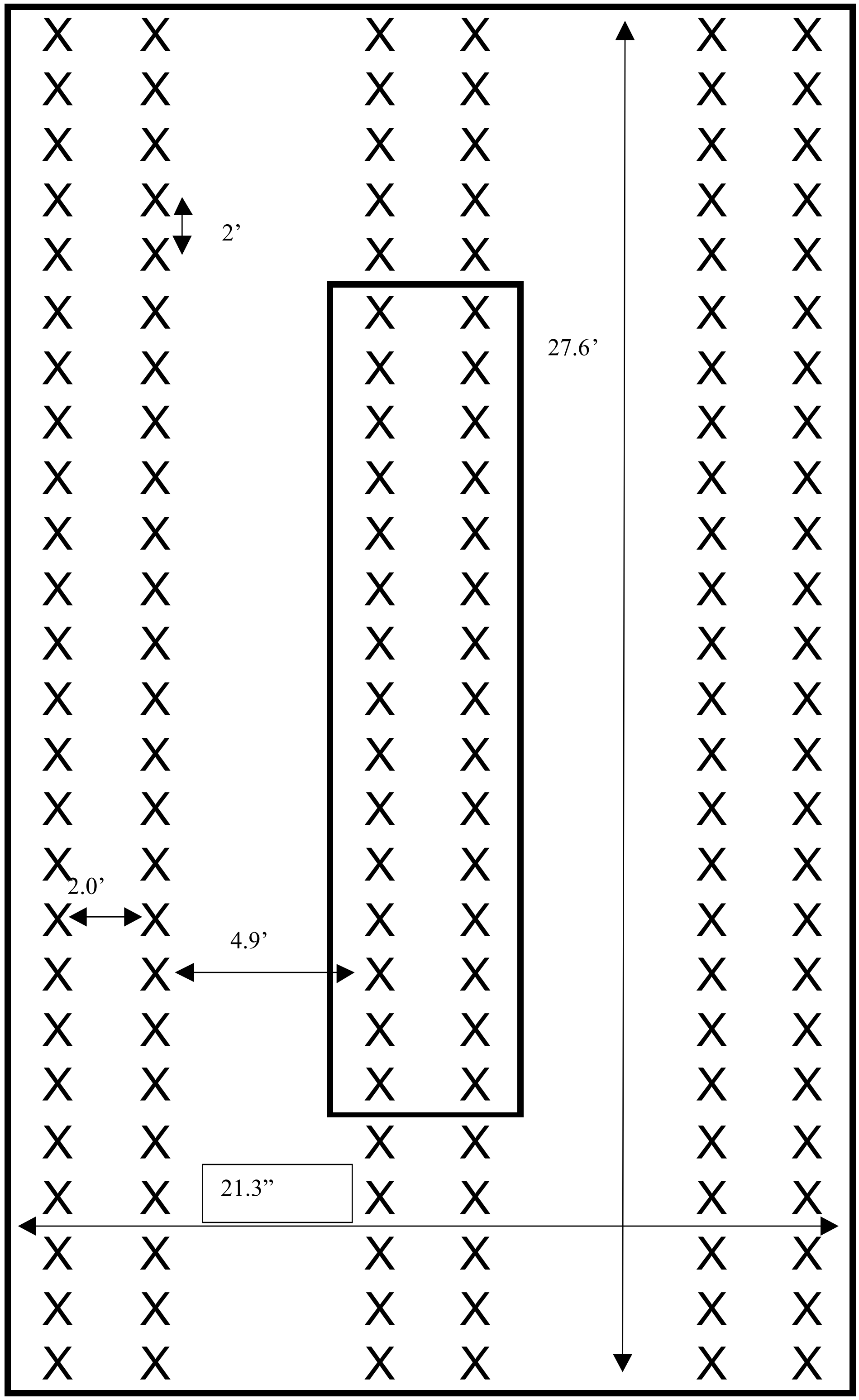


Figure 5. Diagram of an individual plot at Easton and Roaring Branch, 25 stools long (X=stool) with a 30-stool measurement plot (inner box). At Montour Preserve the plots are 13 stools long, with a 14 stool measurement plot. Diagram not to scale.

Diameters were measured in December, 1999 to the nearest 0.004” (0.1 mm) at 12” (30 cm) above soil for all stems on 15 stools in the measurement plot for each clone and used to calculate biomass with either a general willow equation or, when possible, a clone specific equation. The resulting biomass estimates were then weighted by survival percentage for each clone to estimate production on an area basis.

Roaring Branch

SUNY-ESF collaborated with several organizations, including the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry, Pennsylvania Department of Agriculture Division of Conservation and Agricultural Technology, the Pennsylvania Farm Bureau, CONEG, and Stratton Schaeffer, to establish the second willow bioenergy crop clone-site trial. The second trial was laid out on September 15, 1998 at Roaring Branch, PA (Figure 6). The land for the trial was donated by Stratton Schaeffer.

The site had been in a timothy-trefoil-clover hay crop for ten years prior to the establishment of the trial. A mid-September mowing of the site, and lack of rain, raised concerns about the effectiveness of the herbicides. However, delaying application was not an option due to the time of year and potential for fall frost in mid to late October. A mixture of glyphosate (Roundup 2.0 lb ai ac^{-1}) and 2,4-dichlorophenoxyacetic acid (HiDep 0.49 lb ai ac^{-1}) was applied in early October. The site was plowed in November 1998 and left fallow for the winter in order to facilitate drying in the spring. Prior to planting, large rocks were removed and the site was disked. The plots were laid out on May 12, 1999 and planted May 13 and 14 with 12 willow and two hybrid poplar clones. The total area for the trial was 0.5 ha. Clones were hand planted by SUNY-ESF personnel, staff from the Pennsylvania Farm Bureau, Pennsylvania Department of Agriculture, Natural Resources Conservation Service, local volunteers, and Stratton Schaeffer. An herbicide cap of oxyfluorfen (Goal 1.6e 1.0 lb ai ac^{-1}) was applied immediately following planting.

