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GENETIC BIOMASS AND GROWTH ANALYSIS OF CLONAL SILVER MAPLE (Acer saccharinum L.) IN SEVERAL LOCATIONS

Annual Report

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SUMMARY/ABSTRACT FOR 1995

GENETIC BIOMASS AND GROWTH ANALYSIS OF CLONAL SILVER MAPLE (Acer saccharinum L.) IN SEVERAL LOCATIONS.

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The project goal is to utilize genetic selection, clonal propagation, and field growth comparisons to study biomass production from Acer saccharinum L. (silver maple) clones under dense, short-rotation plantings in Illinois, Kansas, and Minnesota. This goal reflects earlier research by the Biofuels Feedstock Development Program that established the suitability of growing silver maple for energy and chemical feedstocks. Broadly defined, the genetic objectives were to obtain plant material, from trees throughout the native range of silver maple, plant them in a replicated manner in a nursery in southern Illinois, and then evaluate the biomass growth characteristics of selected clones at geographically and ecologically diverse locations.

Following the development of macro- and micropropagation techniques, clonally micropropagated plantlets of silver maple were established in biofuel research plantations on a lowland and an upland site in southern Illinois in 1991 and on a central Kansas floodplain and a Minnesota upland site in 1992. Each plantation consists of a randomized complete block design (10 blocks) with 4 clones from each of 13 provenances and 52 3-tree clonal plots per block. Two additional provenances were included in border rows. Other plantations established in southern Illinois include the original provenance nursery, a replicated 90-clone (gene) bank, an intensive-study site for destructive sampling of clonal silver maple and several weed control studies with silver maple and ash or poplar.

The scheduled third-year harvest of five blocks each from the lowland and upland sites occurred in early 1994. Harvest of five blocks each from the Kansas and Minnesota plantations occurred in early 1995. In addition to height, caliper and phenological measurements of all Illinois plantation trees, data collected from the harvested stems included whole-tree weight at all sites, branch architecture from the Illinois and Minnesota sites, and wood specific gravity, stem taper, and wood:bark relationships from the Illinois sites. These measurements continue to be analyzed and related to previous growth performance data.

One primary long-term objective is to select specific clones of silver maple to be established in biofuel plantations. We plan to identify suitable clones at each location as well as those that perform well at multiple sites (narrow and broad adaptability, respectively). The scheduled termination of both Carbondale sites in early 1996 and both remote sites in late 1996 will result in complete five-year growth measurements for approximately 7,000 clonal silver maple trees in four distinct plantation environments. Predictions can be made regarding suitable seed collection areas and a calculated clonal gain for silver maple biomass production.

We have also been active in pursuing research in areas not directly funded under the current contract. We have established a broad-based research program in silver maple silviculture and physiology and have initiated joint efforts whenever possible. Cooperative programs include: weed control plantings with SIU-C, the USDA Forest Service North Central Forest Experiment Station (FS NCFES), Tredegar Film Products of Richmond VA and the Community Foundation for the Fox Valley Region (William Heckrodt in Wisconsin); a silver maple allozyme analysis M.S. program with SIU-C, Alabama A&M University and the USDA FS NCFES; analysis of DNA polymorphism with the USDA FS NCFES (Consortium For Plant Biotechnology Research); cold hardiness research with the University of Maine; drought and heat tolerance experiments with Iowa State University; and silver maple and poplar evaluations with the USDA FS NCFES, Rhinelander WI. Research efforts supported specifically by SIU-C include: two M.S. studies on macro- and micropropagation of adult silver maple, in vitro adventitious regeneration of silver maple, DNA polymorphism analysis, the ability of hardwood cuttings to be rooted directly in the field, the effects of herbicide treatments, repeated-coppice experiments, plantlet chilling experiments, and water relations with coppice and non-coppice silver maple trees.

GOALS AND OBJECTIVES

The major goal of our project was to evaluate four selected clones from each of 13 out of 26 different provenances in various locations. By using clonal replications of these genotypes, we are measuring clonal biomass gain at each site and determining the contributions of tree genotype and the field environment on silver maple phenotype.

Our germplasm was collected throughout the eastern United States and southeastern Canada during the spring and early summer of 1987. Ninety clones were selected at the end of the first growing season in Carbondale and 60 have been propagated by cuttings and in vitro microculture. Large scale micropropagation procedures were developed for these clones and used to produce nearly all material for the plantations. Approximately 6 of the 60 clones did not micropropagate well, and rooted cuttings were used to complete the field plantings of these clones.

Clonal trees were planted in replicated plantations (randomized complete block design with 10 blocks and 3-tree replicates) on both a lowland and an upland site in Carbondale, Illinois in 1991 and in Kansas and Minnesota in 1992. There are approximately 1800 micropropagated trees per planting site, including border rows. Trees in the border rows were from selected clones from two other provenances to expand the scope of inference of our study from 13 provenances (per the original proposal for this project) without the need for additional land.

At the Illinois biofuel plantations, trees from one-half of the plantation (5 complete blocks) were harvested, measured, and evaluated after three seasons of growth (1991 to 1993). These trees have been allowed to coppice during 1994 and 1995. Five complete blocks from

the sites in Kansas and Minnesota were harvested after three seasons (1992 to 1994) and allowed to coppice in 1995 and projected for 1996. Noncoppiced trees and the coppice regrowth at all four sites will be harvested following five complete growing seasons after planting (early and late 1996 for Illinois and remote sites, respectively). This will permit comparisons among the different silver maple genotypes for their growth characteristics and coppicing attributes at a series of geographically and ecologically diverse locations.

In addition, a replicated clonal (gene) bank of all 90 selected trees was established in 1990 and the original seedling nursery is being maintained in Carbondale, Illinois. Preliminary plantings were established during previous years in Kansas and Minnesota. These plantings provided information about the specific sites, transplantability at these diverse locations, maintenance requirements, unique weed and other problems at remote sites, as well as some data on clonal performance at various locations.

An intensive study site was established in 1994 to allow for further growth analysis and destructive sampling of clonal silver maple trees should funding become available. Cold-stored, quiescent micropropagated trees were planted in two adjacent plantations in June using randomized complete block designs with 10 clones and 5 blocks in one planting and 5 clones with 4 blocks in the other planting. The plantation was plowed, disked, rotovated and covered with strips of 1.41 mil white-on-black polyethylene mulch. Plots in both studies consisted of 20 contiguous clonal trees at 1.5 m centers. The six interior plot trees will be used for all analyses to evaluate growth performance of each selection in a "uniform" clonal stand.

A third plantation in a series designed to evaluate the effectiveness of plastic mulches versus conventional establishment management techniques was established in the summer of 1995. The research study is supported by SIU-C, the USDA FS NCFES in Carbondale Illinois and by the Community Foundation for the Fox Valley Region (William Heckrodt in Wisconsin). This study plot is in addition to the two ongoing studies (established in 1992 and 1993) supported by SIU-C, the USFS NCFES and Tredegar Film Products. Site preparation and mulching is complete for the fourth study plot scheduled for planting in the spring of 1996.

We have further objectives for both the genetic and the growth components of our project. Broadly defined, the genetic objectives are to assess the extent of genetic diversity in juvenile silver maple, identify and select superior silver maple clones from well documented plantation populations, and furnish an estimate of the potential for clonal genetic gain in silver maple. The growth objectives center on operational means for clonal propagation of silver maple and for assessment of field growth rates including: height, basal caliper, DBH, canopy volume, tree architecture, coppice development and growth, nutrient requirements, and impact of pests including insects, disease, and animal (deer) browse. Our study methods and results will form the basis for subsequent evaluations of the suitability and economics of using silver maple for biomass production in appropriate biofuel regions, and for preliminary recommendations in selection of appropriate clones for silver maple biomass plantations.

PRESENTATION OF ACCOMPLISHMENTS

The following are accomplishments during 1995 and are in addition to those reported previously, with the last annual report dated 1 January 1995. These accomplishments have been a continuation of findings based on research outlined in our original proposal. To meet the project goals, the following tasks were delineated:

Task 1. Production of Planting Stock for Field Tests.

1. Task 1 was completed as of July 1992.

Task 2. Plantation Establishment.

1. Task 2 was completed as of October 1992.

2. The third weed control study was planted in June 1995 to evaluate plastic mulch efficacy for plantation establishment of silver maple and poplar in southern Illinois. Overall survival of silver maple plantlets was approximately 84%. Populus clones averaged approximately 68%.

3. Site preparation and mulching is completed for the 1996 weed control study.

Task 3. Plantation Maintenance.

1. A complete granular fertilizer (12-12-12-12) was applied to the upland and lowland sites in mid-May at a rate of 2 lbs actual N per 1000 ft^2 (approximately 1 kg per 100 m^2) (90 lbs N per acre or 101 kg N per hectare). Fertilizer was applied to the Minnesota site in April and again in June at 1/2 rate each. The Kansas plantation was fertilized during the last week in June.
2. During June, the perimeter areas under the deer fences on the upland, lowland, and the weed control sites were sprayed with glyphosate using a tractor and sprayer. Within two weeks there was complete kill of the weeds under the deer fences on all sites.

3. Additional plantation maintenance was not required on either the lowland or upland sites other than regular recharging of the electric deer fence batteries as is done for all Carbondale fenced areas. Maintenance was not performed on the KS or MN sites.

4. The intensive I and II sites were maintained according to our standard second year establishment protocols. Tall grass weeds growing between the strips of mulch were occasionally mowed. Weeds in contact with the deer exclusion fence were weedwacked during August.

5. Both intensive sites were fertilized on August 18 with a complete granular fertilizer

(12-12-12-12) at a rate of 1 lb actual N per 1000 sq. ft. (approximately 0.5 kg per 100 sq. m.) (45 lbs N per acre or 55.5 kg N per hectare).

6. Rabbit damage and frost heaving were apparent on the intensive sites. Rabbit damage was estimated at approximately 30% of the trees over both plantations with the most severe damage present in the intensive II site. Frost heaving was estimated at approximately 15-20% of the plantation and the damaged trees were replanted as was previously done for the adjacent weed control II site.

Task 4. Data Collection and Analysis.

Although much of the data have been analyzed, data continue to be collected faster than they can be analyzed thoroughly. This report concentrates on those data that have been analyzed statistically.

Illinois Plantations.

Fifth season (1995) measurements from the Illinois lowland and upland plantations included data from 5 nonharvested blocks of trees, the harvested trees from 5 blocks, and the coppice regrowth from these 5 blocks of trees.

1. Data on nonharvested trees included bud break, caliper, DBH, height and leaf fall.

2. Coppice block data for the lowland and upland sites included bud break, height in June and September, coppice stem caliper class in March and leaf fall.

3. The number of first-year coppice stems for the lowland and upland sites were analyzed by caliper class (<10, 10-20, and >20 mm) and by growth orientation (vertical or horizontal).

4. Branch architecture analysis of data collected from the harvested stems of both Illinois sites in 1994 was completed for the upland site (lowland data were presented in the 1994 Annual Report).

Remote Plantations

Fourth season (1995) measurements from the Kansas and Minnesota plantations included data from 5 nonharvested blocks of trees and the harvested trees from 5 blocks.

5. In January, blocks 1-5 of the Kansas site were harvested in accordance with the original research proposal. The trees were cut with a chain saw at approximately 10 cm from ground level.

6. The fresh weight of the harvested trees were taken on site with a mechanical platform

balance in March. Five randomly selected trees were transported to Carbondale and oven-dried to calculate a fresh weight to oven-dry weight ratio to compute an approximate oven-dry weight for the remaining trees at the Kansas site.

7. In April, blocks 1-5 of the Minnesota site were harvested in accordance with the original research proposal. The trees were harvested using hand loppers at approximately 10 cm above ground level and brought back to Carbondale to be weighed.

8. Branch architecture data were collected on the harvested Minnesota trees in accordance with our previously established protocols.

9. Fourth season (1995) data were collected on 3 visits to the Minnesota plantation and included heights and calipers in April, June and October. Coppice stem data was collected in October.

Additional Plantations

10. Data were collected in the spring of 1995 on the two intensive sites including tree survival, height and damage.

11. The weed control III site planted in June of 1995 was measured for survival, height and caliper.

BODY OF THE REPORT

INTRODUCTION

The goals of this project fit well into the goals of the Biofuels Feedstock Development Program. We are generating valuable data regarding the interactions between silver maple genotypes and the environment by testing selected clones from throughout its native distribution range over a variety of geographically different plantation sites. This should lead to selection of superior clones that will grow well in specific areas, as well as clones that perform well in most locations under short rotation conditions. We have demonstrated clonal differences in micropropagation, cutting propagation, and on field growth parameters as well as effects of genotype on the length of active growth during the growing season.

The research personnel involved in this project are: Professor John E. Preece, Department of Plant and Soil Science, Professor W. Clark Ashby, Department of Plant Biology, Professor Paul L. Roth, Department of Forestry, Researcher III Carl A. Huetteman, and Researcher I Richard G. Adams. Additionally, two undergraduate student employees are utilized part-time for data collection and processing.

As of January of 1996, Mr. Huetteman is longer employed in the Silver Maple Biomass Project at SIUC. Mr. Adams will be leaving in March. Both researchers have accepted positions with Westvaco Forest Research in Summerville South Carolina. Data collection duties will be handled by Mr. David Connolly, a graduate student in Plant and Soil Science and other workers.

Silver maple (Acer saccharinum L.) has been identified as a key woody species in the energy future of the United States (Ashby et al. 1987, Ellis and McCown 1988, Kopp et al. 1988, Meridian Corporation n.d., Ranney et al. 1987, Ranney et al. 1988). Roth et al.(1982) analyzed 508 species as renewable energy resources and rated silver maple higher than Platanus, Populus, Salix, and other Acer species. Silver maple grows well on a variety of sites (Fowells 1965, Gabriel 1990), can be easily propagated (Ashby et al. 1987, Preece et al. 1991a, 1991b), has outstanding qualities for coppice production (Ashby et al. 1993, Geyer 1978), and unlike Populus is relatively free from serious pest problems (Sinclair et al. 1987).

Clonal stock offers advantages for the study of tree genotypes compared to seedlings from open-pollinated seed orchards. Genetic gains of up to 20% can be realized when selecting clones from a seedling nursery (Libby 1983). Genetic analysis of individual tree seedling performance can present problems because the components of genotype and environment are very difficult to separate. Members of clones are genetically identical and as such can allow for the testing of each selected tree genotype in different locations in a replicated study, thus separating the components of genotype and environment. By using clones and reducing genetic variability (compared to seedlings from open-pollinated seed orchards), experimental error can be minimized, thus allowing greater precision in studies of tree phenotype, physiology, nutrition, silviculture, and general performance (Libby 1974).

Uncontrolled herbaceous competition can seriously limit stand establishment and tree growth in forest plantations. Our trees were established into white-on-black polyethylene strips to combat weedy competition, mitigate soil erosion and nutrient runoff, and reduce the need for the application of herbicides. Trees of silver maple and white ash were taller after two growing seasons when planted into plastic mulch rather than when using conventional methods of cultivation or herbicide application (Van Sambeek et al. 1995).

METHODS

The major goal of our project was to evaluate four outstanding clones from each of 13 provenances in various locations. By using clonal replications of these genotypes, we intended to measure clonal biomass gain at each site and to determine the contributions of tree genotype and the field environment on silver maple phenotype.

During the spring of 1987, seeds, seedlings, or plants from rooted stem cuttings from 26 locations across the natural distribution range of silver maple were planted in a replicated provenance nursery in Carbondale, Illinois. Of these, trees from 15 provenances were selected to provide a balanced representation of the natural distribution range for silver maple and to limit the selected provenances to those where the original seed (or other propagule) source trees were clearly native to that area (Appendix Table 1).

We used these 60 clones to establish biofuel test plantations in a lowland and an upland location in southern Illinois as well as one biofuel test site each on a central Kansas floodplain and an upland site in Minnesota. The plantations were plowed, disked, rotovated and covered with 1.25 m wide strips of highly reflective white-on-black 1.41 mil polyethylene mulch. The trees were planted using planting bars pushed through the plastic mulch at the planting spots. A second hole was made for closure. The area of holes remained small, and since planting the mulch has remained more or less intact. We feel that the close spacing that resulted in rapid canopy closure with shading and leaf litter cover have contributed to the long life of the plastic mulch. We feel that the trees continue to benefit from the plastic mulch.

Clonal trees were planted in replicated plantations (randomized complete block design with 10 blocks and 3-tree replicates) on both a lowland and an upland site in Carbondale, Illinois in 1991 and one site each in Kansas and Minnesota in 1992. There were approximately 1800 micropropagated trees per planting site planted on 1.5 m centers. Trees in the border rows were partly composed of selected clones from two additional provenances to expand the scope of inference of our study to 15 widely diverse provenances. To the outside of the border rows, each plantation was enclosed in a portable, electrified deer fence. Deer predation has been effectively controlled by this electrified deer exclusion fence. Appendix Table 2 details the distribution of silver maple trees throughout the life of the project.

Plantations have generally been maintained by mowing between the mulch strips for the first two seasons after planting. Mowing was not necessary if trees grew sufficiently tall

($\geq$1.5 m) during the first growing season as in Kansas and the west blocks of the Illinois upland site (blocks with the largest trees). Where canopy closure was complete, there were almost no weeds beneath the trees, rather the floor of the plantation was covered with a layer of brown silver maple leaves. Where canopy closure was not complete there were some weeds, but when trees were sufficiently tall, we felt that mowing would be cosmetic and have little effect on tree growth. When using plastic mulch strips, we feel that mowing for weed control is unnecessary after the initial 2 years following plantation establishment. Shade provided by the trees seems to control weeds effectively after 2 years.

At the time of planting in Kansas and Minnesota (1992), each tree received a 9 g Agriform Forest Starter Tablet (22 N - 8 P_2O_5 - 2 K_2O with 3% Ca, 1% S, 0.5% Fe and 0.1% Zn) placed in the closure hole. Both Illinois plantations received the same fertilizer one year after planting by inserting the tablet into the original closure hole.

The Illinois biofuel sites each received a 12 N - 12 P_2O_5 - 12 K_2O - 12 S granular fertilizer in late July of the second (1992) growing season (approximately 10 lbs (4.5 kg) of actual nitrogen per acre (11 kg per ha)). All biofuel sites were fertilized at the approximate time of bud break in 1993. The various sites received: 142 kg N/ha (126.7 lb N/acre) lowland and upland sites; 95 kg N/ha (85 lb N/acre) Kansas site, and 47.3 kg N/ha (41.8 lb N/acre) Minnesota. In 1994 and 1995, fertilizer was applied to both Illinois plantations in mid-May and to the Kansas site in late June each at the rate of 2 lb actual N per 1000 ft^2 (approximately 1 kg per 100 m^2) (90 lb actual N per acre or 101 kg per hectare). The Minnesota plantation received fertilizer in early June 1994, and in 1995 twice (at 1/2 rate each) in April and again in June.

The granular fertilizer was broadcast with a cyclone spreader by walking along the grass alleys parallel to the mulch strips for the first three years of plantation growth. A shoulder-held cyclone spreader was used to facilitate movement through the plantation rather than a lawn-type spreader in 1995. We feel that since our sites occupy secondary farmland (not prime farmland) in the spirit of the original RFP, that these poor soils require nutrient supplements to support acceptable levels of biomass yield. It has been our experience in the past that if the trees were not fertilized they became chlorotic and growth rate slows. In fact, trees in the Illinois plantations are bigger than in the nearby clonal bank which has not been fertilized and has been in the ground one year longer than the biofuel plantations.

Measurements collected from the biofuel plantations were designed to address our research questions and support the evaluation of growth parameters to identify superior clones of silver maple. Specific growth relationships were correlated to provide insight on silver maple physiology and silviculture. Appendix Tables 3 and 4 detail our data collection protocols.

Our primary field growth measurements have been total tree height and basal caliper collected once or several times each year. Stem form and crown volume data were collected after the second year of growth. Main stem diameter breast height (dbh) was measured on the

nonharvested trees in years four and five. Phenological data consists of the time of bud break, bud set, and leaf fall.

Harvested trees provide data to form the basis of biofuel utilization recommendations. Chipped-tree oven dry weights, stem specific gravity measurements, and stem:bark ratios will provide biomass yield estimates. Branch architecture and stem taper data will allow for plantation and tree modelling.

RESULTS AND DISCUSSION

Task 1. Production of Planting Stock for Field Tests.

Task 1 has been essentially completed as reported in the 1992 Annual Report.

Current and future requirements for silver maple plants can be met by small-scale production of plants through macropropagation (rooting of cuttings under mist). The clonal bank serves as a continuing resource base for identified and tested silver maple stock material. Large-scale production of maple plantlets can be accomplished relatively quickly by reactivating the tissue culture facilities. Upon initiation of a new micropropagation cycle, several thousand plantlets could be available within 6-12 months depending on the time of year that we would begin production.

We do not envision any particular problems in future attempts to propagate our silver maple selections clonally from the clone bank. A gradual lessening of the ability to be asexually propagated is frequently associated with maturation of forest trees. Earlier Silver Maple Biomass research has demonstrated our ability to micropropagate silver maple from adult source trees.

Task 2. Plantation establishment.

Task 2 has been essentially completed as reported in the 1992 Annual Report.

The third weed control plantation was established in June of 1995 at the USFS NCFES Tree Improvement Center in Carbondale Illinois. It consists of four silver maple and 3 poplar clones planted in a split-split plot design. The main plots are either tilled- or untilled-sod site preparation treatments. Three subplots are solid white-on-black mulch, porous black mulch or herbicide-treated plots.

Each tree received a 9 g Agriform Forest Starter Tablet (22 N - 8 P_2O_5 - 2 K_2O with 3% Ca, 1% S, 0.5% Fe and 0.1% Zn) placed in the closure hole. Height data were collected on these trees at the time of planting and in September. Caliper and bud set were collected in the autumn.

Task 3. Plantation Maintenance.

Deer Fence and Predation.

The maintenance performed on the biofuel plantations entailed periodic recharging of the electric deer fence batteries and applying herbicides to the perimeter to keep the fence clear of weeds. Contact with weeds grounds the fence and the battery loses its charge in a few days compared to lasting more than one month if not excessively grounded by weeds. The fence at Minnesota is shut down every winter due to prolonged snow accumulation which renders the fence ineffective. The fence at Kansas was destroyed during the floods in 1993, yet the trees remain clear of deer predation.

The electric deer fence at the Minnesota site had been damaged at the northeast corner during the winter. The damage apparently occurred from deer walking across the non-electrified fence during the winter months. The fence was repaired and the battery was recharged during a visit in April. The battery was also recharged during a visit to the site in June. Evidence of deer bedding is occasionally apparent in the northeast portion of the plantation when the fence loses its charge between site visits.

Rabbit damage and frost heaving occurred on both intensive sites. Rabbit damage was estimated at approximately 30% of the trees over both plantations with the most severe damage present in the intensive II site. Rabbit damage is generally limited to the first year during establishment. Height and caliper growth during the second season minimize the possibility of further rabbit damage. Frost heaving was estimated at approximately 15-20% of the plantation. Heaved trees were replanted as was previously done for the adjacent weed control II site. Heaving appears to be a problem with later planting. Trees planted in the early spring have not heaved, but those planted in mid- to late summer have shown a tendency to frost heave.

Fertilizer.

A complete granular fertilizer (12-12-12-12) was applied to the upland and lowland sites in mid-May at a rate of 2 lbs actual N per 1000 ft^2 (approximately 1 kg per 100 m^2) (90 lbs N per acre or 101 kg N per hectare). Fertilizer was applied to the Minnesota site in April and again in June at 1/2 rate each. The Kansas plantation was fertilized during the last week in June. A shoulder cyclone-type spreader was used to facilitate movement through the plantation rather than a lawn-type spreader.

Both intensive sites were fertilized on August 18 with a complete granular fertilizer (12-12-12-12) at a rate of 1 lb actual N per 1000 sq. ft. (approximately 0.5 kg per 100 sq. m.) (45 lbs actual N per acre or 55.5 kg actual N per hectare). This rate follows our previous fertilization recommendations.

Weed Control.

During June, the perimeter areas under the deer fences on the upland, lowland, and the two weed control sites were sprayed with glyphosate using a tractor and sprayer. Within two weeks there was complete kill of the weeds under the deer fences on all sites. Weeds were successfully controlled throughout the growing season.

No weed control measures were taken within any of the four biofuel plantations. Maple canopies were sufficiently thick in both nonharvested and harvested blocks at the Carbondale sites so that weedy vegetation was almost completely excluded. Crown closure was completed in both the Kansas and Minnesota nonharvested blocks and coppice sprouting from the harvested trees outgrew weed competition.

Task 4. Data Collection and Analysis.

The emphases of this year's activities have been analysis of data collected from the harvested blocks of trees from the Illinois biofuel plantations and collection and analysis of new growth measurements from all plantations (see appendix tables 3 and 4). Additionally, the summarized data for the initial three years of plantation growth have been synthesized into five manuscripts focusing on (1) plantation establishment, (2) growth data, (3) growth correlations, (4) phenological data and (5) phenological correlations, as well as two laboratory operation manuscripts. The branching architecture data for 1991-1993 and their correlations formed the basis of the poster presentation by Richard Adams at the 1995 ASHS Conference in Montreal Canada.

Specific statistical assumptions were made for computer data analyses of the biofuels plantations. All growth and phenological data in this report were analyzed by the General Linear Model procedure (PROC GLM) of SAS (SAS Institute, Inc. 1990). LSMEANS are reported in all means summary tables. Phenotypic and genetic correlations were computed using calculations specific to our research design. Correlations between growth characteristics and provenance environmental factors were computed via PROC CORR of SAS.

Partitioning of error and the appropriate F-test is fairly complex given our nested clone within provenance design and that provenance values are composed of the clonal values. Homogeneity of the error terms [block x provenance and block x clone(provenance)] were examined and found generally nonsignificant at the 0.05 level. A simplified SAS model was adopted [growth variables = block, provenance and clone(provenance)] for Anova and Manova (correlation) analyses.

Type III error is used in all statistical analyses as it more conservatively partitions variance (Cody and Smith, 1991). The Type III mean square attributes variance to all other effects in the model before evaluating the specified effect. In our SAS model of growth = block, provenance and clone(provenance); block and provenance would first absorb variance when evaluating clone, provenance and clone(provenance) would first absorb variance when evaluating block, etc. Type III error also adjusts more appropriately for design imbalance related to missing replications or clones. The LSMEANS analysis also adjusts for missing

replications or clones.

1994 Field Growth Data.

Illinois Biofuel Sites;

Summarization of the 1991-1993 field-growth characteristics allowed us to rank the height and caliper performance of silver maple clones in both Illinois sites (Tables 1 and 2). Three MS clones and all four IL clones began in the top 5 in height growth in 1991. By 1993, only one IL clone and 2 MS clones remained in the top 5. Three IL clones remained among the top 5 of all clones for basal caliper growth for all three years but the two MS clones dropped down below the top 15. All four clones from IN ended up in the top 5 for caliper growth with 2 in the top 5 for height in 1993. Height and caliper rankings for the fourth and fifth years and from the remote sites will provide a solid basis for making plantation recommendations for future sites.

Main stem height and basal caliper measurements were collected in the autumn on nonharvested trees on the lowland and upland sites. Trees from the IN, KS, MS and PA provenances all had mean heights of at least 6 meters following the fourth growing season on both sites (Tables 3 & 4). Trees from the S. Cen. Ont., VA and WI provenances also had mean heights above 6 m on the lowland site. Mean heights for the lowland site were generally 30 to 40 cm greater than on the upland site. This is interesting because during the first two growing seasons, the trees were taller in the upland site than in the lowland site.

The clones that were the tallest were 012 and 052 on the lowland site (E. Cen. MS and S. Cen. IN, Table 5) and clones 014 and 052 on the upland site (E. Cen. MS and S. Cen. IN, Table 6) with clonal heights of 7.1, 6.6, 6.5 and 6.5 m, respectively. It is interesting that clone 052 was one of the tallest trees at both sites. It is a clone that merits attention.

Mean provenance basal caliper was generally greater on the lowland site by 1-8 mm; except that caliper of clones from the NH and PA provenances was greater on the upland site (Tables 3 & 4). Clone 052 had the largest caliper at both sites with 10.6 cm lowland and 10.0 cm upland. This is an additional reason to consider selecting clone 052 for further studies.

The new measurement obtained on all nonharvested trees during 1995 was diameter breast height (DBH) 1.37 m (4.5 feet) above ground level on the single largest main stem. Mean provenance DBH was generally larger on the upland site than the lowland site (Tables 3 & 4). Trees from the IN, MS and VA provenances had DBHs $\geq$ 4.5 cm in both sites and KS was also greater than 4.5 in the upland site. The largest DBHs were on clones 012, 014 and 052 (Tables 5 & 6) (which were also the tallest trees, confirming earlier findings that the tallest trees had the greatest calipers, (see earlier annual reports)).

Height and basal caliper measurements were collected (twice and once, respectively) on the coppice sprouts from trees that were harvested following the third growing season (Tables 3-6). Coppice height growth during the first growing season was greater than the tree height growth during the initial two growing seasons (compare with Table 3 in the 1994 Annual Report).

Harvested tree biomass weights were collected by oven-drying the chipped trees at 70° C for three days. Though tree weight data collection is still incomplete (scheduling time for the large drying ovens continues to slow data collection), the following analyses are based on approximately 75% of the harvested samples.

Mean provenance biomass production was 2 kg higher for MS on the lowland site than on the upland site (Tables 3 & 4). For trees from the other provenances dry weight ranged from 1.8 kg lower on the lowland site for trees from the Illinois provenance compared to the upland site, to 1.6 kg higher on the lowland than upland site for trees from the Wisconsin provenance. Generally, yields were higher on the lowland site, underscoring the potential of silver maple for bottomland plantations.

On the lowland site, trees from the MS provenance had the greatest mean dry weight (5.6 kg per tree) but MS clone 012 had the largest mean clonal weight of 7.5 kg per tree (Table 5). The largest individual plot weight on the lowland site was 9.5 kg per tree for clone 012 in block 2 (data not shown). This approximates 6.3 dry tons per acre per year for plantation-grown silver maple spaced on 1.5 m centers at three years of age.

On the upland site, the IL provenance had the greatest mean dry weight (4.4 kg per tree) but MS clone 012 had the largest mean clonal weight of 4.9 kg per tree (Table 6). The largest individual plot weights on the upland site were 6.2 kg per tree for clone 012 in blocks 1 and 2 and 6.8 kg per tree for clone 043 in block 1 (data not shown). This approximates 4.5 dry tons per acre per year for plantation-grown silver maple spaced on 1.5 m centers at three years of age.

Weekly bud break observations were collected in Carbondale plantations in the spring and leaf drop data were collected in the autumn. Bud break and leaf drop data were recorded from both nonharvested trees and the coppice stems that grew from the stumps of the harvested trees. Provenance bud break in 1994 was generally 3-9 days earlier than in 1992 and 1993 (compare Tables 7 & 8 with Table 6 in the 1994 Annual Report). Budbreak in 1995 was as great as 17 days earlier than 1992. Mississippi clones 011, 012 and 014 were again among the first to break bud in spring and the last to drop their leaves in the autumn (Tables 9 & 10).

While collecting budbreak data at the upland site, it was noted that Kansas clones 202, 204 and 206 have begun to produce seed from at least 12 individuals per clone. Nine individuals of clone 204 produced seed in the lowland site. This early seed production may be attributed to these clones being originally produced from cuttings of adult trees. Six other individual

trees began seed production in the upland site, one tree each from clone 015 and 083, and 2 trees each from clones 051 and 072. One to three individuals each of clones 051, 073, 075, 113 and 157 produced seed in the lowland site. Except for the original propagules from Kansas, all initial propagules were of juvenile origin (mainly seeds, but some seedlings and cuttings from seedlings). Silver maple appears to have a relatively short juvenility period.

The coppice stems that resulted from tree harvest were evaluated for growth and classified by basal caliper class of <10, 10-20, and >20 mm. All stems were measured 10 cm above ground level and characterized as having either horizontal or vertical orientation. Horizontal stems were those having the terminal bud a greater distance horizontally from the stem base than vertically from the ground-line. This orientation was noticed during field observations with the stems appearing to be laid over against the ground. Horizontal stems were recorded in <20 and >20 mm basal caliper size categories. Though highly significant, no apparent trends are discernible for provenance affects on the number of horizontal stems (Tables 11-14). There also does not seem to be any relationship between the number of vertical and the number horizontal stems as clones with a large number of vertical stems have similar numbers of horizontal stems as those clones with few vertical stems (Tables 13 & 14). Further analysis may demonstrate specific provenance or clonal correlations.

Total coppice stem number ranged from 12-21, with significant differences among provenances and clones within provenances. With most stumps producing coppice shoots numbering in the middle teens, this confirms that silver maple freely produces coppice shoots following harvest. It should be recalled that these trees are not seedlings, but were clonally micropropagated. Obviously, sufficient buds remain in the lower trunk to allow for coppice shoot production following harvest of the original shoot.

One drawback of silver maple for pulpwood production is that it has opposite branches and a freely branching crown. Coppice shoots grow differently than initial shoots. They tend to be taller, straighter and have relatively less branching than the initial shoots. Coppicing and thinning might be a silvicultural solution to the branching phenomenon in silver maple, thus making it more desirable as a pulpwood species.

Harvested stem disks:

Stem disks (approximately 1 cm thick) were removed at 1 m intervals along the main stem of selected trees at the time of harvest at the lowland and upland sites in early 1994. The disks were frozen at approximately -22° C after harvest. Data measurements from these disks consisting of diameter, weight of dry wood, weight of dry bark, and green volume were recently completed. These data will be used to calculate main stem taper, wood to bark ratio, and wood specific gravity on approximately 550 trees, one clonal tree per plot per block per site.