First year survival and foliage samples were collected in August 1999. Percent survival for each clone was calculated using data from the 30 stools in the measurement plot. Foliar sampling was done in accordance with the Standard Operating Procedure developed by SUNY-ESF (Appendix 1). Oven dried woody biomass and moisture concentration calculations were made around the time of coppice (11/19/99) for all clones at Roaring Branch. Samples were cut at ground level, bagged, and returned to SUNY-

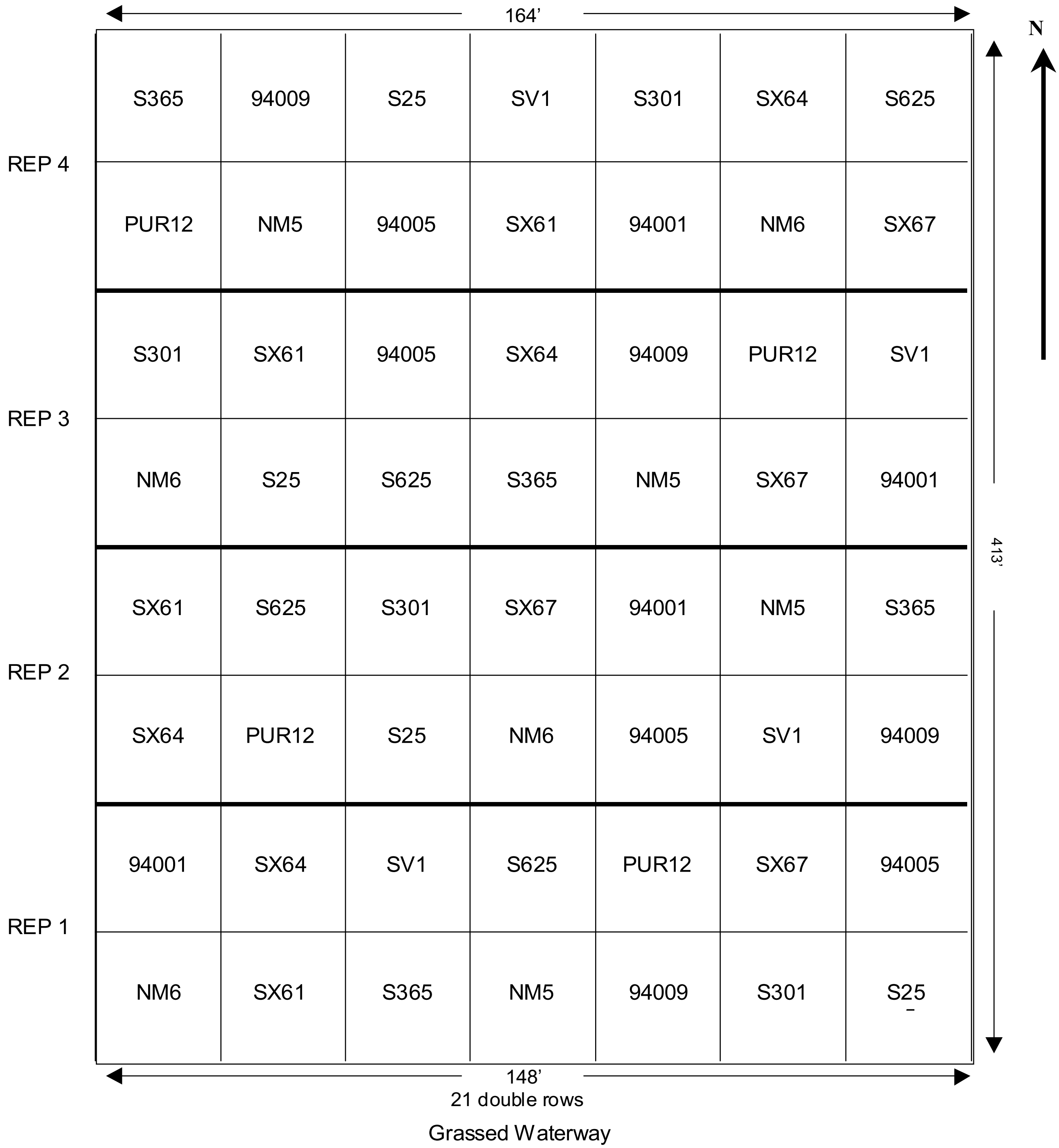


Figure 6. Site map of willow and poplar clones planted at Roaring Branch, PA in the spring of 1999. See Table 3 for specific clone information. Diagram not to scale.

ESF. Samples were dried for a minimum of seven days at 97 °F (65 °C) to a constant weight. Comparable data for the Easton site was not collected. Moisture concentration of the woody biomass was defined as:

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

A site visit in April 2000 indicated that a number of clones at Roaring Branch had suffered frost heave damage during the winter (Figure 7). As a result, an assessment of frost heave damage was made at the site. Each stool was categorized based on whether it was alive or dead, and by how far out of the ground it was frost heaved. Categories were as follows:

A = B+C+D (total alive)
B = 0”-3” above soil and alive
C = 3”-6” above soil and alive
D = 6”-9” above soil and alive
E = 0”-3” above soil and dead
F = 3”-6” above soil and dead
G = 6”-9” above soil and dead
H = Completely out of ground

Figure 7. Frost heave damage at Roaring Branch, May 2000.
(Photo by Tim Volk, SUNY-ESF.)

Cuttings forced completely out of ground are assumed dead for this assessment. Percent of each clone in each category was calculated and statistically analyzed.

Montour Preserve

SUNY-ESF collaborated with PP&L, Inc., Pennsylvania Department of Agriculture Division of Conservation and Agricultural Technology, and the Pennsylvania Farm Bureau to establish the third willow bioenergy crop clone-site trial. The land for the trial was donated by PP&L, Inc.

The Montour Preserve site (26 clones; Figure 8) was planted May 15 and 16, 2000. The site was in corn in 1999. The site was rototilled prior to planting and a pre-emergent herbicide cap mixture of oxyflouren (Goal 1.6e 1.0 lb ai ac^{-1}) and simazine (Princep 2.2 lb ai ac^{-1}) was applied shortly after planting. The site was monitored throughout the first growing season (Figure 9). Survival data for Montour Preserve was collected in August 2000, as was foliage for nutrient analyses that will be performed, provided funding can be secured to continue the trial. Percent survival for each clone was calculated using data from the 18 stools in the measurement plot in each block at Montour Preserve. Foliar sampling was done in accordance with the Standard Operating Procedure developed by SUNY-ESF.

Laboratory and Statistical Analysis

Leaf nutrient concentration of the clones at each site was analyzed for N, P, K, Ca, and Mg. Bickelhaupt and White (1982) set forth the protocol used for determining foliar nutrient concentration. The dried foliage samples were ground using a Wylie® mill. Percent foliar N was determined using the Kjeldahl method. Phosphorus concentration of the sample was determined by spectroscopic comparison to known standards. Atomic absorption spectroscopy was used to determine potassium, magnesium and calcium concentrations. Survival, foliar nutrient concentration, biomass and frost heave data were analyzed using RCBD ANOVA after Kuehl (1994), using SAS v. 8.0 (SAS Institute, 1999). Waller-Duncan's Bayesian k-ratio t-Test (k= 100) was used to evaluate means separation where ANOVA results indicated differences. Due to the much higher biomass of the poplar clones, means separation was conducted with and without poplar in the model, to adequately examine differences among the willow.

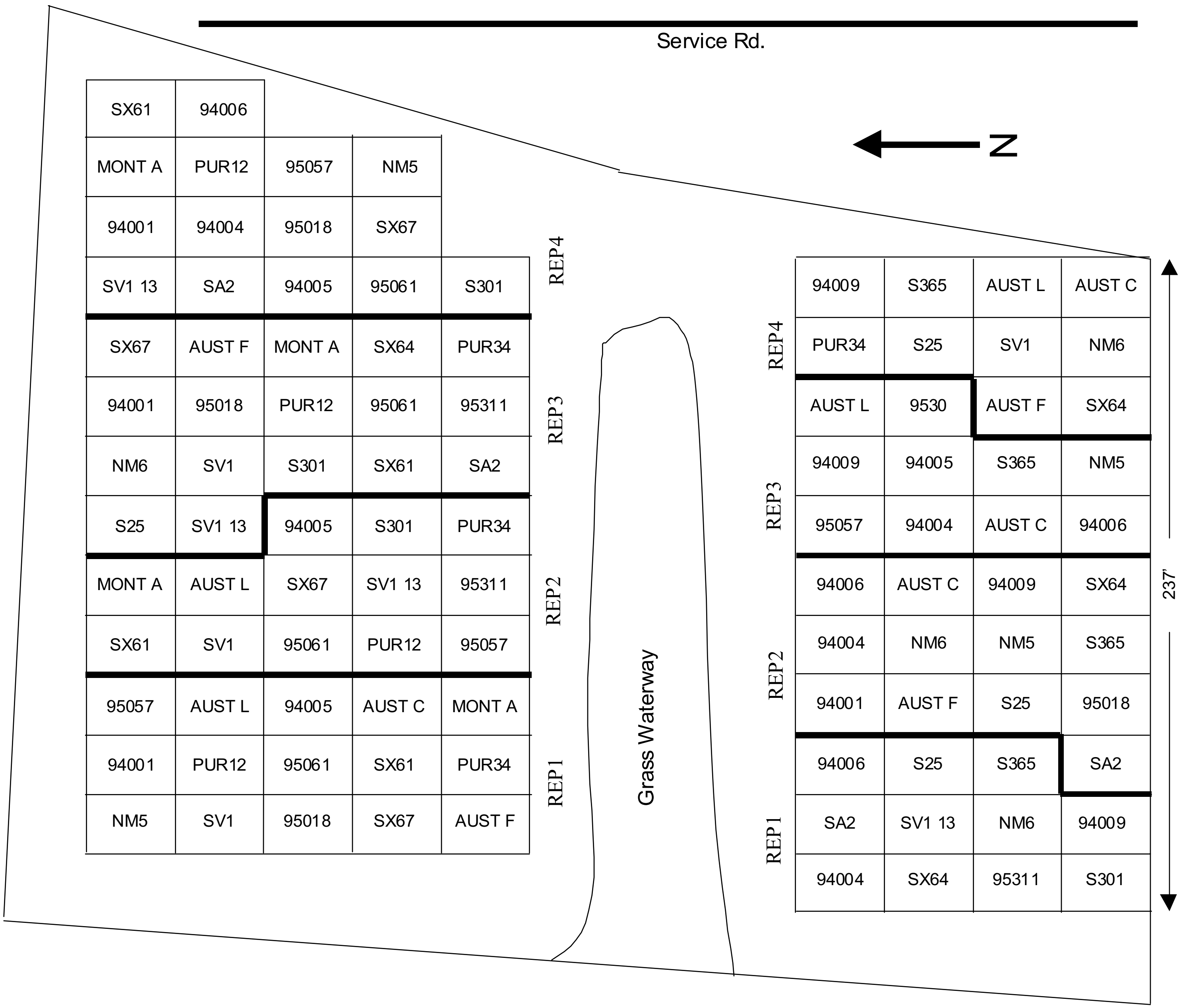


Figure 8. Site map of willow and poplar clones planted at Montour Preserve, PA in the spring of 2000. See Table 3 for specific clone information. Diagram not to scale.

Figure 9. Monitoring Montour Preserve clone-site trial for weed and insect populations, July 2000. (*Photo by Dan Cullican, SUNY-ESF, Mark Appleby, SUNY-ESF pictured.*)

Results

Survival

Survival among clones grown at Easton, ranged from 100% for NM6, S25 and SX64 to 94% for SX67 (Table 4). Overall, survival at Easton was 98%. Survival at Roaring Branch ranged from 100% for the willow clone SX64 to 90% for the poplar clone NM5 (Table 5). Average survival across all clones was 97%. The two poplar clones had the lowest survival at Roaring Branch; NM6 and NM5 averaged 95% and 90 % respectively. All of the willow clones had over 95% survival. Mid-year survival at Montour Preserve (Table 6) averaged 88%, ranging from 100% for clones NM6, 94001, Aust. F and 94006 to 32% for clone Mont. A.

Foliar nutrients, Easton

At the Easton site, there were significant differences in all foliar nutrient concentrations among the clones (Table 7). Foliar N ranged from 3.71% in willow clone 94006 to 2.61% in NM6. The four clones with the highest foliar N concentrations (94006, 94009, 94004, 94001) did not differ significantly.

Foliar P concentrations at Easton ranged from 0.23% in SV1 to 0.17% in 94004. The clone with the highest concentration, SV1 (0.23%), did not differ significantly from S365 (0.22%), but it was significantly greater than the other 12 clones. The 10 clones with the lowest foliar P were statistically similar.