Caliper measurements from all disks were collected as the disks thawed for further procedures. The basal disks were soaked in water until saturation and green volume was

calculated as stated below. All the disks were then autoclaved for 15 minutes at 121° C so that the bark could be removed. The samples were dried in a forced air oven at 103° C for 48 hours and bark and wood oven-dry weights recorded.

Green volume of the basal stem disks was taken according to the guidelines outlined in the 1991 Annual Book of ASTM Standards, Vol 04.09 Wood, which includes standards of the D-7 Committee on Wood. Volume was calculated using a water immersion method because of the irregular disk shapes that precluded calculating the volume by measuring height and diameter of a cylinder.

A pan of water was tared on an electronic top loading balance and a water saturated disk lowered into the water by means of a stand and needle apparatus so that the disk would be completely submerged and not touch the sides or bottom of the pan. The disk weight (g) and volume (cm^3) are equal to the weight of water displaced by the disk since 1 g of water equals 1 cm^3.

Data collected from the stem disks have not been analyzed yet. Along with branching architecture, these data will be included in the M.S. degree work of Mr. Adams.

Tree architecture growth.

Analysis of the crown architecture data were completed for the upland site in January. The upland data generally follow the trends of the lowland site discussed in the 1994 Annual Report. In the top 1 m of tree growth, significance was evident for the number of nodes and the number of branches (Table 15). The number of branches <0.25 m long on the upland site were highly significant while those longer than 0.25 m were nonsignificant. The opposite is true for trees on the lowland site.

The analyses of the number of primary branches formed on wood from 1993 and 1991 and the numbers of basal, secondary and tertiary branches for the upland site closely follows the analyses from the lowland site (Tables 16 & 18-21). The total number of branches formed is highly significant for all categories except for the number of basal branches (Table 19).

The total number of primary branches formed on wood from 1992 was highly significant on the lowland site and nonsignificant for the upland site (Table 17). Several provenances in the lowland site had up to 50% more branches formed on 1992 wood than those upland site provenances. This is most likely a carryover effect of uniform deer browse damage to the lowland site during the 1991 establishment year. The total number of primary branches formed on 1991 and 1993 wood in the lowland is similarly higher than the upland.

Upland clonal branch architecture data are summarized in Tables 22-28. Generally, the statistical significance of the number of branches of individual length classes followed the total number of branches for that branch type, i.e. the number of primary branches on 1993 wood in classes < 0.1cm, 0.1-<0.25cm, 0.25-<0.5cm, 0.5-<1m and ≥1m were significant or

highly significant and the total number of primary branches was significant (Table 23).

Clonal differences in the number of nodes and the number of branches in the top 1 m were both highly significant for the upland site (Table 22). Though significant, the ranges for the number of nodes and branches in the top 1 m was fewer than 11 nodes and 14 branches. For most of the clones, new primary branches are formed in the top 1 m approximately every 2 nodal segments. In several clones, (076, 056 and all of provenance 11) branches form approximately every 4 nodes and clones 111 and 184 only formed new branches every 8 nodes. The additional number of nodes does not seem to add any appreciably greater increment to overall height growth with the clones mentioned above having grown 1.8-2.3m during 1993, and were approximately in the middle of the clonal height increment gains. These anomalies bear additional scrutiny in the development of an overall growth model for silver maple.

The number of primary branches was significant for those formed on wood from 1993 but nonsignificant for those formed on 1992 or 1991 wood (Tables 23-25). These findings closely follow the trends apparent in measurements from the lowland site. The greatest number of primary branches was on Mississippi clone 012 which had a mean of over 53.6 branches formed on the current season's wood. Its height increment of 2.6 m during 1993 was the most growth on the upland site. The fewest number of primary branches on current season wood was 5.4 on New York clone 173 with a height increment of 1.8 m, one of the lowest height increases.

The total number of basal branches among clones was not significantly different in either the lowland or upland sites (Table 26). On both biofuel sites, the total number of basal branches as well as the number found in each size class were generally nonsignificant. In the tallest length class of basal branches ($\geq$ 3m), there were highly significant differences among provenances in the upland site and significant differences among provenances in the lowland site. This possibly points more to a difference in the tree architecture in the number of main stems rather than branch architecture.

The formation of secondary and tertiary branches, however, was highly significant for trees from the upland site (Tables 27 & 28). Again, MS clone 012 had the greatest number of secondary and tertiary branches of all analyzed clones with 238 and 73 branches, respectively (Illinois clone 046 in the border rows had a mean of 98.2 tertiary branches).

Tree architecture correlations.

There are few trends apparent when comparing the branch architecture correlations between the lowland and upland sites, other than the obvious relationship between the total number of primary branches and the number of primaries formed on wood from each season. The total number of primary branches is highly correlated with the number of secondary and tertiary branches on trees in the upland site but is not highly correlated with tertiary branches at the lowland site (Tables 29 and 30). The number of primary branches in the top 1 m is highly

correlated with the number of basal and secondary branches in the lowland site but not at the upland site.

There are significant negative correlations between the number of nodes in the top 1 m and the number of branches (total primary number and the number in the top 1 m) for the lowland site but not for the upland site (Tables 31 and 32). A comparison of the number of primary branches formed on wood from different seasons (1991-1993) shows highly significant relationships between 1993 and 1992 and between 1992 and 1991 for the lowland site, but only a significant correlation between 1993 and 1992 on the upland site and none at all for 1992 and 1991.

One early hypothesis was that there would be a strong relationship between the number of branches and tree growth. The logic being that more branches support a greater leaf area and thus an increased production of photosynthates available for height growth. Support for this argument is found in the highly significant correlation between the number of primary branches in 1993 and the length of wood formed during that year (Table 30 upland), and in the significant correlation between the number of primary branches in 1992 and the length of wood formed during that year (Table 29, lowland). However, one consistent feature of the analysis of both sites is that there is no significant correlation between the number of basal, secondary or tertiary branches and the length of wood formed in either 1993 or 1992 (Tables 33 and 34). The phenotypic relationship between crown architecture and caliper growth may yet support this hypothesis but, as yet, has not been analyzed.

Correlations (via PROC CORR of SAS) between branching architecture data and the environmental factors of the provenance of origin were nonsignificant in every case for both the lowland and upland sites (Tables 35-38). This is not particularly unexpected given the generally low genotypic correlation values within branching architecture characteristics. One would expect characteristics under little genetic control to have a low correlation to those factors under which the genotype developed.

Minnesota Biofuel Site.

Branch architecture data were collected by Mr. Adams on approximately 300 trees that were harvested from 5 blocks of the Minnesota site in April. The method of data collection is identical to that of the upland and lowland plantations in 1994. Because of the relatively small size of the Minnesota trees compared to the Carbondale trees on which crown architecture data were collected previously, measurements required about 10 to 15 minutes per tree as opposed to approximately 1 hour per tree for the Carbondale trees. Analysis of branch architecture will form the basis of Mr. Adams' Master's thesis in Plant and Soil Science.

Biomass weight data (field-weights) were collected on all the trees harvested from the Minnesota site. The trees were weighed using a toploading balance within two days of being brought to Carbondale. Five medium-sized trees were randomly selected and oven-dried to obtain a fresh weight to oven-dry weight ratio to calculate an estimated oven-dry weight for

the Minnesota site trees. The trees are currently being stored at the HRC and actual biomass dry weight data can be collected if resources are available.

The data collected from Minnesota during 1994 have not yet been analyzed. We are encouraged that after a relatively slow establishment period, the trees in Minnesota are now growing rapidly.

Kansas Biofuel Site.

Biomass weight data (field-weights) were collected on all harvested trees from the Kansas site and weighed on site using a toploading balance. Five medium-sized trees were randomly selected and oven-dried to obtain a fresh weight to oven-dry weight ratio to calculate an estimated oven-dry weight. Tree height, caliper, DBH and coppice characteristics data will be collected this winter. Analyses will be performed as time permits.

CONCLUDING REMARKS

Estimates of single-clone weight has yielded as much as 6.3 dry tons per acre per year for plantation-grown silver maple spaced on 1.5 m centers three years after planting on the lowland site in Carbondale Illinois. Silver maples on the upland site yielded up to 4.5 dry tons per acre per year when spaced on 1.5 m centers three years after planting. These preliminary estimates appear very encouraging for plantation production of silver maple as a biofuel crop.

Clone numbers 012 (MS) and 052 (IN) should certainly be included in any future evaluation of silver maple biofuel plantations. Additionally, IL clone 043 and MS clone 014 could also be recommended based on performance in the upland site. Other specific clonal recommendations should be made based on final examination of the five-year data now in progress.

Much of the data to be collected during the next year will form the criteria for definitive selection of superior provenances and clones for silver maple biofuel plantations. Of primary interest will be data collected on five-year nonharvested and two-year coppice tree heights, and tree weights (yield). Both Illinois sites will be harvested during the 1995/1996 winter with the remote sites similarly terminated the following year. Harvest of the trees after the fifth-year, collection of data, analyses, and interpretation of these data will complete the tasks originally proposed for the Silver Maple Biomass Project.

Table 1. Ranking of height growth performance in the Carbondale biofuel plantations for the first three years.

Provenance (N to S)	Clone	Upland 1991	Upland 1992	Upland 1993	Lowland 1991	Lowland 1992	Lowland 1993
E Cen MS	011	1 (1.3) zy	12	11	1 (0.9)	1 (2.8)	2
	012	4	3	1 (4.8)	12	2	1 (5.2)
	014	4	2	1			
	015	44	47	44	12	25	27
SW VA	182	11	12	11	12	14	17
	183	11	31	30	12	13	11
	184	24	20	18	4	14	11
	186	11	8	11	4	3	2
S Cen WV	072	33	41	37	29	46	42
	073	44	41	37	29	36	33
	075	53	50	51	29	36	36
	076	33	34	41	46	30	33
S IL[x]	043	1	3	7	53 (0.3)	14	42
	044	1	1 (2.5)	3	4	8	26
	045	11	3	7			
	046	11	12	30			
S Cen IN	051	11	20	18	12	6	11
	052	4	3	3	12	8	8
	054	11	20	24	29	14	17
	056	10	3	3	4	6	5
E Cen KS	202	33	34	24			
	203	24	12	11			
	204	33	20	11	12	13	11
	206	4	12	7	12	4	5
NE PA	111	11	8	3	4	8	11
	113	11	8	11	2	4	5
	114	11	20	24	4	14	21
	116	11	12	18	4	14	8
Cen IA	061	33	41	41	29	30	27
	062	11	12	18	12	25	21
	063	11	12	30	29	14	17
	065	33	41	41	29	30	36
S Cen NY	171	44	50	51	12	30	42
	173	44	56	55	12	46	42
	174	33	34	54	12	36	46
	175	11	8	7	12	8	8
Cen WI	081	24	20	24	12	14	11
	083	24	20	30	12	14	21
	084	11	20	18	29	25	26
	085	24	20	30	4	14	17
Cen NH	151	60 (0.5)	59	59	46	46	48
	153	53	47	44	46	36	38
	154	44	50	51	29	30	38
	157	53	50	47	29	36	46

S Cen Ont	121	53	34	30	29	25	21
	122	33	20	24			
	125	33	31	18	12	25	21
	126	33	20	11	29	36	26
NW VT	161	44	56	55	29	46	38
	162	44	34	37	29	36	27
	163	24	31	24	2	8	4
	165	44	50	47	29	36	33
S Cen MN[x]	192	33	34	37			
	193	24	47	47	46	52	51
	195	24	34	36	29	36	38
	196	24	41	47	12	36	52
Cen Ont	131	53	50	57	46	50	49
	132	44	41	44	29	30	26
	133	53	60 (1.2)	60 (2.7)	46	53 (1.2)	53 (3.2)
	134	53	56	58	46	50	50

Numbers in () are the heights in meters of the tallest and the shortest trees.

[z]Numbers based upon approximately ten 3-tree clonal plots.

[y]Mean clone heights (m) for the top and bottom performers.

[x]Border row trees along the exterior of the plantation.

Table 2. Ranking of basal caliper growth performance in the Carbondale biofuel plantations for the first three years.

Provenance (N to S)	Clone	Upland 1991	Upland 1992	Upland 1993	Lowland 1991	Lowland 1992	Lowland 1993
E Cen MS	011	3	25	20	1 (1.6) zy	2	2
	012	1 (1.8)	7	11	3	5	6
	014	11	15	17			
	015	39	43	47	11	14	27
SW VA	182	11	11	12	11	14	21
	183	18	15	25	3	6	7
	184	25	15	10	46	14	12
	186	5	5	11	3	2	3
S Cen WV	072	25	25	31	22	39	41
	073	39	35	39	22	29	21
	075	47	49	49	35	43	40
	076	34	38	32	35	39	27
S IL[x]	043	1	2	1 (6.8)	53 (0.3)	34	39
	044	3	2	4	11	25	12
	045	5	7	8			
	046	5	7	4			
S Cen IN	051	11	2	3	2	1 (4.1)	1 (7.5)
	052	5	1 (3.9)	1	11	4	4
	054	18	5	4	46	10	12
	056	5	7	4	11	10	21
E Cen KS	202	39	43	45			
	203	25	12	9			
	204	34	38	32	11	14	27
	206	18	20	25	11	14	34
NE PA	111	18	15	11	11	14	12
	113	34	38	32	3	31	34
	114	11	20	20	3	10	12
	116	11	12	17	3	6	25
Cen IA	061	25	25	32	35	34	36
	062	25	25	20	35	31	36
	063	5	15	17	22	10	5
	065	47	48	48	35	34	32
S Cen NY	171	47	56	55	35	48	49
	173	53	59	58	22	50	50
	174	39	50	55	22	43	46
	175	18	25	20	22	29	32
Cen WI	081	25	25	25	22	14	7
	083	25	20	25	3	6	7
	084	11	12	12	11	14	10
	085	18	20	20	3	6	11
Cen NH	151	60 (0.6)	60 (1.5)	60 (2.9)	52	53 (1.6)	52
	153	53	43	45	46	43	38
	154	39	43	40	22	39	46
	157	53	53	51	22	43	48

S Cen Ont	121	53	41	32	35	14	12
	122	25	20	12			
	125	34	33	32	11	14	19
	126	39	35	30	22	25	12
NW VT	161	39	50	52	22	39	25
	162	47	43	43	35	31	27
	163	39	41	40	11	14	21
	165	47	53	49	35	25	41
S Cen MN[x]	192	25	35	43			
	193	11	25	32	22	34	27
	195	34	25	25	22	25	19
	196	18	33	40	35	34	43
Cen Ont	131	53	53	52	46	49	43
	132	47	50	52	35	43	43
	133	53	57	59	46	50	51
	134	53	57	57	46	50	53 (3.5)

Numbers in () are the calipers in cm of the first and last place trees.

[z]Numbers based upon approximately ten 3-tree clonal plots.

[y]Mean clone caliper (cm) for the top and bottom performers.

[x]Border row trees along the exterior of the plantation.

Table 3. Mean provenance growth characteristics in the Lowland biofuel plantation during 1994.

Provenance (S to N)	Nonharvested blocks N	Height[z] Dec. (m)	Caliper[y] Sept. (cm)	DBH Nov. (cm)	Harvested blocks N	Height June (m)	Height Aug. (m)	N	Prelim. weight (kg)
E Cen MS	34	6.2	8.4	4.5	45	1.7	3.5	10	5.6
SW VA	30	6.2	7.8	4.5	54	1.8	3.1	11	4.1
S Cen WV	50	5.7	6.8	3.7	59	1.6	2.9	22	3.1
S Cen IN	46	6.3	8.9	4.5	59	1.8	3.3	16	4.3
E Cen KS	10	6.5	7.9	4.0	21	1.7	3.3		
NE PA	53	6.1	7.4	4.0	59	1.9	3.4	18	3.9
Cen IA	30	5.8	7.7	3.9	56	1.9	3.0	20	2.4
S Cen NY	48	5.5	5.7	3.3	60	1.7	3.0	17	2.6
Cen WI	47	6.0	8.0	4.1	59	1.7	3.1	21	4.4
Cen NH	42	4.8	5.0	3.0	59	1.8	2.8	13	2.1
S Cen Ont	37	6.1	7.6	4.1	43	1.8	3.1	5	4.2
NW VT	41	5.7	7.0	3.6	54	1.9	2.9	15	3.0
Cen Ont	24	4.3	4.5	2.4	50	1.7	2.6	7	1.2
Significance[x]		**	**	**		**	**		**
5% t-test[w]		0.2	0.6	0.3		0.2	0.8		0.8
1% t-test		0.3	0.8	0.4		0.3	1.1		1.0
Border Row Trees[v]									
S IL	17	5.6	7.6	3.9	15	1.7	3.4	1	2.6
S Cen MN	29	5.1	7.1	3.5	12	1.9	3.2		

N = approximate number of clonal trees

[z]The height of the tallest live bud of the tree is measured in a direct line straight up from the ground.