Foliar K concentration ranged from 1.60% in NM6 to 0.97% in the willow clone PUR34. There were no significant differences among the seven clones with the most foliar K, nor did the eight clones with least foliar K differ significantly.

Foliar Ca concentrations ranged from 1.88% in the willow clone SX64 to 0.98% in NM6. Foliar Ca concentrations did not differ significantly among the top three clones, SX64, SX67 and SX61, though they were significantly greater than any other clones.

Foliar Mg concentrations ranged from 0.30% in the willow clone PUR12 to 0.15% in the willow clone 94009. There were no significant differences among the five clones with the greatest concentrations of foliar Mg, nor were there a significant differences among the nine clones with the lowest concentrations of foliar Mg.

Foliar nutrients, Roaring Branch

There were significant differences among clones for all foliar nutrient concentrations measured at Roaring Branch (Table 8). Foliar N concentrations ranged from 2.65% in willow clone 94009 to 1.53% in willow clone S25. The three clones highest in foliar N concentrations (94009, 94005 and NM6) did not differ significantly, but were significantly greater than the lowest 10 clones. The six clones with the lowest foliar N concentrations did not differ significantly.

Foliar P concentrations ranged from 0.23% in clones NM5 and NM6 to 0.07% in willow clone S301. The poplar clones had significantly greater foliar P concentrations than any willow, almost double the highest values in willow clones and three times the lowest values. Among the willow clones, S365 had the highest foliar P concentration (0.12%), but there were no differences in P concentrations among the other 11 willows.

Foliar K concentrations ranged from 1.29% in clone NM6 to 0.66% in the willow clone SV1. There were no significant differences among the eight clones highest in foliar K concentrations, nor did the six clones lowest in foliar K concentrations differ.

Foliar Ca concentrations ranged from 1.50% in willow clone SX67 to 0.60% in NM6 and NM5. The poplar clones were significantly lower than the top 10 willow clones. Foliar Mg ranged from 0.32% in S25 to 0.17% in willow clone SX61. Many of the clones were significantly different from each other in both foliar Ca and foliar Mg concentrations.

First year after coppice (1999) biomass, Easton

First year after coppice biomass production estimates for Easton varied by clone (Table 9). Estimates ranged from 16 odt ac^{-1} (7.1 Mg ha^{-1}) for NM6 to 2.7 odt ac^{-1} (1.2

Mg ha^{-1}) for PUR34. SX64 had the highest willow biomass (13.3 odt ac^{-1}; 5.9 Mg ha^{-1}) and eight willow clones averaged more than 4.5 odt ac^{-1} (2.0 Mg ha^{-1}).

Establishment year (1999) biomass and moisture concentration, Roaring Branch

First year biomass production at Roaring Branch ranged from 0.14 odt ac^{-1} (0.061 Mg ha^{-1}) for poplar clone NM6 to 0.007 odt ac^{-1} (0.003 Mg ha^{-1}) for willow clone S625 (Table 10). The biomass of both poplar clones was significantly greater than of any willow clone. Biomass of NM6 was significantly greater than NM5, the other poplar clone. SX64 (0.2 odt ac^{-1}; 0.01 Mg ha^{-1}) had the highest biomass among the willow clones, though there were no significant differences among the top eight willow clones.

Moisture concentration of the stems at time of harvest at Roaring Branch ranged from 55.3% in willow clone SX67 to 46.5% in willow clone S365 (Table 11), with an overall average of 51.6%. SX67 was significantly greater than the three clones with the lowest moisture concentration, but most of the clones were not significantly different from each other.

Frost heave assessment, Roaring Branch

Frost heave damage for Roaring Branch is summarized in Table 12. Clone 94001 suffered the least from frost heave, with 92.5% of the stools in the 0”-3” above ground and alive (B) category. There was no statistical difference among the top nine clones in the B category. S625 suffered the most the most from frost heaving with only 76.8% in the A category. Although SX61 and S301 both had a smaller percentage in the B category (55.5% and 48.3%), they both had higher percentage of living clones (79.3% and 85.8%). NM5 had the most clones pushed completely out of the ground (6.0%), followed closely in that category by SX67 (5.8%).

Discussion

Survival was excellent at all sites, though slightly lower at the Montour Preserve site. Sites with survival rates greater than 80% are considered successful (Volk et al. 2000). Overall survival at Easton was 98.4% compared to 97.0% at Roaring Branch. Both poplar clones had lower survival numbers than all willow clones at Roaring Branch. NM6 had 100% survival at Easton, where it was the only poplar. The overall mean survival at Montour Preserve was skewed by the low survival rates of three clones planted only at that site, SV1-13 (75.0%), 95018 (73.8%), and Mont. A (31.9%). The extremely poor survival of Mont. A was due to the poor quality of the cuttings. The material, shipped from Montreal, Canada, was delayed at customs. Consequently, the cuttings were stored at temperatures above freezing for an extended period of time, resulting in root and shoot development prior to planting. Survival at Easton and Roaring Branch was better than for three New York trials, one planted in 1997 and two planted in 1999. The Montour Preserve survival was comparable to the New York State trials. The 1997 planting was in Tully, NY, where 38 clones of willow and poplar are being assessed. Survival ranged from 67.7% for 94004 to 100% for SA2 (not planted in Pennsylvania) and 94006 (Tharakan, 1999) with an overall mean survival of 90.3%. At a site planted in 1998 in Wolcott, NY, survival ranged from 40.0% for SX67 to 98.8% for NM6, with an overall survival of 78.0% (Fillhart et al. 1999). A second site planted in 1998, in Canastota, NY, had a survival rate (Volk et al. 2000), ranging from 74.2% for S652 (which was not planted in Pennsylvania) to 100% for SV1, 94006, and NM6. The overall average survival was 95.7%.