[y]Basal caliper is measured at a point 10 cm above ground level.

[x]Significant at the 1% level according to the F-test.

[w]t-test for paired comparisons.

[v]Border row trees were excluded from statistical analysis.

Table 4. Mean provenance growth characteristics in the Upland biofuel plantation during 1994.

Provenance (S to N)	Nonharvested blocks N	Height[z] Dec. (m)	Caliper[y] Sept. (cm)	DBH Nov. (cm)	Harvested blocks N	Height June (m)	Aug. (m)	N	Prelim. weight (kg)
E Cen MS	57	6.0	7.6	4.6	52	1.6	3.2	42	3.6
SW VA	58	5.9	7.7	4.5	57	1.6	3.0	36	3.0
S Cen WV	55	5.5	6.8	3.7	59	1.5	2.7	42	2.2
S Cen IN	59	6.0	8.8	4.8	60	1.7	3.2	42	4.0
E Cen KS	56	6.1	7.3	4.6	58	1.6	3.1	40	2.6
NE PA	55	6.0	7.7	4.2	60	1.7	3.1	44	2.8
Cen IA	59	5.4	7.3	3.7	59	1.8	3.0	35	2.7
S Cen NY	56	5.1	5.3	3.2	55	1.4	2.7	36	1.7
Cen WI	58	5.7	7.5	4.1	60	1.6	3.0	40	2.9
Cen NH	53	4.9	5.9	3.2	56	1.5	2.5	34	1.6
S Cen Ont	52	5.7	7.4	4.1	58	1.6	2.9	42	2.6
NW VT	42	5.2	6.1	3.3	52	1.6	2.7	30	2.2
Cen Ont	55	4.0	4.2	2.2	57	1.5	2.3	27	1.3
Significance[x]		**	**	**		**	**		**
5% t-test[w]		0.2	0.5	0.3		0.06	0.1		0.5
1% t-test		0.3	0.7	0.4		0.08	0.2		0.6
Border Row Trees[v]									
S IL	40	5.6	7.3	4.1	54	1.5	2.9	50	4.43
S Cen MN	57	4.5	5.8	2.9	59	1.5	2.5	51	2.84

N = approximate number of clonal trees

[z]The height of the tallest live bud of the tree is measured in a direct line straight up from the ground.

[y]Basal caliper is measured at a point 10 cm above ground level.

[x]Significant at the 1% level according to the F-test.

[w]t-test for paired comparisons.

[v]Border row trees were excluded from statistical analysis.

Table 5. Mean clonal growth characteristics in the Lowland biofuel plantation during 1994.

Provenance (S to N)	Clone	Nonharvested blocks N	Height[z] Dec. (m)	Caliper[y] Sept. (cm)	DBH Nov. (cm)	Harvested blocks N	Height June (m)	Height Aug. (m)	N	Prelim. weight (kg)
E Cen MS	011	9	6.0	9.0	4.4	15	1.7	3.5	3	5.5
	012	13	7.1	9.1	5.3	15	1.8	3.8	3	7.5
	015	12	5.6	7.0	3.9	15	1.5	3.1	4	3.8
SW VA	182	15	6.3	8.2	4.3	15	1.8	3.2	4	4.0
	183	15	6.2	7.4	4.7	15	1.8	3.4	3	5.0
	184					15	1.9	3.1	3	3.0
	186					9	1.9	2.9	2	4.5
S Cen WV	072	10	5.4	5.9	3.3	15	1.7	2.9	6	2.4
	073	13	6.1	7.4	3.7	15	1.7	3.0	2	3.9
	075	14	5.7	6.3	3.6	15	1.5	2.7	7	2.9
	076	13	5.6	7.5	4.0	14	1.6	2.9	7	3.1
S Cen IN	051	12	6.2	9.0	4.5	15	1.6	3.2	3	5.3
	052	9	6.6	10.6	4.8	15	1.9	3.4	4	3.8
	054	12	6.3	8.4	4.4	14	2.0	3.3	4	4.2
	056	13	6.2	7.7	4.2	15	1.9	3.4	5	4.2
E Cen KS	204	10	6.5	7.9	4.0	15	1.7	3.3		
	206					6	1.7	3.3		
NE PA	111	12	6.2	8.0	4.2	14	2.0	3.5	6	3.7
	113	14	6.3	6.9	3.9	15	2.0	3.6	6	4.5
	114	15	6.0	7.4	4.0	15	1.9	3.4	3	3.1
	116	12	5.8	7.3	3.9	15	1.8	3.3	3	4.2
Cen IA	061	11	5.7	6.7	3.7	15	1.9	3.3	5	2.5
	062					14	1.8	2.8	5	1.7
	063	5	6.0	8.3	4.1	12	1.9	3.0	6	2.9
	065	14	5.6	7.9	3.9	15	2.0	3.0	4	2.6
S Cen NY	171	11	5.3	4.9	3.3	15	1.7	3.0	4	2.1
	173	11	5.5	4.9	3.1	15	1.6	2.7	6	2.2
	174	13	4.9	5.3	2.9	15	1.7	3.0	3	1.9
	175	13	6.5	7.8	4.1	15	1.9	3.3	4	4.0
Cen WI	081	15	6.4	8.1	4.3	14	1.8	3.1	4	4.0
	083	15	6.1	8.2	4.0	15	1.6	2.9	4	4.3
	084	8	5.9	8.2	3.8	15	1.7	3.1	5	4.5
	085	9	5.8	7.7	4.1	15	1.8	3.1	8	4.8
Cen NH	151	15	5.6	4.8	3.1	14	1.7	2.8	2	1.4
	153	14	5.4	5.9	3.5	15	1.9	2.7	4	2.6
	154	1	3.4	3.4	2.1	15	1.7	2.9	3	1.6
	157	12	5.0	5.7	3.3	15	1.8	2.8	4	2.9
S Cen Ont	121	11	6.0	7.9	4.0	14	1.9	3.4	2	5.0
	125	11	5.9	7.3	4.0	15	1.9	3.2	2	3.9
	126	15	6.3	7.7	4.2	14	1.7	2.9	1	3.7

NW VT	161	15	5.6	7.9	3.4	15	1.8	2.6	4	3.4
	162	12	5.7	7.0	3.6	15	1.9	2.9	6	3.4
	163					9	1.9	3.1	2	3.4
	165	14	5.7	6.1	3.8	15	1.9	3.1	3	1.8
Cen Ont	131	13	4.5	5.0	2.7	15	1.7	2.9	1	1.9
	132					5	1.9	2.9	1	1.0
	133	11	4.1	4.1	2.2	15	1.5	2.2	2	1.2
	134					15	1.5	2.3	3	0.5
Significance[x]			**	**	**		**	**		**
5% t-test[w]			0.4	1.1	0.5		0.4	0.8		1.5
1% t-test			0.6	1.4	0.7		0.5	1.1		2.0
Border Row Tree[v]										
S IL	043	2	5.8	7.2	3.8					
	044	15	5.5	8.0	3.9	15	1.7	3.4	1	2.6
S Cen MN	193	10	4.8	7.1	3.4					
	195	15	5.4	7.9	3.9	12	1.9	3.2		
	196	4	5.0	6.2	3.3					

N = approximate number of clonal trees

[z]The height of the tallest live bud of the tree is measured in a direct line straight up from the ground.

[y]Basal caliper is measured at a point 10 cm above ground level.

[x]Significant at the 1% according to the F-test.

[w]t-test for paired comparisons.

[v]Border row trees were excluded from statistical analysis.

Table 6. Mean clonal growth characteristics in the Upland biofuel plantation during 1994.

Provenance (S to N)	Clone	Nonharvested blocks N	Height[z] Dec. (m)	Caliper[y] Sept. (cm)	DBH Nov. (cm)	Harvested blocks N	Height June (m)	Height Aug. (m)	N	Prelim. weight (kg)
E Cen MS	011	13	6.0	7.3	4.4	12	1.6	3.6	9	3.8
	012	15	6.2	8.2	5.2	15	1.6	3.2	12	4.9
	014	14	6.5	8.0	5.3	15	1.6	3.4	11	3.8
	015	15	5.2	6.7	3.7	15	1.5	2.7	10	1.9
SW VA	182	13	6.1	7.5	4.5	14	1.7	3.1	10	3.2
	183	15	5.5	7.3	4.3	11	1.7	3.1	8	2.6
	184	15	5.9	8.6	4.4	14	1.6	3.1	10	2.4
	186	15	5.9	7.6	4.8	13	1.5	2.9	8	3.6
S Cen WV	072	15	5.4	7.1	4.1	14	1.6	2.9	10	2.6
	073	11	5.8	6.7	3.6	15	1.5	2.6	11	2.0
	075	14	5.4	5.6	3.2	15	1.4	2.4	12	1.6
	076	15	5.3	7.7	3.9	15	1.6	2.8	9	2.8
S Cen IN	051	14	5.7	8.9	4.4	15	1.5	3.2	8	4.3
	052	15	6.5	10.0	6.0	15	1.7	3.1	12	4.1
	054	15	5.8	7.7	4.4	15	1.7	3.2	11	3.9
	056	15	6.1	8.3	4.7	15	1.7	3.3	11	3.8
E Cen KS	202	15	6.1	7.0	4.7	15	1.6	3.0	11	2.0
	203	12	5.9	8.4	4.8	13	1.6	3.0	10	2.6
	204	15	6.1	6.9	4.3	15	1.5	3.0	9	2.6
	206	14	6.2	7.0	4.5	15	1.6	3.3	10	3.2
NE PA	111	12	6.1	8.4	4.2	15	1.8	3.1	12	2.9
	113	13	5.9	7.3	4.0	15	1.8	3.1	8	2.9
	114	15	5.9	7.7	4.3	15	1.8	3.2	12	2.3
	116	15	5.8	7.4	4.1	15	1.6	3.1	12	3.1
Cen IA	061	14	5.1	7.3	3.5	14	1.8	3.0	9	2.6
	062	15	5.8	7.6	4.0	15	1.6	3.0	8	3.5
	063	15	5.5	8.1	3.9	15	1.8	3.1	8	3.5
	065	15	5.1	6.3	3.3	15	1.9	2.9	10	2.2
S Cen NY	171	14	4.9	4.4	2.9	14	1.4	2.6	9	1.4
	173	13	4.8	4.5	2.5	12	1.4	2.4	10	1.4
	174	14	4.6	4.9	2.8	14	1.4	2.6	10	1.3
	175	15	6.1	7.4	4.4	15	1.6	3.0	7	2.8
Cen WI	081	15	5.8	7.4	4.3	15	1.5	3.0	11	2.5
	083	13	5.8	7.6	4.0	15	1.5	2.8	9	2.6
	084	15	5.7	7.8	4.3	15	1.6	3.2	10	3.4
	085	15	5.6	7.3	3.8	15	1.6	2.9	10	3.0
Cen NH	151	15	4.6	4.3	2.7	15	1.2	2.1	6	1.2
	153	15	5.1	6.7	3.3	15	1.7	2.4	11	1.8
	154	12	5.1	6.5	3.4	12	1.5	2.7	7	2.1
	157	11	4.9	5.9	3.3	14	1.6	2.7	10	1.5

S Cen Ont	121	14	5.7	6.8	3.8	15	1.6	3.1	11	2.2
	122	9	5.4	6.8	3.6	14	1.6	3.0	10	3.1
	125	15	5.7	8.1	4.4	14	1.8	3.0	11	2.8
	126	14	6.2	7.8	4.5	15	1.5	2.7	10	2.2
NW VT	161	9	4.9	5.9	2.7	12	1.6	2.4	6	2.7
	162	15	5.2	6.5	3.6	15	1.6	2.7	7	1.8
	163	9	5.8	6.6	3.9	12	1.6	2.9	8	2.3
	165	9	4.9	5.4	3.1	13	1.6	2.9	9	2.0
Cen Ont	131	12	4.2	4.7	2.4	15	1.6	2.5	5	1.6
	132	14	4.7	4.8	2.8	15	1.6	2.5	9	1.6
	133	14	3.4	3.7	1.7	14	1.4	2.0	8	0.9
	134	15	3.8	3.8	1.9	13	1.4	2.3	5	1.2
Significance[x]			**	**	**		**	**		**
5% t-test[w]			0.5	1.0	0.6		0.1	0.2		0.9
1% t-test			0.6	1.3	0.8		0.2	0.3		1.1
Border Row Tree[v]										
S IL	043	10	5.6	8.0	4.3	15	1.3	2.9	13	4.7
	044	14	5.8	7.6	4.2	15	1.6	3.2	15	4.1
	045	12	5.7	7.6	4.3	15	1.5	2.8	15	4.2
	046	4	5.1	5.8	3.6	9	1.5	2.6	7	4.6
S Cen MN	192	13	4.7	5.5	3.0	14	1.6	2.6	12	2.4
	193	14	4.1	5.4	2.7	15	1.7	2.6	14	3.0
	195	15	5.0	6.6	3.3	15	1.4	2.5	13	2.8
	196	15	4.2	5.8	2.6	15	1.3	2.2	12	3.0

N = approximate number of clonal trees

[z]The height of the tallest live bud of the tree is measured in a direct line straight up from the ground.

[y]Basal caliper is measured at a point 10 cm above ground level.

[x]Significant at the 1% according to the F-test.

[w]t-test for paired comparisons.

[v]Border row trees were excluded from statistical analysis.

Table 7. Mean provenance phenological characteristics in the Lowland biofuel plantation during 1994 and 1995.

Provenance (S to N)	N	1994 Budbreak[z]	1994 Leaf Fall[y]	1995 Budbreak
E Cen MS	79	5	101	-6
SW VA	84	10	79	6
S Cen WV	109	14	85	9
S Cen IN	105	6	89	-4
E Cen KS	31	11	97	3
NE PA	112	11	81	3
Cen IA	86	11	74	0
S Cen NY	108	10	77	-2
Cen WI	106	15	87	12
Cen NH	101	9	65	0
S Cen Ont	80	12	73	3
NW VT	95	10	69	4
Cen Ont	74	13	64	-3
Significance[w]		**	**	**
5% t-test[v]		1.7	2	1
1% t-test		2.2	3	2
Border Row Trees[u]				
S IL	32	11	92	3
S Cen MN	41	9	65	-3

N = approximate number of clonal trees.

[z]Bud break is designated as the number of days after 31 March for new stem growth to elongate to 1 cm.

[y]Leaf fall is designated as the number of days after 31 August for the leaves to have dropped from the tree.

[x]Trees in approximately 25% of the plots failed to drop their leaves during the data collection period.

[w]Significant at the 1% level according to the F-test.

[v]t-test for paired comparisons.

[u]Border row trees were excluded from statistical analysis.

Table 8. Mean provenance phenological characteristics in the Upland biofuel plantation during 1994 and 1995.

Provenance (S to N)	N	1994 Budbreak[z]	1994 Leaf Fall[y]	1995 Budbreak
E Cen MS	114	3	103[x]	-6
SW VA	110	11	80	3
S Cen WV	115	11	86	6
S Cen IN	119	5	89	-5
E Cen KS	114	10	101	1
NE PA	115	9	86	2
Cen IA	118	9	80	-2
S Cen NY	111	11	81	-2
Cen WI	115	11	90	7
Cen NH	109	10	68	-1
S Cen Ont	106	9	82	0
NW VT	94	10	70	1
Cen Ont	112	10	64	-3
Significance[w]		**	**	**
5% t-test[v]		1.6	2	0.9
1% t-test		2.1	3	1.1
Border Row Trees[u]				
S IL	95	5	94	-1
S Cen MN	116	6	65	-1

N = approximate number of clonal trees.

[z]Bud break is designated as the number of days after 31 March for new stem growth to elongate to 1 cm.

[y]Leaf fall is designated as the number of days after 31 August for the leaves to have dropped from the tree.

[x]Trees in approximately 25% of the plots failed to drop their leaves during the data collection period.

[w]Significant at the 1% level according to the F-test.

[v]t-test for paired comparisons.

[u]Border row trees were excluded from statistical analysis.

Table 9. Mean clonal phenological characteristics in the Lowland biofuel plantation during 1994 and 1995.