While foliar nutrient concentrations vary among clones, they can be used as an indicator of site fertility and soil conditions (Ericsson et al. 1992). Foliar nutrient data is useful for assessing the growth potential of the plant, since there is a positive relationship between tissue nutrient status of a limiting nutrient and plant growth (Ericsson et al. 1992). The ratio of nutrient concentrations is important, as shifts can be expected in growth limiting nutrients under high N conditions (Aerts et al., 1992; Ericsson et al. 1992). Foliar nutrient concentrations were all higher at Easton compared to Roaring Branch, except for Mg, which was similar at both sites. Mean foliar N concentration was 3.16% at Easton and 2.02% at Roaring Branch. The foliar N values for the poplar clone NM6 were similar at both sites. All the willow clones had higher foliar N concentrations at the Easton site, where the lowest value for willow (S365, 2.88%) was greater than the highest value at Roaring Branch (94009, 2.65%). Most nutrient percentages at Easton are generally comparable to published data (Table 13) for *Salix* species and *Populus* species as presented in Eriksson et al. (1992). Published values for foliar N averaged 3.1% in willow and 2.4% in poplar. Willow clones averaged 0.8% P, 1.6% K, 0.7% Ca and 0.3% Mg. Poplar clones averaged 0.3% P, 1.3% K, 2.5% Ca, and 0.4% Mg. Hansen (1994) states that poplar foliage should be maintained at >3.0% foliar N and >0.33% foliar P concentrations for optimal growth. The upper level values published for foliar P in willow is much higher than that found at either Easton or Roaring Branch, suggesting a potential need for P addition at these sites. This observation appears to be supported by a strong correlation between foliar P and first year biomass production at Roaring Branch

(ρ=0.95; p<0.0001). Published data for Ca concentrations in poplar is about twice the values for the poplars at the Pennsylvania sites, but Ca uptake is highly dependent on soil water and transpiration rates. However, there is a negative correlation between foliar Ca and biomass (ρ= -0.57; p=0.03) in first year biomass production at Roaring Branch. Closer examination of these observations needs to be made to determine if the trend continues within and between sites.

First year after coppice biomass production (1999 growing season) at Easton was slightly below what has been recorded in other trials. A 1995 planting of SV1 in New York State at the same spacing and fertilizer regime as the Pennsylvania trials, had first year after coppice biomass of about 23.6 odt ac^{-1} (10.5 Mg ha^{-1}) in 1996 (Adegbidi, 1999). SV1 at Easton averaged 6.4 odt ac^{-1} (2.8 Mg ha^{-1}). However, SV1 was only the sixth highest biomass producer at Easton. In a study of somewhat more densely planted clones (7,500 stools ac^{-1}), Tharakan (1999) found first year after coppice biomass in 1998 ranged from 6.4 odt ac^{-1} (2.8 Mg ha^{-1}) for S25 to 19.8 odt ac^{-1} (8.8 Mg ha^{-1}) for PUR12, only slightly higher than the values found at Easton. All values reported are for the same fertilizer regime, 89 lb N ac^{-1} (100 kg N ha^{-1}) applied in the spring after coppice. However, both the Adegbidi (1999) and Tharakan (1999) studies began with full site preparation and rigorous weed control throughout establishment. Growth at the Easton site was likely retarded appreciably due to some weed competition during establishment and the drought conditions in 1999 (Table 2). Plots in the Adegbidi (1999) study had an average first year after coppice biomass of approximately 20.3 odt ac^{-1} (9 Mg ha^{-1}), when the root systems were two years old. First year after harvest biomass production, when the root systems are five years old, is expected to be greater than first year after coppice due to the additional years of root establishment. However, first year after harvest (1999) biomass on this site had fallen to 11.9 odt ac^{-1} (5.3 Mg ha^{-1}), probably due to the drought conditions. Biomass production estimates are planned for Roaring Branch in fall 2000.

Frost heaving at Roaring Branch was not as damaging as originally feared. Only five clones suffered greatly from frost heave damage. SX61 and S625 each suffered a further 20% reduction in survival (over 1999 data) due to frost heave damage and SX67, S301 and 94009 suffered an addition 11% and 12% reduction in survival. Among the remaining nine clones, most frost heave damage was primarily on cuttings that were already dead. Thriving clones with well-established roots systems are more resistant to frost heaving. There is some evidence for a positive correlation (ρ=0.46; p=0.096) between foliar P and the percentage of plants in the B category. Conversely, foliar P in living plants pushed further out of the ground (C and D) had a negative relationship. Plants in the C category had $\rho = -0.50$ ($p=0.07$), and plants in the D category had $\rho = -0.45$ correlation ($p=0.10$). This may be due to P's association with enhanced root development (Anghinoni and Barber, 1980). No other element had any correlation to frost heave category.

Future Plans

Future work on these trials is dependent on the availability of funding. The intention is to continue to regularly monitor the two remaining trials in Pennsylvania and measure survival and growth on an annual basis. Recent results from a clone-site trial established in central New York in 1993 and harvested in 1997 and 1999 indicate that yields from first to second rotation increase by 18–62%, depending on the clone. In addition, three of the ten top yielding clones in 1993 were no longer among the top ten in 1999 (Volk, unpublished data). These results indicate that clone site trials should be followed for at least two rotations (seven years) in order to provide more information on clone-site interactions. This will occur in the winter of 2004/05 for Roaring Branch and 2005/06 for Montour Preserve. The data from the Pennsylvania trials could be a beneficial addition to efforts underway at SUNY-ESF to develop a model that can be used to predict growth and yield of different clones of willow across a wide range of soils and climatic conditions (Tharakan et al. 2000). To date there are trials with over fifty different clones in eight other states and southern Quebec (Volk et al. 2000) that SUNY-ESF is collaborating on. Collectively, with the use standardized data collection procedures, this network of trials can provide an excellent opportunity to develop a regional growth and yield model.

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Tables

Table 1. Collaborators involved in the establishment of clone-site trials in Pennsylvania from 1998 – 2000.

Trial Location	**Collaborators**
Easton, PA	Lafayette College, Pennsylvania Farm Bureau, Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry, CONEG
Roaring Branch, PA	Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry, Pennsylvania Farm Bureau, Pennsylvania Department of Agriculture Division of Conservation and Agricultural Technology, CONEG, Stratton Schaeffer
Montour Preserve, PA	PP&L Inc., Pennsylvania Department of Agriculture Division of Conservation and Agricultural Technology, Pennsylvania Farm Bureau

Table 2. Summary of mean growing season (April 1- Oct. 31) temperature, growing degree days (GDD) and growing season precipitation for Belvedere Bridge, NJ (representative of the Easton site) and Wellsboro, PA (representative of the Roaring Branch site). SE is the standard error of the long-term averages.