Provenance (S to N)	Clone	N	1994 Budbreak[z]	1994 Leaf Fall[y]	1995 Budbreak
E Cen MS[x]	011	24	2	105	-9
	012	28	-1	102	-8
	015	27	15	95	-1
SW VA	182	30	7	68	4
	183	30	14	92	4
	184	15	12	71	6
	186	9	6	84	10
S Cen WV	072	25	11	86	10
	073	28	14	83	6
	075	29	14	87	6
	076	27	16	85	14
S Cen IN	051	27	10	93	-2
	052	24	10	90	0
	054	26	1	88	-7
	056	28	2	83	-8
E Cen KS	204	25	11	101	2
	206	6	12	93	5
NE PA	111	26	12	79	12
	113	29	12	86	8
	114	30	7	77	-2
	116	27	11	80	-3
Cen IA	061	26	12	69	0
	062	14	11	72	6
	063	17	10	82	-1
	065	29	10	71	-4
S Cen NY	171	26	10	71	-1
	173	26	8	71	-6
	174	28	13	78	-2
	175	28	11	86	-1
Cen WI	081	29	15	89	12
	083	30	17	86	14
	084	23	16	87	12
	085	24	14	87	12
Cen NH	151	29	12	67	-3
	153	29	8	65	-1
	154	16	7	65	4
	157	27	9	64	2
S Cen Ont	121	25	15	71	6
	125	26	9	76	2
	126	29	11	72	-1
NW VT	161	30	9	67	0
	162	27	12	63	4
	163	9	13	71	8
	165	29	8	76	3

Cen Ont	131	28	11	66	-6
	132	5	13	68	0
	133	26	13	65	2
	134	15	17	58	-7
Significance[w]			**	**	**
5% t-test[v]			3	4	2
1% t-test			4	6	3
Border Row Tree[u]					
S IL	043	2	11	92	8
	044	29	12	92	-2
	045				
	046				
S Cen MN	192				
	193	10	6	61	-5
	195	27	9	68	-3
	196	4	13	66	0

N = approximate number of clonal trees.

[z]Bud break is designated as the number of days after 31 March for new stem growth to elongate to 1 cm.

[y]Leaf fall is designated as the number of days after 31 August for the leaves to have dropped from the tree.

[x]Trees in approximately 25% of the plots failed to drop their leaves during the data collection period.

[w]Significant at the 1% level according to the F-test.

[v]t-test for paired comparisons.

[u]Border row trees were excluded from statistical analysis.

Table 10. Mean clonal phenological characteristics in the Upland biofuel plantation during 1994 and 1995.

Provenance (S to N)	Clone	N	1994 Budbreak[z]	1994 Leaf Fall[y]	1995 Budbreak
E Cen MS[x]	011	25	2	110	-8
	012	30	-1	101	-8
	014	29	-1	107	-8
	015	30	11	92	1
SW VA	182	27	8	71	-2
	183	26	11	92	2
	184	29	11	75	3
	186	28	12	82	9
S Cen WV	072	29	12	90	4
	073	26	12	84	3
	075	30	11	88	5
	076	30	11	84	10
S Cen IN	051	29	9	95	-1
	052	30	8	93	-4
	054	30	2	85	-8
	056	30	3	82	-8
E Cen KS	202	30	9	102	4
	203	25	8	94	-5
	204	30	12	102	2
	206	29	9	104	2
NE PA	111	27	10	85	5
	113	28	12	90	7
	114	30	6	80	-2
	116	30	8	91	-2
Cen IA	061	28	10	76	-2
	062	30	13	81	7
	063	30	8	92	-3
	065	30	6	72	-8
S Cen NY	171	28	10	77	0
	173	26	11	73	-8
	174	28	11	81	-3
	175	29	11	93	1
Cen WI	081	30	14	94	9
	083	28	8	90	6
	084	30	12	89	7
	085	27	12	85	7
Cen NH	151	30	13	65	-5
	153	30	7	65	-3
	154	24	6	76	3
	157	25	12	66	0
S Cen Ont	121	28	11	79	5
	122	23	10	80	-3
	125	29	7	81	-1
	126	26	7	88	-2

NW VT	161	21	10	70	-1
	162	30	11	63	1
	163	21	10	75	7
	165	22	6	74	0
Cen Ont	131	27	10	65	-4
	132	29	9	66	-1
	133	28	12	62	0
	134	28	8	62	-6
Significance[w]			**	**	**
5% t-test[v]			4	6	2
1% t-test			6	7	3
Border Row Tree[u]					
S IL	043	26	10	97	5
	044	29	6	93	-3
	045	27	0	93	-5
	046	13	6	92	0
S Cen MN	192	27	10	64	5
	193	29	2	63	-5
	195	30	3	68	-5
	196	30	8	65	-1

N = approximate number of clonal trees.

[z]Bud break is designated as the number of days after 31 March for new stem growth to elongate to 1 cm.

[y]Leaf fall is designated as the number of days after 31 August for the leaves to have dropped from the tree.

[x]Trees in approximately 25% of the plots failed to drop their leaves during the data collection period.

[w]Significant at the 1% level according to the F-test.

[v]t-test for paired comparisons.

[u]Border row trees were excluded from statistical analysis.

Table 11. Mean provenance coppice growth characteristics (number of stems by basal caliper size class) in the Lowland biofuel plantation during 1994.

Provenance (S to N)	N	Total stems	Vertical Stems < 10cm	Vertical Stems 10-20cm	Vertical Stems > 20cm	Horizontal stems < 20cm	Horizontal stems ≥ 20cm
E Cen MS	45	15.5	3.2	6.8	5.1	0.4	0
SW VA	54	14.0	2.0	7.4	4.2	0.3	0
S Cen WV	59	18.0	4.8	9.8	3.1	0.2	0
S Cen IN	59	15.1	3.2	6.4	5.0	0.3	0.1
E Cen KS	21	18.2	6.1	7.9	3.6	0.6	0
NE PA	59	17.1	3.3	8.7	4.6	0.5	0
Cen IA	56	15.4	2.1	8.2	4.4	0.5	0.2
S Cen NY	60	16.1	3.4	9.4	3.2	0.1	0
Cen WI	59	17.1	3.7	8.4	4.8	0.1	0
Cen NH	59	19.3	5.9	10.2	2.9	0.3	0
S Cen Ont	43	15.1	3.4	6.8	3.8	0.8	0.2
NW VT	54	20.0	5.6	10.2	3.7	0.5	0
Cen Ont	50	12.2	3.1	7.3	1.7	0.1	0
Significance[z]		**	**	**	**	*	ns
5% t-test[y]		1.2	1.0	1.2	0.8	0.4	
1% t-test		1.5	1.3	1.6	1.0		
Border Row Trees[x]							
S IL	15	15.3	4.9	4.3	4.8	1.3	0.1
S Cen MN	12	20.0	7.0	6.1	5.2	1.6	0.1

N = approximate number of clonal trees

[z]Significant at the 1% level according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 12. Mean provenance coppice growth characteristics (number of stems by basal caliper size class) in the Upland biofuel plantation during 1994.

Provenance (S to N)	N	Vertical Stems < 10cm		10-20cm	> 20cm	Horizontal stems < 20cm	≥ 20cm
E Cen MS	57	19.3	6.1	7.7	4.1	1.3	0.1
SW VA	52	17.7	5.1	8.4	3.4	0.8	0.1
S Cen WV	59	20.9	7.7	10.8	2.0	0.4	0
S Cen IN	60	18.9	5.9	8.5	4.0	0.5	0.1
E Cen KS	58	20.2	7.3	8.6	3.4	0.9	0
NE PA	60	19.8	5.7	9.5	3.1	1.3	0.1
Cen IA	59	18.0	4.4	9.0	3.4	1.0	0.2
S Cen NY	55	19.1	7.1	10.1	1.5	0.3	0
Cen WI	60	18.3	5.6	8.3	3.8	0.6	0.1
Cen NH	55	18.0	7.5	8.5	1.6	0.3	0
S Cen Ont	58	15.8	4.7	6.7	3.2	1.1	0.2
NW VT	52	19.0	6.7	9.1	2.5	0.7	0
Cen Ont	57	13.7	5.1	7.7	0.6	0.3	0
Significance[z]		**	**	**	**	**	**
5% t-test[y]		1.9	1.1	1.3	0.7	0.5	0.10
1% t-test		2.5	1.4	1.7	0.9	0.6	0.13
Border Row Trees[x]							
S IL	54	16.9	3.7	6.9	4.8	1.4	0.2
S Cen MN	59	23.8	6.6	12.0	3.9	1.2	0

N = approximate number of clonal trees

[z]Significant at the 1% level according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 13. Mean clonal coppice growth characteristics (number of stems by basal caliper size class) in the Lowland biofuel plantation during 1994.

Provenance (S to N)	Clone	N	Total stems	Vertical Stems < 10cm	10-20cm	> 20cm	Horizontal stems < 20cm	≥ 20cm
E Cen MS	011	15	13.3	3.2	4.7	5.1	0.3	0
	012	15	14.3	2.8	5.1	5.8	0.5	0
	015	15	18.9	3.5	10.7	4.4	0.3	0
SW VA	182	15	21.6	3.9	13.6	3.7	0.4	0
	183	15	13.2	1.6	5.7	5.7	0.1	0
	184	15	10.7	1.7	4.3	4.6	0.1	0.1
	186	9	10.4	1.0	5.8	2.8	0.6	0.1
S Cen WV	072	15	16.7	3.2	9.8	3.3	0.3	0.1
	073	15	17.8	3.5	10.7	3.7	0	0
	075	15	21.9	8.3	11.8	1.1	0.7	0
	076	14	15.5	4.2	7.0	4.3	0	0
S Cen IN	051	15	14.5	3.7	5.0	5.3	0.1	0.4
	052	15	13.2	3.1	4.5	5.0	0.6	0
	054	14	17.4	2.4	10.0	4.7	0.1	0.1
	056	15	15.2	3.7	6.1	5.0	0.4	0
E Cen KS	204	15	20.5	7.4	8.3	4.3	0.6	0
	206	6	15.8	4.8	7.5	3.0	0.5	0
NE PA	111	14	16.6	3.3	8.5	4.1	0.6	0.1
	113	15	20.7	4.7	10.0	5.6	0.4	0
	114	15	16.9	2.7	9.6	4.5	0	0
	116	15	14.1	2.3	6.7	4.1	1.0	0
Cen IA	061	15	11.2	1.1	4.5	5.5	0.1	0.1
	062	14	17.8	2.7	10.7	3.8	0.6	0
	063	12	19.4	2.8	11.8	4.1	0.6	0.1
	065	15	13.0	1.7	5.7	4.3	0.8	0.5
S Cen NY	171	15	13.9	2.8	7.9	3.1	0.1	0
	173	15	21.4	6.5	13.7	1.1	0.1	0
	174	15	14.2	2.5	8.5	3.2	0	0
	175	15	14.9	1.7	7.5	5.3	0.3	0
Cen WI	081	14	18.5	4.4	9.2	4.9	0	0
	083	15	15.4	4.9	5.9	4.5	0.1	0
	084	15	14.5	3.3	6.5	4.5	0.3	0
	085	15	19.9	2.1	12.2	5.4	0.2	0
Cen NH	151	14	16.3	5.4	9.5	1.4	0	0
	153	15	19.3	3.9	11.9	3.2	0.3	0
	154	15	17.1	4.1	9.4	3.3	0.3	0
	157	15	24.7	10.1	10.2	3.7	0.7	0
S Cen Ont	121	14	13.0	2.3	5.5	3.9	1.1	0.2
	125	15	18.3	4.4	8.7	4.4	0.6	0.1
	126	14	14.1	3.5	6.3	3.1	0.9	0.3
NW VT	161	15	24.4	7.5	14.0	2.9	0.1	0
	162	15	21.5	6.3	11.3	3.7	0.1	0
	163	9	18.0	3.8	9.3	4.7	0.3	0
	165	15	16.3	4.7	6.3	3.7	1.6	0

Cen Ont	131	15	11.1	2.3	6.5	2.2	0.1	0
	132	5	12.9	2.4	6.7	3.8	0.1	0
	133	15	13.2	4.5	7.9	0.3	0.5	0
	134	15	11.7	3.1	8.3	0.3	0	0
Significance[z]			**	**	**	**	*	ns
5% t-test[y]			2.2	1.8	2.4	1.4	0.7	
1% t-test			2.9	2.4	3.1	1.9		
Border Row Trees[x]								
S IL	044	15	15.3	4.9	4.3	4.8	1.3	0.1
S Cen MN	195	12	20.0	7.0	6.1	5.2	1.6	0.1

N = approximate number of clonal trees

[z]Significant at the 1% (**) or 5% (*) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 14. Mean clonal coppice growth characteristics (number of stems by basal caliper size class) in the Upland biofuel plantation during 1994.

Provenance (S to N)	Clone	N	Total stems	Vertical Stems < 10cm	Vertical Stems 10-20cm	Vertical Stems > 20cm	Horizontal stems < 20cm	Horizontal stems ≥ 20cm
E Cen MS	011	12	19.9	5.1	7.6	6.0	1.1	0
	012	15	19.0	5.8	6.6	3.4	3.0	0.2
	014	15	22.5	9.4	8.1	4.4	0.5	0.1
	015	15	15.9	4.1	8.6	2.6	0.7	0
SW VA	182	14	24.8	9.3	11.4	3.4	0.7	0
	183	11	16.2	3.7	6.8	5.1	0.6	0
	184	14	15.2	3.1	7.7	3.5	0.9	0.1
	186	13	14.6	4.3	7.6	1.5	1.0	0.3
S Cen WV	072	14	22.6	8.2	12.0	2.1	0.3	0
	073	15	18.7	5.8	10.6	1.6	0.6	0.1
	075	15	21.0	9.5	10.2	0.9	0.4	0
	076	15	21.3	7.5	10.4	3.3	0.1	0
S Cen IN	051	15	14.3	4.7	5.6	3.5	0.5	0
	052	15	20.4	6.5	7.7	5.4	0.7	0.2
	054	15	21.7	6.7	11.3	3.6	0.2	0
	056	15	19.3	5.9	9.4	3.5	0.6	0
E Cen KS	202	15	19.0	7.0	8.2	2.9	0.9	0
	203	15	16.3	4.8	7.9	3.3	0.3	0
	204	15	21.5	8.4	8.8	2.9	1.2	0.1
	206	15	24.0	9.2	9.3	4.5	1.0	0
NE PA	111	15	20.3	4.9	11.0	3.1	1.4	0
	113	15	22.5	7.2	10.5	3.7	1.0	0.2
	114	15	17.9	6.3	7.2	3.2	1.0	0.2
	116	15	18.4	4.4	9.4	2.6	1.8	0.2
Cen IA	061	14	14.2	3.1	5.0	4.9	1.2	0
	062	15	22.7	6.6	13.5	1.8	0.8	0
	063	15	20.3	4.5	10.8	3.8	0.8	0.4
	065	15	14.8	3.4	7.0	3.0	1.0	0.4
S Cen NY	171	14	14.0	5.4	7.1	1.2	0.3	0
	173	12	23.6	10.4	12.4	0.3	0.5	0
	174	14	17.6	6.2	10.0	1.1	0.3	0
	175	15	21.1	6.5	11.2	3.2	0.2	0
Cen WI	081	15	18.0	5.5	8.8	3.3	0.4	0
	083	15	19.2	7.4	8.6	3.0	0.1	0
	084	15	19.5	4.9	8.8	4.9	0.8	0.1
	085	15	16.6	4.4	7.0	4.0	1.0	0.2
Cen NH	151	14	12.5	5.6	6.6	0	0.3	0
	153	15	21.5	7.8	12.0	1.6	0.2	0
	154	12	19.9	9.0	8.3	2.4	0.3	0
	157	14	18.1	7.7	7.2	2.5	0.6	0.1
S Cen Ont	121	15	14.4	4.1	6.6	3.4	0.2	0.1
	122	14	14.7	4.1	5.6	3.1	1.8	0.1
	125	14	20.6	6.2	8.7	4.5	1.0	0.2
	126	15	13.5	4.3	6.0	1.7	1.3	0.2

NW VT	161	12	23.1	8.2	12.2	2.0	0.5	0.1
	162	15	21.6	8.5	11.0	2.0	0.1	0
	163	12	16.1	5.4	7.1	3.4	0.3	0
	165	13	15.4	4.8	6.1	2.6	1.8	0
Cen Ont	131	15	13.3	4.9	7.8	0.5	0.1	0
	132	15	15.5	5.1	8.8	1.1	0.4	0
	133	14	11.6	5.4	5.8	0.1	0.3	0
	134	13	14.3	5.1	8.2	0.6	0.5	0
Significance[z]			**	**	**	**	**	*
5% t-test[y]			3.8	2.1	2.6	1.3	1.0	0.2
1% t-test			5.0	2.8	3.4	1.8	1.2	
Border Row Trees[x]								
S IL	043	15	12.0	2.6	3.6	4.7	0.9	0.3
	044	15	15.5	2.6	6.6	4.0	2.2	0.1
	045	15	16.8	4.2	7.2	4.2	1.1	0.2
	046	9	23.1	5.5	10.1	6.2	1.2	0.1
S Cen MN	192	14	27.6	10.0	12.3	4.6	0.7	0
	193	15	28.9	6.5	15.0	6.4	0.8	0.2
	195	15	20.2	5.0	9.9	2.7	2.5	0.1
	196	15	18.7	5.0	10.9	1.9	0.9	0

N = approximate number of clonal trees

[z]Significant at the 1% (**) or 5% (*) level according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 15. Mean provenance crown architecture data for the Upland biofuel plantation; The top 1 meter of tree growth.

Provenance (S to N)	N	Number of nodes	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	≥0.5
E Cen MS	19	18.0	9.9	3.0	2.9	3.0	0.9
SW VA	19	17.1	7.5	2.6	2.2	1.7	1.0
S Cen WV	19	17.5	8.8	2.6	3.8	1.9	0.5
S Cen IN	19	17.8	8.2	2.7	3.2	2.0	0.3
E Cen KS	16	18.0	11.9	6.4	4.0	1.4	0.1
NE PA	19	17.3	3.6	1.1	1.0	1.2	0.2
Cen IA	20	19.3	8.2	2.8	2.7	2.2	0.5
S Cen NY	19	19.3	4.4	2.5	1.3	0.7	0
Cen WI	20	17.1	6.8	3.1	2.3	1.4	0
Cen NH	17	16.6	8.0	2.2	2.5	2.4	0.9
S Cen Ont	16	16.3	6.5	2.1	2.6	1.6	0.2
NW VT	16	16.2	9.2	4.4	2.4	1.8	0.6
Cen Ont	16	17.2	9.9	4.8	3.2	1.8	0.2
Significance[z]		**	**	**	**	ns	ns
5% t-test[y]		1.30	2.69	1.52	1.44		
1% t-test		1.72	3.56	2.01	1.90		
Border Row Trees[x]							
S IL	16	18.9	6.9	2.8	1.8	2.2	0.1
S Cen MN	19	14.6	8.0	4.7	2.3	0.9	0

N = approximate number of clonal trees

[z]Significant at the 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 16. Mean provenance crown architecture data for the Upland biofuel plantation; Primary branch growth on 1993 wood.

Provenance (S to N)	N	1993 height growth (m)	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	≥1
E Cen MS	19	2.3	33.3	9.5	7.8	10.3	5.0	0.9
SW VA	19	2.2	18.3	5.5	3.0	4.6	4.2	1.0
S Cen WV	19	2.0	19.6	5.8	6.8	4.9	1.7	0.2
S Cen IN	19	2.2	21.2	7.2	5.7	5.2	2.7	0.3
E Cen KS	16	2.3	31.3	15.5	6.4	5.5	3.8	0
NE PA	19	2.1	12.3	4.0	2.5	3.5	1.7	0.5
Cen IA	20	2.0	19.0	5.2	4.8	5.4	3.1	0.4
S Cen NY	19	1.9	10.3	4.2	2.0	1.9	1.4	0.8
Cen WI	20	2.1	15.0	5.4	3.7	3.2	2.1	0.6
Cen NH	17	2.1	16.5	4.1	4.5	4.9	2.5	0.4
S Cen Ont	16	2.2	15.6	4.4	3.9	3.8	2.7	0.7
NW VT	16	2.3	23.9	8.0	5.2	4.8	4.5	1.3
Cen Ont	16	1.9	15.8	6.8	4.3	3.0	1.8	0
Significance[z]		**	**	**	**	**	**	*
5% t-test[y]		0.14	6.98	2.80	2.20	2.55	1.99	0.70
1% t-test		0.19	9.22	3.71	2.91	3.37	2.63	
Border Row Trees[x]								
S IL	16	2.3	26.5	9.4	4.6	7.2	4.4	0.9
S Cen MN	19	2.1	18.5	9.4	4.2	3.2	1.3	0.5

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 17. Mean provenance crown architecture data for the Upland biofuel plantation; Primary branch growth on 1992 wood.

Provenance (S to N)	N	1992 height growth (m)	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	1-<1.5	1.5-<2	≥2
E Cen MS	19	1.0	22.9	10.1	3.4	2.4	3.2	2.2	0.8	0.9
SW VA	19	1.1	17.7	5.8	2.2	2.0	3.2	2.7	1.4	0.4
S Cen WV	19	1.0	17.4	6.3	3.6	2.4	2.2	1.5	1.0	0.4
S Cen IN	19	1.1	23.4	6.2	2.7	3.2	5.2	3.3	1.8	1.0
E Cen KS	16	1.1	24.6	9.7	3.8	2.8	4.4	2.3	0.8	0.7
NE PA	19	1.2	22.2	8.8	3.6	2.3	3.5	2.3	1.3	0.3
Cen IA	20	1.1	21.4	5.0	3.7	4.6	4.5	2.6	0.8	0.2
S Cen NY	19	1.0	17.6	4.3	3.2	3.6	3.8	1.8	0.6	0.2
Cen WI	20	1.1	16.5	4.8	3.0	2.3	2.4	2.2	1.2	0.5
Cen NH	17	0.9	19.1	4.8	4.7	3.4	3.9	1.6	0.5	0.2
S Cen Ont	16	1.2	17.1	5.5	2.6	2.9	3.8	1.2	0.9	0.2
NW VT	16	1.0	17.9	5.4	3.0	3.5	3.4	1.6	0.8	0.3
Cen Ont	16	1.0	17.0	4.3	3.2	3.3	3.7	1.8	0.5	0.2
Significance[z]		**	ns	**	ns	*	ns	*	*	**
5% t-test[y]		0.10		2.80		1.41		1.07	0.73	0.43
1% t-test		0.13		3.71						0.57
Border Row Trees[x]										
S IL	16	1.2	28.3	11.9	4.7	3.3	3.6	2.0	1.7	1.0
S Cen MN	19	1.0	23.0	9.8	3.8	2.6	3.0	2.2	1.0	0.4

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 18. Mean provenance crown architecture data for the Upland biofuel plantation; Primary branch growth on 1991 wood.

Provenance (S to N)	N	1991 height growth (m)	Number of branches	Number of branches by size class (m) <0.25	0.25-<0.5	0.5-<1	1-<1.5	1.5-<2	2-<2.5	2.5-<3	≥3
E Cen MS	19	1.3	10.8	3.0	1.4	2.0	1.8	1.3	0.4	0.5	3.5
SW VA	19	1.1	14.0	3.4	1.9	2.3	2.8	1.1	1.2	0.4	4.3
S Cen WV	19	0.8	11.2	2.8	1.8	2.3	1.8	1.0	0.6	0.3	3.4
S Cen IN	19	1.2	13.5	2.6	1.0	2.3	2.8	1.4	1.2	0.8	3.8
E Cen KS	16	1.0	15.3	6.7	1.5	2.6	2.2	0.8	0.8	0.3	7.1
NE PA	19	1.1	12.9	5.3	1.4	2.2	2.0	0.7	0.6	0.1	5.8
Cen IA	20	0.9	11.0	2.0	1.3	2.4	2.4	0.8	0.8	0.4	2.9
S Cen NY	19	0.9	8.2	2.2	0.7	2.1	1.4	0.5	0.5	0.4	2.6
Cen WI	20	1.0	11.8	3.2	0.8	2.0	2.7	1.0	0.7	0.4	4.1
Cen NH	17	0.7	8.1	2.0	1.4	2.2	1.2	0.4	0.3	0.4	2.2
S Cen Ont	16	0.8	6.9	1.9	0.9	1.1	1.0	1.0	0.2	0.4	2.2
NW VT	16	0.9	7.6	1.5	0.8	1.8	0.9	0.8	0.4	0.4	2.4
Cen Ont	16	0.8	11.2	3.7	2.3	2.8	1.5	0.4	0.2	0.1	3.9
Significance[z]		**	**	**	*	ns	**	*	*	ns	*
5% t-test[y]		0.23	4.21	2.43	1.01		0.99	0.62	0.65		2.49
1% t-test		0.31	5.56	3.21			1.30				
Border Row Trees[x]											
S IL	16	1.5	19.6	8.6	2.3	3.4	1.8	1.1	0.7	0.4	9.9
S Cen MN	19	1.1	17.2	5.8	1.4	3.9	2.4	1.0	1.2	0.5	6.8

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 19. Mean provenance crown architecture data for the Upland biofuel plantation; Basal branch growth.

Provenance (S to N)	N	Number of branches	Number of branches by size class (m) <1	1-<1.5	1.5-<2	2-<2.5	2.5-<3	≥3
E Cen MS	19	2.2	0.4	0.2	0.2	0.2	0.2	1.2
SW VA	19	1.7	0.2	0.3	0.4	0.3	0.3	0.3
S Cen WV	19	2.0	0.4	0.4	0.1	0.3	0.2	0.5
S Cen IN	19	1.6	0.5	0.4	0.2	0.1	0.2	0.3
E Cen KS	16	2.2	0.3	0.4	0.3	0.2	0.4	0.6
NE PA	19	2.0	0.3	0.2	0.3	0.3	0.2	0.8
Cen IA	20	2.2	0.4	0.4	0	0.2	0.4	0.6
S Cen NY	19	1.5	0.2	0.4	0.2	0.2	0.2	0.2
Cen WI	20	1.3	0.2	0.2	0.2	0.2	0.2	0.4
Cen NH	17	1.5	0.5	0.2	0.2	0	0.2	0.4
S Cen Ont	16	1.1	0.1	0.2	0.2	0.3	0.2	0.1
NW VT	16	2.4	0.8	0.4	0.1	0.1	0.4	0.5
Cen Ont	16	1.0	0.2	0.5	0.1	0.1	0	0.1
Significance[z]		ns	ns	ns	ns	ns	ns	**
5% t-test[y]								0.46
1% t-test								0.61
Border Row Trees[x]								
S IL	16	2.3	0.6	0.5	0.3	0.2	0.3	0.4
S Cen MN	19	4.6	2.3	0.4	0.2	0.3	0.4	1.0

N = approximate number of clonal trees

[z]Significant at the 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 20. Mean provenance crown architecture data for the Upland biofuel plantation; Number of secondary branches.

Provenance (S to N)	N	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	1-<1.5	1.5-<2	≥2
E Cen MS	19	136.7	63.9	28.1	24.2	13.8	4.6	1.6	0.6
SW VA	19	106.6	48.7	19.6	17.8	14.5	4.7	0.9	0.4
S Cen WV	19	117.4	55.4	25.6	20.0	11.4	3.8	1.0	0.2
S Cen IN	19	129.2	56.5	25.3	22.1	16.6	6.8	1.3	0.6
E Cen KS	16	104.9	60.4	17.0	13.3	10.4	2.7	0.7	0.4
NE PA	19	80.2	41.4	13.7	11.3	9.7	3.0	0.6	0.4
Cen IA	20	106.2	45.0	21.2	21.6	12.8	4.3	0.8	0.5
S Cen NY	19	67.3	32.4	12.3	11.4	8.2	2.3	0.6	0.1
Cen WI	20	90.6	41.8	16.1	14.2	10.9	5.4	1.6	0.6
Cen NH	17	74.9	30.0	18.5	15.6	8.7	1.8	0.2	0.2
S Cen Ont	16	63.0	34.4	10.9	8.6	6.4	2.2	0.2	0.2
NW VT	16	98.2	43.0	18.8	16.1	15.0	4.0	0.8	0.6
Cen Ont	16	52.1	28.5	10.2	7.5	4.3	1.3	0.2	0.2
Significance[z]		**	**	**	**	**	**	**	ns
5% t-test[y]		27.38	16.03	6.03	5.71	4.19	1.87	0.69	
1% t-test		36.18	21.19	7.97	7.55	5.53	2.48	0.91	
Border Row Trees[x]									
S IL	16	160.4	83.5	26.5	21.6	18.4	6.9	2.3	1.1
S Cen MN	19	128.8	64.3	22.4	18.8	15.8	5.6	1.4	0.6

N = approximate number of clonal trees

[z]Significant at the 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 21. Mean provenance crown architecture data for the Upland biofuel plantation; Number of tertiary branches.

Provenance (S to N)	N	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	≥1
E Cen MS	19	41.8	23.8	8.4	6.8	2.4	0.4
SW VA	19	22.5	13.9	4.7	1.9	1.7	0.3
S Cen WV	19	18.8	12.6	3.7	2.1	0.2	0.1
S Cen IN	19	39.8	23.4	8.0	5.2	2.9	0.3
E Cen KS	16	21.7	15.3	3.4	1.9	1.0	0
NE PA	19	18.8	10.9	3.7	2.8	1.0	0.3
Cen IA	20	25.6	14.5	4.9	4.0	1.8	0.5
S Cen NY	19	17.0	11.2	3.1	1.7	1.0	0.1
Cen WI	20	25.8	13.4	6.0	3.8	2.2	0.5
Cen NH	17	20.8	10.9	4.9	3.5	1.4	0.1
S Cen Ont	16	6.4	3.9	1.5	0.9	0.2	0
NW VT	16	31.0	20.9	4.5	3.4	1.7	0.5
Cen Ont	16	9.3	6.2	2.4	0.5	0.2	0
Significance[z]		**	**	**	**	**	ns
5% t-test[y]		13.92	8.90	3.22	2.24	1.40	
1% t-test		18.40	11.77	4.25	2.96	1.86	
Border Row Trees[x]							
S IL	16	59.7	39.8	9.7	5.9	3.3	0.9
S Cen MN	19	35.6	24.6	4.6	3.9	1.8	0.6

N = approximate number of clonal trees

[z]Significant at the 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 22. Mean clonal crown architecture data for the Upland biofuel plantation; The top 1 meter of tree growth.

Prov. (S to N)	Clone	N	Number of nodes	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	≥0.5
E Cen	011	5	17.4	10.0	2.8	2.6	3.4	1.2
MS	012	5	18.4	12.2	1.8	3.0	5.4	2.0
	014	4	18.0	8.2	3.5	3.2	1.5	0
	015	5	18.2	8.8	4.2	2.8	1.4	0.4
SW	182	5	14.6	7.6	1.6	3.0	2.0	1.0
VA	183	4	19.0	9.5	2.2	1.2	3.0	3.0
	184	5	16.6	2.0	1.4	0.6	0	0
	186	5	18.6	11.4	5.2	3.6	2.0	0.6
S Cen	072	5	17.4	12.0	3.2	6.0	2.6	0.2
WV	073	4	19.0	8.2	1.5	4.5	1.5	0.8
	075	5	16.8	10.4	4.8	3.8	1.0	0.8
	076	5	17.2	4.6	0.6	1.2	2.6	0.2
S Cen	051	5	17.0	11.0	3.6	5.4	2.0	0
IN	052	5	16.8	8.8	3.2	3.2	2.0	0.4
	054	5	17.4	7.2	1.8	2.6	2.2	0.6
	056	4	20.5	5.0	2.0	1.2	1.8	0
E Cen	202	3	18.7	8.3	3.0	5.0	0.3	0
KS	203	4	16.8	11.2	5.2	4.0	2.0	0
	204	5	18.4	12.8	6.6	4.6	1.6	0
	206	4	18.2	14.2	0.0	2.5	1.2	0.5
NE	111	5	18.4	2.2	1.2	0.8	0.2	0
PA	113	4	18.5	4.5	1.0	1.8	1.8	0
	114	5	16.4	3.8	1.4	0.6	1.0	0.8
	116	5	16.0	4.0	0.8	1.2	2.0	0
Cen	061	5	19.2	6.0	2.4	2.4	1.2	0
IA	062	5	17.0	9.8	4.8	2.6	2.2	0.2
	063	5	22.0	9.0	2.6	2.8	2.8	0.8
	065	5	19.0	7.8	1.4	3.0	2.4	1.0
S Cen	171	5	22.2	6.2	4.8	0.8	0.6	0
NY	173	5	18.2	4.4	2.4	0.8	1.2	0
	174	4	18.2	2.5	1.2	1.0	0.2	0
	175	5	18.2	4.2	1.2	2.4	0.6	0
Cen	081	5	17.2	7.0	4.0	2.4	0.6	0
WI	083	5	17.2	5.6	1.6	2.6	1.2	0.2
	084	5	16.8	8.6	4.6	2.4	1.6	0
	085	5	17.2	6.0	2.2	1.8	2.0	0
Cen	151	3	17.0	2.0	1.3	0.7	0.0	0
NH	153	5	17.6	7.6	1.4	1.8	2.4	2.0
	154	4	16.2	12.8	4.0	4.5	4.2	0
	157	5	15.8	8.2	2.0	2.8	2.4	1.0
S Cen	121	5	16.0	7.2	3.2	2.6	1.4	0
Ont	122	4	16.5	5.8	1.5	3.0	1.2	0
	125	2	15.5	7.0	1.0	2.5	1.5	2.0
	126	5	16.8	6.2	1.8	2.4	2.0	0

NW	161	4	16.5	8.5	5.5	2.5	0.2	0.2
VT	162	5	15.4	6.8	2.4	2.8	0.6	1.0
	163	3	15.3	8.0	2.7	2.0	3.0	0.3
	165	4	17.8	13.8	7.0	2.2	4.0	0.5
Cen	131	5	19.8	9.6	5.0	2.8	1.6	0.2
Ont	132	4	14.5	10.2	5.8	2.2	2.0	0.2
	133	4	17.0	8.5	2.5	3.8	2.0	0.2
	134	3	16.7	12.0	6.0	4.3	1.3	0.3
Significance[z]			**	**	**	ns	ns	ns
5% t-test[y]			2.83	5.86	3.31			
1% t-test			3.74	7.75	4.38			
Border Row Trees[x]								
S IL	043	4	18.5	2.5	0.8	0.8	1.0	0
	044	4	16.8	7.0	3.5	1.5	2.0	0
	045	4	19.5	8.0	3.8	2.5	1.5	0.2
	046	4	20.8	10.0	3.2	2.2	4.2	0.2
S Cen	192	5	15.8	11.2	6.4	3.4	1.4	0
MN	193	5	14.8	4.4	3.6	0.8	0	0
	195	4	11.8	5.0	3.2	1.0	0.8	0
	196	5	15.6	10.8	5.4	3.6	1.6	0.2

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 23. Mean clonal crown architecture data for the Upland biofuel plantation; Primary branch growth on 1993 wood.