		Temp ^{o}F	SE	GDD	SE	Precipitation	SE
Belvedere Bridge	1998	63.7	9.6	3026		31.1"	
	1999	63.7	11.7	3066		20.0"	
	1982-1999 mean	**61.8**	**8.9**	**2741**	**246**	**28.5"**	**5.6"**
Wellsboro	1999	57.6	11.1	1821		19.51"	
	1960-1990 mean	**56.2**	**8.8**	**1863**	**155**	**21.81"**	**4.0"**

Table 3. Willow and poplar clones, with parentage and origin, planted in the Pennsylvania clone-site trials at Easton, Roaring Branch and Montour Preserve.

Clone	Parentage	Origin	Easton 1998	Roaring Branch 1999	Montour Preserve 2000
S25	S. eriocephala 16 x eriocephala 276	UT	X	X	X
S301	S. interior 62	UT	X	X	X
S365	S. discolor 18	UT	X	X	X
S625	S. eriocephala 39 x interior 42	UT		X	
SV1	S. dasyclados	Brantford, Ontario	X	X	X
SX61	S. sachalinensis	Japan	X	X	X
SX64	S. miyabeana	Japan	X	X	X
SX67	S. miyabeana	Japan	X	X	X
PUR12	S. purpurea	Ontario	X	X	X
PUR34	S. purpurea	Ontario	X		X
94001	S. purpurea (FC185)	Blossvale, NY	X	X	X
94004	S. purpurea (FC188)	Blossvale, NY	X		X
94005	S. purpurea (FC189)	Blossvale, NY		X	X
94006	S. purpurea (FC190)	Blossvale, NY	X		X
94009	S. purpurea (B193)	Georgetown, NY	X	X	X
NM6	P. nigra x maximowiczii	OMNR	X	X	X
NM5	P. nigra x maximowiczii	OMNR		X	X
95018	S. eriocephala	Putnam NY			X
95057	S. purpurea	Allegany, NY			X
95061	S. eriocephala	Allegany, NY			X
95311	S. eriocephala	Bradford, PA			X
SA2	S. alba	Novi Sad, Yugoslavia			X
SV1-13	open pollinated SV1	Tully, NY			X
Aust C	S. matsudana x alba	Austrees, Inc.			X
Aust F	S. matsudana x alba	Austrees, Inc.			X
Aust L	S. matsudana x alba	Austrees, Inc.			X
Mont A	S. spp.	N/A			X

Note: S = Salix; P = Populus; UT = University of Toronto; SUNY-ESF = State University of New York College of Environmental Science and Forestry; OMNR = Ontario Ministry of Natural Resources

Table 4. Mean percent survival for clones planted in 1998 at Easton, PA.

Clone	Mean[1]	SE[2]	
NM6	100.0	0.0	a
S25	100.0	0.0	a
SX64	100.0	0.0	a
94001	99.6	0.9	ab
SV1	99.6	0.9	ab
S301	99.6	0.9	ab
PUR12	99.2	1.7	abc
PUR34	99.2	1.0	abc
FC188	98.8	1.6	abc
S365	98.3	1.3	abc
FC190	97.5	3.2	abc
SX61	96.7	2.7	abc
94009	94.6	7.6	bc
SX67	94.2	5.2	c
Average	**98.4**	**1.9**	

[1]Means with the same letter are not significantly different (α=0.05)
Minimum significant difference is 5.2%.
[2]Standard error.

Table 5. Mean percent survival for clones planted in 1999 at Roaring Branch, PA.

Clone	Mean[1]	SE[2]	
SX64	100.0	0.00	a
SX61	99.6	0.43	a
94001	98.8	0.79	ab
S25	98.7	0.43	ab
PUR12	98.4	0.95	ab
SX67	97.9	0.79	ab
SV1	97.9	1.05	ab
S301	97.9	0.40	ab
S365	96.7	0.67	ab
94009	96.3	1.56	ab
94005	96.3	2.19	ab
S625	95.8	1.08	ab
NM6	94.6	2.74	b
NM5	89.6	4.17	c
Average	**97.0**	**2.63**	

[1]Means with the same letter are not significantly different (α=0.05)
Minimum significant difference is 5.8%.
[2]Standard error.

Table 6. Mean percent survival for clones planted in 2000 at Montour Preserve, PA.

Clone	Mean[1]	SE[2]	
NM6	100.0	0.0	a
94006	100.0	0.0	a
94001	100.0	0.0	a
AUST. F	100.0	0.6	a
AUST. L	98.6	2.8	ab
SV 1	97.2	5.6	abc
94005	97.2	5.6	abc
AUST. C	97.2	3.2	abc
94004	95.8	5.3	abc
PUR12	95.8	5.3	abc
95311	94.4	4.5	abc
95057	94.4	7.9	abc
SA 2	94.4	4.5	abc
NM5	94.4	4.5	abc
S301	93.1	10.5	abc
95061	90.3	2.8	abc
B193	88.9	12.0	abcd
S365	86.1	9.6	bcde
SX64	84.7	14.6	cde
SX61	84.7	11.5	cde
PUR34	76.4	22.4	def
SV1-13	75.0	17.3	ef
95018	73.6	16.0	ef
S25	69.4	11.6	f
SX67	63.9	14.7	f
MONT.A	31.9	13.9	g
Mean	**87.6**	**7.9**	

[1]Means with the same letter are not significantly different (α=0.05)
Minimum significant difference is 5.8%.
[2]Standard error.

Table 7. Mean percent foliar nutrient concentrations after one growing season for clones grown at Easton, PA.