Prov. (S to N)	Clone	N	1993 height growth (m)	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	≥1
E Cen	011	5	2.4	23.2	6.4	4.2	7.6	4.6	0.4
MS	012	5	2.6	53.6	12.0	12.4	19.8	8.6	0.8
	014	4	2.2	26.8	8.8	5.2	6.2	4.5	2.4
	015	5	2.0	28.4	10.6	9.0	6.6	2.2	0
SW	182	5	2.2	14.8	3.6	3.4	4.6	2.4	0.8
VA	183	4	2.0	17.2	4.0	1.8	4.8	5.2	1.5
	184	5	2.3	7.2	3.2	1.6	0.6	0.8	1.0
	186	5	2.2	33.6	11.0	5.0	8.4	8.4	0.8
S Cen	072	5	2.3	35.4	10.4	13.0	9.0	2.6	0.4
WV	073	4	2.1	19.8	4.8	7.2	5.5	2.0	0.2
	075	5	1.9	16.4	7.4	5.6	2.0	1.4	0
	076	5	1.8	6.8	0.6	1.6	3.2	1.0	0.4
S Cen	051	5	2.2	28.4	10.8	9.4	5.6	2.2	0.4
IN	052	5	2.2	24.2	7.0	5.6	4.8	6.4	0.4
	054	5	2.2	19.8	5.8	5.2	7.0	1.6	0.2
	056	4	2.3	10.0	4.8	1.8	3.0	0.2	0.2
E Cen	202	3	2.2	20.7	11.0	6.0	2.3	1.3	0
KS	203	4	2.4	27.2	14.8	6.2	3.5	2.8	0
	204	5	2.4	30.2	13.4	7.4	5.2	4.2	0
	206	4	2.4	44.8	22.2	5.8	10.2	6.2	0.2
NE	111	5	2.2	15.4	5.8	2.8	3.8	2.2	0.8
PA	113	4	2.1	13.2	4.2	3.2	4.8	1.0	0
	114	5	1.9	12.2	3.8	2.0	2.6	3.4	0.4
	116	5	2.1	8.6	2.2	2.2	3.2	0.2	0.8
Cen	061	5	1.8	10.6	2.8	3.2	3.0	1.2	0.4
IA	062	5	2.1	22.2	7.8	4.2	6.4	3.4	0.4
	063	5	2.1	25.4	6.2	6.6	7.4	5.0	0.2
	065	5	2.1	17.6	4.2	5.2	4.6	2.8	0.8
S Cen	171	5	1.9	11.0	6.2	1.4	2.0	0.8	0.6
NY	173	5	1.8	5.4	2.4	1.0	1.6	0.2	0.2
	174	4	1.7	7.8	2.8	2.0	1.5	1.2	0.2
	175	5	2.4	16.6	5.2	3.8	2.4	3.2	2.0
Cen	081	5	2.2	14.0	6.4	3.2	1.2	2.6	0.6
WI	083	5	1.9	7.6	1.8	2.8	1.8	0.8	0.4
	084	5	2.4	21.6	9.0	5.6	4.2	2.4	0.4
	085	5	2.0	16.8	4.4	3.2	5.8	2.6	0.8
Cen	151	3	1.3	13.0	3.0	3.7	4.0	2.0	0.3
NH	153	5	2.1	13.8	3.0	2.8	4.0	3.2	0.8
	154	4	2.4	25.5	8.0	8.0	8.2	1.2	0
	157	5	2.3	14.0	2.8	3.8	3.8	3.2	0.4
S Cen	121	5	2.2	11.4	4.8	3.2	2.2	0.8	0.4
Ont	122	4	2.2	21.2	6.0	5.0	5.0	4.5	0.8
	125	2	2.1	11.0	1.0	3.0	2.0	5.0	0
	126	5	2.2	17.0	4.2	4.2	5.0	2.2	1.4

NW	161	4	2.0	22.0	10.0	5.2	3.5	1.8	1.5
VT	162	5	2.3	22.8	5.6	6.2	2.8	6.4	1.8
	163	3	2.5	25.7	7.0	3.3	7.7	6.3	1.3
	165	4	2.4	25.8	9.8	5.2	6.5	3.5	0.6
Cen	131	5	1.8	15.2	6.4	4.0	3.0	1.8	0
Ont	132	4	2.2	16.8	8.8	3.2	3.0	1.8	0
	133	4	1.7	14.5	4.5	4.8	3.2	2.0	0
	134	3	2.0	17.3	7.7	5.7	2.7	1.3	0
Significance[z]			**	*	**	**	**	*	ns
5% t-test[y]			0.31	15.21	6.11	4.79	5.55	4.33	
1% t-test			0.40		8.08	6.33	7.34		
Border Row Trees[x]									
S IL	043	4	2.4	14.0	3.5	2.8	3.2	3.0	1.4
	044	4	2.4	26.8	10.8	4.5	7.2	3.2	1.0
	045	4	2.1	26.5	10.0	6.0	7.8	2.5	0.2
	046	4	2.2	38.8	13.5	5.0	10.5	8.8	1.0
S Cen	192	5	1.9	26.2	9.0	7.8	5.8	2.6	1.0
MN	193	5	2.3	17.4	12.0	2.0	2.2	0.8	0.4
	195	4	2.2	11.8	7.0	2.5	1.0	0.5	0.6
	196	5	1.9	17.4	9.0	4.2	3.2	1.0	0

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 24. Mean clonal crown architecture data for the Upland biofuel plantation; Primary branch growth on 1992 wood.

Prov. (S to N)	Clone	N	1992 height growth (m)	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	1-<1.5	1.5-<2	≥3
E Cen	011	5	0.7	18.8	7.6	2.0	3.0	1.8	2.6	1.4	0.4
MS	012	5	1.1	33.6	16.8	5.2	3.0	3.4	3.0	0.8	1.4
	014	4	1.2	25.8	11.6	3.2	1.8	5.0	2.2	0.8	1.2
	015	5	0.8	13.4	4.4	3.2	1.8	2.4	0.8	0.2	0.6
SW	182	5	0.9	17.4	5.2	2.6	2.8	3.2	2.4	0.4	0.8
VA	183	4	1.1	16.8	6.5	1.8	2.0	2.0	2.2	1.2	1.0
	184	5	1.1	16.0	4.6	2.2	2.6	1.8	3.4	1.4	0
	186	5	1.3	20.6	7.2	2.2	0.8	5.4	2.6	2.4	0
S Cen	072	5	0.9	18.8	6.8	5.2	2.2	1.4	1.8	1.0	0.4
WV	073	4	1.1	21.2	5.2	5.8	4.2	2.6	1.6	1.0	0.8
	075	5	0.8	14.4	6.4	1.8	1.8	2.0	1.6	0.8	0
	076	5	1.0	15.2	6.8	1.8	1.2	2.8	1.0	1.0	0.6
S Cen	051	5	1.1	21.0	5.6	1.4	2.8	5.2	3.4	2.0	0.6
IN	052	5	1.3	27.8	6.6	3.8	5.0	6.8	3.4	1.4	0.8
	054	5	1.2	21.0	6.2	2.6	3.0	4.4	2.4	1.4	1.0
	056	4	1.1	24.0	6.6	3.0	2.2	4.4	4.0	2.2	1.6
E Cen	202	3	0.8	16.2	6.2	2.2	2.2	2.2	2.2	0.5	0.5
KS	203	4	1.3	26.8	8.8	5.8	2.8	5.8	2.0	1.2	0.5
	204	5	1.3	29.2	10.2	4.8	3.4	5.4	3.8	0.8	0.8
	206	4	1.0	24.8	12.6	2.6	2.8	4.0	1.2	0.8	0.8
NE	111	5	1.2	26.4	11.0	4.0	1.8	4.2	3.6	1.8	0
PA	113	4	1.3	20.2	9.0	4.2	1.5	3.0	1.8	0.5	0.2
	114	5	1.2	24.0	8.0	2.2	4.4	4.8	3.0	1.0	0.6
	116	5	1.0	17.6	7.4	4.0	1.2	2.0	0.8	1.8	0.4
Cen	061	5	1.2	21.6	3.0	2.8	6.8	5.8	2.4	0.6	0.2
IA	062	5	1.2	23.4	5.8	3.6	4.4	4.6	3.4	1.2	0.4
	063	5	1.1	17.2	3.4	4.2	2.8	3.6	2.6	0.6	0
	065	5	1.0	23.6	7.8	4.2	4.2	4.0	2.2	0.8	0.4
S Cen	171	5	1.0	15.4	2.6	4.0	2.2	3.8	2.0	0.6	0.2
NY	173	5	0.9	14.6	4.0	3.2	2.8	2.4	2.0	0.0	0.2
	174	4	1.1	17.0	4.8	2.4	3.6	4.6	1.2	0.4	0
	175	5	1.1	23.4	5.8	3.4	5.8	4.6	1.8	1.4	0.6
Cen	081	5	1.1	17.0	5.2	2.2	3.0	4.4	1.2	0.6	0.4
WI	083	5	1.2	13.6	3.8	3.6	1.2	1.0	2.6	1.2	0.2
	084	5	0.9	17.0	4.4	2.0	2.4	2.8	3.2	1.4	0.8
	085	5	1.1	18.4	6.0	4.2	2.6	1.6	1.8	1.6	0.6
Cen	151	3	0.6	11.0	3.3	3.3	2.0	1.0	1.0	0.3	0
NH	153	5	1.0	25.2	4.8	5.4	5.2	7.0	1.4	0.8	0.6
	154	4	1.0	22.0	5.2	6.5	4.2	4.0	1.8	0.2	0
	157	5	1.0	15.6	5.4	3.4	1.8	2.6	2.0	0.4	0
S Cen	121	5	1.3	15.2	2.8	2.4	3.4	3.6	1.4	1.2	0.4
Ont	122	4	1.1	15.8	5.0	2.2	3.5	2.8	1.0	1.2	0
	125	2	1.0	14.0	7.0	2.0	0.7	2.3	1.3	0.3	0.3
	126	5	1.3	22.0	7.6	3.4	3.4	5.6	1.2	0.6	0.2

NW	161	4	0.8	17.0	4.2	4.8	3.5	2.0	1.0	1.2	0.2
VT	162	5	1.2	21.0	7.4	2.8	3.6	4.2	2.4	0.0	0.6
	163	3	1.1	24.0	8.0	3.0	4.0	5.7	2.0	1.3	0.0
	165	4	0.9	11.8	2.6	1.8	3.0	2.2	1.0	1.0	0.2
Cen	131	5	1.0	12.8	2.8	2.8	2.4	3.2	1.2	0.2	0.2
Ont	132	4	1.2	21.4	5.8	3.8	4.0	4.6	2.4	0.4	0.4
	133	4	0.7	15.4	4.4	4.2	3.0	2.8	1.0	0.0	0
	134	3	1.3	19.0	4.2	1.8	3.8	4.5	3.0	1.5	0.2
Significance[z]			**	ns	ns	ns	ns	ns	ns	ns	ns
5% t-test[y]			0.21								
1% t-test			0.28								
Border Row Trees[x]											
S IL	043	4	1.2	21.4	11.0	2.2	1.2	2.2	1.6	1.8	1.4
	044	4	1.2	31.2	12.0	6.8	3.2	4.4	2.4	1.2	1.2
	045	4	1.3	28.0	13.6	4.2	3.2	3.6	1.4	1.6	0.4
	046	4	1.0	33.8	11.0	6.0	6.0	4.5	2.8	2.2	1.2
S Cen	192	5	1.1	21.8	7.2	4.0	2.4	4.2	3.0	0.4	0.6
MN	193	5	0.8	22.6	11.4	3.4	3.0	1.8	1.4	1.0	0.6
	195	4	1.2	29.8	14.4	5.6	2.2	3.0	3.0	1.2	0.4
	196	5	0.9	17.8	6.2	2.4	3.0	3.2	1.6	1.2	0.2

N = approximate number of clonal trees

[z]Significant at the 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 25. Mean clonal crown architecture data for the Upland biofuel plantation; Primary branch growth on 1991 wood.

Prov. (S to N)	Clone	N	1991 height growth (m)	Number of branches	Number of branches by size class (m) <0.25	0.25-<0.5	0.5-<1	1-<1.5	1.5-<2	2-<2.5	2.5-<3	≥3
E Cen	011	5	1.8	14.6	5.6	2.0	2.6	1.8	1.0	0.8	0.4	6.0
MS	012	5	1.3	10.2	2.4	0.4	1.8	2.2	2.0	0	0.8	3.0
	014	4	1.4	12.4	2.6	1.8	3.0	2.0	1.6	0.2	0.6	3.2
	015	5	0.7	6.0	1.6	1.2	0.8	1.0	0.6	0.4	0.2	1.8
SW	182	5	1.0	15.8	3.8	2.8	3.2	2.6	1.2	0.8	0.4	4.8
VA	183	4	1.1	12.0	3.5	0.8	2.5	2.8	1.8	0.5	0	3.8
	184	5	1.0	12.0	3.2	1.4	2.2	1.2	0.6	1.0	1.0	4.6
	186	5	1.2	15.8	3.0	2.6	1.2	4.8	1.0	2.2	0.2	3.8
S Cen	072	5	0.8	9.0	1.8	1.4	2.2	1.0	1.6	0.2	0.2	2.4
WV	073	4	0.9	10.0	1.6	1.6	2.0	1.8	1.2	1.0	0.2	2.2
	075	5	0.8	9.4	3.0	2.2	1.4	1.6	0.4	0.4	0	3.4
	076	5	1.0	16.6	4.8	2.2	3.6	2.8	1.0	0.8	0.8	5.4
S Cen	051	5	1.2	14.4	2.0	1.2	3.2	1.8	2.4	1.0	0.6	4.2
IN	052	5	1.2	16.6	2.0	1.4	3.8	5.2	1.4	1.6	0.4	2.8
	054	5	1.0	12.0	2.4	1.2	1.2	2.0	1.2	1.6	1.0	3.6
	056	4	1.2	11.0	4.0	0.4	1.0	2.2	0.8	0.8	1.0	4.8
E Cen	202	3	1.0	12.2	5.0	0.5	2.8	2.0	1.0	0.8	0.2	5.0
KS	203	4	1.0	16.2	4.8	1.2	4.0	3.2	0.8	1.2	0.8	5.0
	204	5	0.9	15.4	9.0	1.4	2.0	1.2	0.4	1.0	0.2	9.2
	206	4	1.2	17.0	7.4	2.6	2.0	2.4	1.2	0.4	0	8.4
NE	111	5	1.2	17.6	7.2	2.8	2.6	3.0	0.4	0.4	0.2	8.2
PA	113	4	1.0	9.2	3.2	1.2	1.5	2.0	0.2	0.5	0.2	3.5
	114	5	1.0	10.2	3.6	0.8	2.2	1.4	1.0	0.6	0	4.0
	116	5	1.2	13.8	6.6	0.6	2.4	1.6	1.0	1.0	0	7.2
Cen	061	5	0.7	9.0	2.0	1.4	2.4	2.0	0.6	0.2	0	2.4
IA	062	5	1.2	15.8	3.0	3.0	3.0	3.6	1.2	0.8	0.2	4.0
	063	5	1.0	11.4	1.6	0.2	2.4	2.0	1.0	1.8	0.6	3.0
	065	5	0.8	7.6	1.6	0.6	1.6	1.8	0.6	0.2	0.6	2.2
S Cen	171	5	0.8	9.0	3.4	1.0	2.0	1.0	0.6	0.8	0.2	3.4
NY	173	5	0.8	5.0	1.2	0.4	2.0	0.6	0.2	0.4	0	1.4
	174	4	0.8	7.6	1.2	0.4	2.4	1.6	0.6	0.4	0.8	1.4
	175	5	1.1	11.0	3.0	1.0	2.0	2.4	0.6	0.4	0.4	4.0
Cen	081	5	1.0	13.6	3.8	1.2	2.4	3.4	1.0	0.8	0	4.8
WI	083	5	0.8	9.8	3.2	1.0	1.2	2.2	0.4	0.6	0.2	4.2
	084	5	1.1	11.4	2.4	0	2.8	3.4	1.6	0.8	0	2.8
	085	5	1.1	12.2	3.6	1.2	1.8	1.8	1.0	0.6	1.2	4.6
Cen	151	3	0.5	7.0	2.7	1.0	1.7	1.3	0	0.3	0	2.7
NH	153	5	0.7	8.2	2.2	1.0	2.0	0.8	0.8	0.4	0.8	2.4
	154	4	0.8	12.0	2.5	3.2	3.5	1.5	0.2	0.2	0.2	3.0
	157	5	0.7	5.6	1.0	0.6	1.8	1.4	0.4	0.2	0.2	1.0
S Cen	121	5	0.6	5.8	0.8	1.4	1.6	1.0	0.4	0	0.4	1.0
Ont	122	4	0.7	7.0	2.0	0.2	0.5	1.0	1.5	0.5	0.5	2.8
	125	2	0.7	8.0	3.7	0.7	1.3	0.7	1.0	0.3	0.3	3.7
	126	5	0.8	7.4	2.0	1.0	1.0	1.4	1.4	0.2	0.2	2.2