%N				%P				%K				%Ca				
Clone	Mean[1]	SE[2]		Clone	Mean[1]	SE[2]		Clone	Mean[1]	SE[2]		Clone	Mean[1]	SE[2]		Clone
94006	3.71	0.18	a	SV1	0.23	0.01	a	NM6	1.60	0.13	a	SX64	1.88	0.07	a	Pur12
94009	3.49	0.18	ab	S365	0.22	0.02	ab	94004	1.48	0.14	ab	SX67	1.87	0.39	a	S365
94004	3.44	0.48	ab	S25	0.20	0.02	bc	S365	1.47	0.15	ab	SX61	1.81	0.10	a	SV1
94001	3.43	0.14	ab	Pur12	0.20	0.01	cd	SV1	1.39	0.20	abc	94004	1.47	0.08	b	S25
SV1	3.33	0.15	bc	NM6	0.19	0.01	cde	S25	1.37	0.18	abc	94006	1.44	0.16	b	Pur34
Pur34	3.24	0.23	bcd	94001	0.19	0.01	cde	94006	1.34	0.30	abcd	SV1	1.43	0.17	b	S301
Pur12	3.16	0.25	bcde	SX64	0.19	0.01	cde	94009	1.28	0.22	abcde	S301	1.42	0.11	b	NM6
SX64	3.03	0.09	cde	SX67	0.19	0.02	cde	S301	1.20	0.11	bcde	Pur12	1.40	0.14	bc	94004
S25	3.03	0.27	cde	Pur34	0.19	0.01	cde	Pur12	1.15	0.37	bcde	94009	1.38	0.14	bc	94006
SX61	3.03	0.17	cde	94006	0.18	0.02	cde	SX67	1.13	0.36	bcde	S25	1.34	0.14	bc	94001
SX67	2.93	0.35	def	94009	0.18	0.02	de	94001	1.09	0.23	cde	94001	1.22	0.08	cd	SX67
S301	2.92	0.23	def	SX61	0.17	0.01	e	SX64	1.06	0.22	cde	S365	1.11	0.05	de	SX61
S365	2.88	0.16	ef	S301	0.17	0.01	e	SX61	0.99	0.26	de	Pur34	1.10	0.11	de	SX64
NM6	2.61	0.21	f	94004	0.17	0.03	e	Pur34	0.97	0.22	e	NM6	0.98	0.17	e	94009
Mean	**3.16**	**0.30**		**Mean**	**0.19**	**0.02**		**Mean**	**1.25**	**0.20**		**Mean**	**1.42**	**0.28**		**Mean**

[1]Means with the same letter are not significantly different (α=0.05)
[2]Standard error.

Table 8. Mean percent foliar nutrient concentrations after one growing season for clones grown at Roaring Branch, PA.

%N				%P				%K				%Ca				
Clone	Mean[1]	SE[2]		Clone	Mean[1]	SE[2]		Clone	Mean[1]	SE[2]		Clone	Mean[1]	SE[2]		Clone
94009	2.65	0.30	a	NM5	0.23	0.09	a	NM6	1.29	0.12	a	SX67	1.50	0.11	a	S25
94005	2.59	0.37	a	NM6	0.23	0.04	a	NM5	1.23	0.30	ab	SX64	1.41	0.15	ab	S365
NM6	2.55	0.50	ab	S365	0.12	0.07	b	94005	1.14	0.11	abc	S625	1.31	0.08	bc	SV1
NM5	2.30	0.50	bc	94009	0.11	0.04	cb	94001	1.08	0.17	abc	SX61	1.22	0.07	cd	S625
94001	2.23	0.24	c	94001	0.10	0.02	cb	94009	1.04	0.27	abc	S25	1.21	0.03	cd	94005
SV1	2.14	0.15	c	PUR12	0.09	0.02	cb	PUR12	1.02	0.12	abc	S301	1.15	0.11	d	S301
PUR12	2.12	0.41	c	SX67	0.09	0.03	cb	S625	1.01	0.07	abc	SV1	1.12	0.15	d	NM5
S365	2.07	0.44	c	S25	0.09	0.01	cb	S365	0.99	0.38	abc	S365	0.90	0.07	e	94001
SX67	1.75	0.35	d	SV1	0.08	0.01	cb	SX61	0.94	0.11	bcd	94009	0.84	0.05	e	NM6
S625	1.65	0.09	d	94005	0.08	0.01	cb	SX64	0.93	0.17	bcd	94001	0.81	0.05	ef	PUR12
SX61	1.64	0.21	d	SX64	0.08	0.00	cb	S301	0.92	0.06	bcd	PUR12	0.72	0.12	fg	SX64
SX64	1.57	0.14	d	SX61	0.07	0.01	c	S25	0.91	0.15	cd	94005	0.72	0.07	fg	SX67
S301	1.57	0.21	d	S625	0.07	0.01	c	SX67	0.90	0.18	cd	NM5	0.60	0.06	gh	94009
S25	1.53	0.21	d	S301	0.07	0.01	c	SV1	0.66	0.06	d	NM6	0.60	0.08	h	SX61
Mean	**2.02**	**0.41**		**Mean**	**0.11**	**0.05**		**Mean**	**1.00**	**0.16**		**Mean**	**1.01**	**0.30**		**Mean**

[1]Means with the same letter are not significantly different (α=0.05)
[2]Standard error.

Table 9. Estimated oven dried biomass production (odt ac^{-1}) of one-year-old above ground material on two-year-old root stock at Easton, PA.

	Biomass[1]	SE[2]	
NM6	16.0	2.8	a
SX64	13.4	2.8	a
SX67	8.5	2.2	b
SX61	8.1	4.8	bc
S365	7.4	3.0	bcd
S25	6.9	2.3	bcde
SV1	6.4	2.9	bcde
PUR12	5.6	1.7	bcdef
94006	5.1	2.2	cdef
S301	4.2	1.4	def
94001	4.0	1.0	ef
94009	3.3	0.9	ef
94004	2.9	1.9	f
PUR34	2.7	0.6	f

[1]Means with the same letter are not significantly different (α=0.05)
Minimum significant difference is 1.55.
[2]Standard error.

Table 10. Mean oven dried woody biomass (odt ac^{-1}) for clones planted in 1999 at Roaring Branch, PA.

Clone	Mean[1]	SE[2]	A[3]	B[4]
NM6	0.14	0.070	a	
NM5	0.10	0.060	b	
SX64	0.02	0.004	c	a
S365	0.02	0.012	c	ab
94005	0.02	0.007	c	ab
94001	0.02	0.006	c	ab
S25	0.02	0.005	c	ab
SV1	0.02	0.002	c	abc
SX61	0.01	0.006	c	abc
PUR12	0.01	0.005	c	abc
SX67	0.01	0.006	c	bc
S301	0.01	0.003	c	bc
94009	0.01	0.002	c	bc
S625	0.01	0.001	c	c

[1]Means with the same letter are not significantly different (α=0.05)
[2]Standard error.
[3]A=model with poplar included. Minimum significant difference is 0.14.
[3]B=model with poplar excluded. Minimum significant difference is 0.42.

Table 11. Mean percent moisture content for clones planted in 1999 at Roaring Branch, PA.

Clone	Mean[1]	SE[2]	
SX67	55.3	1.7	a
S625	53.2	1.4	ab
SX61	53.1	2.7	ab
SX64	52.8	0.4	ab
94009	52.3	0.8	ab
NM5	52.0	1.4	ab
PUR12	52.0	1.6	ab
94005	51.8	0.7	ab
94001	51.7	1.5	ab
S25	51.5	1.1	ab
S301	51.1	1.3	abc
NM6	50.3	1.7	bc
SV1	49.4	1.3	bc
S365	46.5	10.2	c
Average	**51.6**	**2.01**	

[1]Means with the same letter are not significantly different (α=0.05)
Minimum significant difference is 4.8%.

Table 12. Frost heave damage assessment in April 2000 for Roaring Branch, PA. Results are mean percent of each clone in each category (see Legend).

	A			B			C			D	
Clone	Mean[1]	SE[2]		Mean[1]	SE[2]		Mean[1]	SE[2]		Mean[1]	SE[2]
SX64	99.50	0.58	a	88.25	9.78	ab	10.50	9.00	c	0.75	0.50
94001	98.75	1.50	ab	92.50	6.40	a	4.75	5.50	c	1.50	2.38
SV1	96.75	2.75	abc	82.75	14.29	abc	12.25	10.78	c	1.75	2.22
S365	95.50	4.80	abc	88.50	9.98	ab	5.50	4.12	c	1.50	1.73
S25	95.00	3.56	abc	80.00	8.81	abcd	14.25	9.50	bc	0.75	0.00
NM6	95.00	4.69	abc	90.25	14.76	ab	4.75	11.00	c	0.00	0.96
PUR12	91.50	8.96	abc	70.75	24.66	abcde	18.75	19.74	abc	2.00	1.83
94005	91.00	2.16	abcd	56.25	13.20	de	32.25	14.82	ab	2.50	1.91
NM5	90.75	7.41	abcd	79.50	8.19	abcd	9.50	1.00	c	1.75	1.71
SX67	86.75	17.44	bcde	71.75	21.65	abcde	12.00	8.04	c	3.00	2.31
S301	85.75	11.87	cde	48.25	24.17	e	33.25	19.45	a	4.25	3.40
94009	84.75	8.54	cde	66.50	8.35	bcde	15.50	3.79	abc	2.75	2.06
SX61	79.25	13.89	de	55.50	28.34	de	20.75	11.03	abc	3.00	4.08
S625	76.75	9.91	e	61.00	11.52	cde	14.25	10.69	bc	1.50	1.73

[1]Means with the same letter are not statistically different.
[2]Standard error

Legend: A=B+C+D
B=0"-3" above/alive
C=3"-6" above/alive
D=6"-9" above/alive

Table 12 (cont'd). Frost heave damage assessment in April 2000 for Roaring Branch, PA. Results are mean percent of each clone in each category (see Legend).

	E			F			G			H		
Clone	Mean[1]	SE[2]		Mean[1]	SE[2]		Mean[1]	SE[2]		Mean[1]	SE[2]	
SX64	0.00	0.00	b	0.25	0.50	c	0.25	0.50	c	0.75	0.96	b
94001	0.00	0.00	b	0.50	0.58	c	0.25	0.50	c	1.50	1.29	b
SV1	0.50	0.58	ab	0.25	0.50	c	0.50	1.00	bc	2.00	1.83	b
S365	0.25	0.50	ab	0.50	0.58	c	1.50	0.58	bc	2.25	3.30	b
S25	0.25	0.50	ab	2.00	0.82	c	1.75	0.96	bc	1.75	2.71	b
NM6	0.25	0.50	ab	1.00	1.83	c	1.25	1.50	bc	3.00	2.22	ab
PUR12	0.25	0.50	ab	2.50	2.38	bc	2.50	3.11	bc	4.00	3.83	ab
94005	1.25	1.50	ab	1.25	1.50	c	2.00	1.41	bc	4.50	1.00	ab
NM5	0.25	0.50	ab	1.25	1.50	c	2.25	0.96	bc	6.00	4.97	ab
SX67	0.25	0.50	ab	4.50	7.68	abc	3.25	2.87	bc	5.75	6.24	ab
S301	1.00	0.82	ab	3.25	4.57	bc	4.25	3.77	bc	6.00	2.94	ab
94009	1.25	1.89	ab	4.50	4.73	abc	5.50	1.73	ab	4.50	2.52	ab
SX61	0.50	0.58	ab	7.00	4.40	ab	9.50	8.89	a	3.50	3.11	ab
S625	2.25	2.50	a	8.50	3.42	a	5.00	2.94	abc	8.00	3.37	a

[1]Means with the same letter are not statistically different.
[2]Standard error

Legend: E=0"-3" above/dead
F=3"-6" above/dead
G=6"-9" above/dead
H=out of ground

Table 13. Range of values for foliar nutrients in poplar and willow clones grown at Easton, PA and Roaring Branch, PA in comparison to values published in Ericsson et al. (1992).

	Easton		Roaring Branch		Ericsson et al. (1992)	
	Poplar	Willow	Poplar	Willow	Poplar	Willow
%N	2.61	3.71-2.88	2.55-2.30	2.65-1.53	3.00-1.60	4.20-2.00
%P	0.19	0.23-0.17	0.23	0.12-0.01	0.46-0.21	0.64-0.12
%K	1.60	1.48-0.97	1.29-1.23	1.14-0.66	2.00-0.70	2.40-0.91
%Ca	0.98	1.88-1.10	0.60	1.50-0.72	3.7-1.60	1.00-0.50
%Mg	0.21	0.30-0.15	0.24-0.20	0.32-0.17	0.50-0.24	0.43-0.30

Appendix 1

SUNY-ESF Short-Rotation Woody Crops Program

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 analyses 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 leaves 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—within 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 (20 leaves from 10 trees) of small-leaved clones (e.g., *Salix purpurea*) or 100 leaves (10 leaves from 10 trees) from large-leaved clones (e.g., *Salix dasyclados*). The purpose 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.