NW	161	4	0.9	9.2	0.8	1.0	3.2	0.5	1.5	0.2	0.8	2.0
VT	162	5	0.8	6.6	1.0	0.8	1.2	1.2	0.8	0.4	0.6	1.6
	163	3	1.2	6.7	2.7	0.3	1.0	0.3	0.7	0.7	0	3.3
	165	4	1.0	8.0	1.8	0.8	1.8	1.4	0.4	0.4	0.2	3.0
Cen	131	5	0.6	10.4	3.2	2.0	2.6	1.4	0.8	0.2	0.2	3.2
Ont	132	4	0.9	12.8	4.2	3.0	3.2	1.8	0.2	0	0.2	4.4
	133	4	0.7	7.2	1.4	1.0	3.0	1.2	0.2	0.4	0	1.4
	134	3	1.0	15.0	6.5	3.5	2.2	1.5	0.5	0	0	7.2
Significance[z]			**	ns	ns	ns	ns	*	ns	ns	ns	ns
5% t-test[y]			0.23					2.15				
1% t-test			0.31									
Border Row Trees[x]												
S IL	043	4	1.6	26.4	16.4	2.2	2.8	1.4	1.2	0.6	0.2	18.0
	044	4	1.6	17.2	4.6	1.8	5.0	1.8	1.2	0.6	0.2	6.2
	045	4	1.4	10.6	3.8	0.8	1.6	1.0	0.6	1.4	0.6	4.4
	046	4	1.4	25.5	9.8	4.8	4.2	3.2	1.5	0	0.5	11.2
S Cen	192	5	1.0	31.2	12.6	3.0	6.8	4.2	2.0	1.2	0.4	13.6
MN	193	5	1.1	14.2	4.4	0.8	3.6	2.2	0.6	0.6	0.6	5.8
	195	4	1.1	11.6	4.2	0.8	2.6	1.6	0.4	0.8	0.4	5.0
	196	5	1.2	12.0	1.8	1.2	2.6	1.8	0.8	2.0	0.6	3.0

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 26. Mean clonal crown architecture data for the Upland biofuel plantation; Basal branch growth.

Prov. (S to N)	Clone	N	Number of branches	Number of branches by size class (m) <1	1-<1.5	1.5-<2	2-<2.5	2.5-<3	≥3
E Cen	011	5	2.6	0.6	0	0.2	0	0.4	1.4
MS	012	5	2.4	0.2	0.2	0	0.2	0	1.8
	014	4	2.8	0.2	0.4	0.2	0.4	0	1.6
	015	5	1.2	0.4	0.2	0.4	0	0.2	0
SW	182	5	3.0	0.4	0.8	0.8	0.6	0.2	0.2
VA	183	4	2.0	0	0.2	0.2	0.2	0.5	0.8
	184	5	1.0	0.4	0	0.2	0.2	0	0.2
	186	5	1.0	0	0.2	0.2	0	0.6	0
S Cen	072	5	1.8	0.4	0.6	0	0	0.4	0.4
WV	073	4	2.4	0.8	0.8	0.2	0	0	0.6
	075	5	2.0	0.4	0.2	0.2	0.6	0.2	0.4
	076	5	1.8	0	0.2	0	0.6	0.4	0.6
S Cen	051	5	1.6	0.8	0.6	0.2	0	0	0
IN	052	5	0.8	0	0	0.4	0	0.2	0.2
	054	5	1.8	0.4	0.8	0	0	0.4	0.2
	056	4	2.2	0.8	0	0.2	0.4	0	0.8
E Cen	202	3	3.5	1.2	0.5	0.5	0	0.8	0.5
KS	203	4	0.5	0.2	0.2	0	0	0	0
	204	5	1.8	0	0.2	0.2	0.2	0.4	0.8
	206	4	2.8	0	0.6	0.4	0.6	0.4	0.8
NE	111	5	2.2	0.4	0	0.2	1.0	0	0.6
PA	113	4	2.5	0.2	0.2	0	0.2	0.5	1.2
	114	5	1.8	0.4	0.2	0.4	0	0.2	0.6
	116	5	1.8	0.2	0.2	0.6	0	0	0.8
Cen	061	5	2.0	0.4	0	0	0.8	0.2	0.6
IA	062	5	2.0	0.6	0.8	0	0.2	0.2	0.2
	063	5	2.8	0.2	0.6	0	0	1.0	1.0
	065	5	1.8	0.6	0.2	0.2	0	0.2	0.6
S Cen	171	5	0.2	0	0	0.2	0	0	0
NY	173	5	3.2	0	1.4	0.2	0.4	0.6	0.6
	174	4	2.0	0.6	0.4	0.2	0.4	0.2	0.2
	175	5	0.6	0	0	0.2	0	0.2	0.2
Cen	081	5	0.2	0	0	0	0	0.2	0
WI	083	5	1.8	0.2	0	0	0.4	0.2	1.0
	084	5	1.8	0.4	0.8	0.2	0.2	0	0.2
	085	5	1.4	0	0.2	0.4	0.2	0.2	0.4
Cen	151	3	2.3	1.0	0.3	0.7	0	0	0.3
NH	153	5	1.6	1.0	0	0	0	0.4	0.2
	154	4	1.0	0	0.2	0	0	0	0.8
	157	5	1.2	0.2	0.2	0.2	0	0.2	0.4
S Cen	121	5	1.4	0.2	0	0.2	0.6	0.4	0
Ont	122	4	0.5	0	0	0	0	0.2	0.2
	125	2	2.0	0.3	0.3	0.3	0.3	0.3	0.3
	126	5	0.8	0	0.4	0.2	0.2	0	0

NW	161	4	3.0	0.2	1.0	0.2	0.2	0.8	0.5
VT	162	5	2.4	1.8	0.4	0	0	0	0.2
	163	3	1.3	0.3	0	0	0	0.3	0.7
	165	4	2.6	0.6	0.2	0.2	0.2	0.6	0.8
Cen	131	5	0.6	0.2	0.2	0	0.2	0	0
Ont	132	4	1.0	0	0.6	0.2	0	0.2	0
	133	4	1.6	0.4	0.6	0.2	0.2	0	0.2
	134	3	0.8	0	0.5	0	0	0	0.2
Significance[z]			ns	ns	ns	ns	*	ns	ns
5% t-test[y]							0.65		
Border Row Trees[x]									
S IL	043	4	1.8	0.2	0.2	0.2	0.4	0.4	0.4
	044	4	2.6	1.6	0.4	0.4	0	0	0.2
	045	4	3.0	0.4	1.0	0.2	0.2	0.4	0.8
	046	4	1.5	0.2	0.2	0.2	0.2	0.2	0.2
S Cen	192	5	9.8	7.8	0.6	0.2	0.2	0.6	0.4
MN	193	5	3.8	1.2	0.8	0.4	0.4	0.2	0.8
	195	4	1.6	0.2	0.2	0	0.4	0.2	0.6
	196	5	3.2	0	0	0	0.2	0.8	2.2

N = approximate number of clonal trees

[z]Significant at the 5% (*) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 27. Mean clonal crown architecture data for the Upland biofuel plantation; Number of secondary branches.

Prov. (S to N)	Clone	N	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	1-<1.5	1.5-<2	≥2
E Cen	011	5	128.2	60.6	24.8	21.2	14.2	5.2	1.4	0.8
MS	012	5	238.0	107.6	51.8	47.4	21.8	5.2	3.0	1.2
	014	4	128.2	58.2	23.8	23.2	14.4	6.6	2.0	0
	015	5	52.4	29.2	12.0	4.8	4.8	1.2	0.2	0.2
SW	182	5	99.8	42.4	19.6	20.4	13.0	3.6	0.6	0.2
VA	183	4	154.2	74.5	32.8	20.5	19.5	5.8	1.0	0.2
	184	5	67.8	24.2	12.2	11.6	11.8	5.8	1.4	0.8
	186	5	114.2	59.0	16.6	19.2	14.8	3.8	0.6	0.2
S Cen	072	5	124.6	59.8	26.0	21.4	13.4	3.2	0.8	0
WV	073	4	116.6	51.2	25.2	22.0	12.4	4.2	1.4	0.2
	075	5	110.8	56.8	27.4	17.4	6.6	2.2	0.4	0
	076	5	117.4	53.8	23.6	19.2	13.2	5.6	1.6	0.4
S Cen	051	5	145.2	57.2	32.4	26.0	18.8	8.4	1.2	1.2
IN	052	5	113.6	50.4	23.2	20.8	14.8	4.0	0.4	0
	054	5	151.6	64.8	25.6	26.4	22.4	9.4	2.2	0.8
	056	4	106.6	53.6	20.0	15.2	10.4	5.4	1.4	0.6
E Cen	202	3	98.5	53.2	14.5	12.0	13.0	3.2	1.5	1.0
KS	203	4	81.2	45.8	16.2	11.0	6.5	1.5	0.2	0
	204	5	94.6	51.2	17.8	14.0	8.8	2.2	0.4	0.2
	206	4	139.2	87.2	19.0	15.4	13.0	3.6	0.6	0.4
NE	111	5	74.0	37.2	11.0	11.0	10.4	3.6	0.2	0.6
PA	113	4	92.5	37.0	22.0	14.0	12.2	4.8	1.8	0.8
	114	5	74.4	47.6	9.6	8.0	6.8	2.2	0	0.2
	116	5	82.2	42.8	14.0	12.6	10.0	2.0	0.8	0
Cen	061	5	70.0	25.0	16.4	15.6	8.6	2.6	0.8	1.0
IA	062	5	118.2	54.0	21.4	26.4	13.2	2.6	0.2	0.4
	063	5	148.2	58.4	28.2	28.8	21.4	9.2	1.6	0.6
	065	5	88.6	42.8	18.6	15.6	8.0	2.8	0.8	0
S Cen	171	5	44.0	20.2	9.4	7.8	4.8	1.4	0.4	0
NY	173	5	61.6	32.0	11.2	7.4	7.0	2.8	1.0	0.2
	174	4	66.0	27.4	11.4	13.4	11.8	1.4	0.4	0.2
	175	5	97.6	49.8	17.2	17.2	9.0	3.6	0.8	0
Cen	081	5	62.2	29.2	8.4	11.0	9.0	3.6	0.8	0.2
WI	083	5	80.6	37.4	12.8	13.8	9.4	4.6	1.6	1.0
	084	5	121.4	62.8	24.4	16.6	11.4	5.2	0.4	0.6
	085	5	98.4	38.0	18.8	15.2	13.8	8.4	3.6	0.6
Cen	151	3	58.7	19.0	20.3	15.0	2.3	1.3	0.7	0
NH	153	5	80.6	33.0	19.2	14.2	11.6	2.4	0.2	0
	154	4	99.0	48.0	21.5	18.2	9.2	1.5	0	0.5
	157	5	59.6	19.2	14.2	15.2	9.2	1.6	0	0.2
S Cen	121	5	47.6	22.2	10.0	7.8	5.8	1.2	0.2	0.4
Ont	122	4	66.5	32.5	11.2	10.0	8.5	3.5	0.5	0.2
	125	2	81.3	45.3	15.3	10.7	6.0	3.7	0.3	0
	126	5	64.6	41.6	9.0	7.2	5.6	1.2	0	0

NW	161	4	153.0	68.8	30.2	26.2	21.8	5.2	0.8	0
VT	162	5	52.8	18.4	14.2	7.6	8.2	3.2	0.4	0.8
	163	3	94.0	46.0	13.0	15.3	15.7	3.0	0.7	0.3
	165	4	102.4	45.2	17.6	17.0	16.0	4.4	1.2	1.0
Cen	131	5	43.4	24.8	9.0	5.0	3.4	0.8	0.2	0.2
Ont	132	4	58.4	39.0	8.4	7.0	3.4	0.6	0	0
	133	4	60.2	28.0	13.0	12.0	5.6	1.6	0	0
	134	3	45.0	20.8	10.2	5.8	4.8	2.2	0.8	0.5
Significance[z]			**	**	**	**	**	*	**	ns
5% t-test[y]			59.66	34.93	13.14	12.45	9.12	4.08	1.50	
1% t-test			78.86	46.17	17.36	16.46	12.06		1.98	
Border Row Trees[x]										
S IL	043	4	149.6	89.4	20.0	12.2	17.6	7.8	2.0	0.6
	044	4	160.2	83.6	24.8	22.2	17.6	7.4	2.8	1.8
	045	4	128.2	63.8	28.4	18.0	10.8	4.2	2.2	0.8
	046	4	214.2	100.5	34.5	37.0	30.0	8.8	2.2	1.2
S Cen	192	5	195.6	112.6	36.0	23.6	18.0	4.4	0.6	0.4
MN	193	5	114.6	56.6	18.0	17.8	14.6	6.2	1.0	0.4
	195	4	86.8	41.6	14.6	12.6	11.6	4.6	1.0	0.8
	196	5	118.2	46.4	21.2	21.2	18.8	7.0	2.8	0.8

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 28. Mean clonal crown architecture data for the Upland biofuel plantation; Number of tertiary branches.

Prov. (S to N)	Clone	N	Number of branches	Number of branches by size class (m) <0.1	0.1-<0.25	0.25-<0.5	0.5-<1	≥1
E Cen	011	5	33.6	19.0	7.0	6.4	0.8	0.4
MS	012	5	73.0	36.8	17.2	13.4	5.0	0.6
	014	4	46.6	30.0	6.4	6.4	3.0	0.8
	015	5	14.0	9.2	3.0	1.2	0.6	0
SW	182	5	14.8	9.6	3.2	1.4	0.6	0
VA	183	4	42.5	27.5	9.8	3.0	2.2	0
	184	5	17.0	10.4	3.0	1.8	1.8	0
	186	5	19.6	10.8	3.8	1.8	2.2	1.0
S Cen	072	5	23.0	17.4	3.0	2.2	0.4	0
WV	073	4	19.6	8.2	7.2	3.4	0.4	0.4
	075	5	16.6	14.0	2.2	0.4	0	0
	076	5	16.0	11.0	2.4	2.4	0.2	0
S Cen	051	5	51.6	24.2	13.2	8.0	5.8	0.4
IN	052	5	8.4	6.0	1.6	0.8	0	0.0
	054	5	63.4	37.4	12.0	9.4	4.0	0.6
	056	4	35.6	26.2	5.0	2.4	1.8	0.2
E Cen	202	3	31.5	19.0	5.8	3.5	3.0	0.2
KS	203	4	3.5	2.0	0.5	0.2	0.8	0
	204	5	9.2	6.0	1.6	1.4	0.2	0
	206	4	41.0	32.2	5.8	2.4	0.6	0
NE	111	5	11.2	6.0	1.0	2.2	1.6	0.4
PA	113	4	38.8	19.0	10.8	7.0	1.8	0.2
	114	5	8.4	5.6	1.6	0.4	0.6	0.2
	116	5	20.8	14.8	2.8	2.6	0.4	0.2
Cen	061	5	27.4	11.4	5.8	7.0	2.8	0.4
IA	062	5	21.0	14.4	2.4	2.2	1.2	0.8
	063	5	44.4	26.0	9.2	5.4	3.0	0.8
	065	5	9.8	6.2	2.2	1.4	0	0
S Cen	171	5	13.4	8.2	2.8	1.2	1.2	0
NY	173	5	24.0	17.2	3.2	2.2	1.0	0.4
	174	4	22.0	13.6	4.6	2.2	1.6	0
	175	5	8.6	5.6	1.8	1.2	0	0
Cen	081	5	8.4	3.8	1.4	1.6	1.4	0.2
WI	083	5	33.0	17.8	7.8	4.2	2.4	0.8
	084	5	27.6	14.4	5.8	4.0	2.6	0.8
	085	5	34.2	17.4	9.0	5.2	2.4	0.2
Cen	151	3	21.3	12.0	5.7	2.3	1.0	0.3
NH	153	5	14.8	8.4	3.2	1.6	1.4	0.2
	154	4	26.2	15.0	5.8	4.8	0.8	0
	157	5	22.2	9.4	5.6	5.2	2.0	0
S Cen	121	5	5.6	2.4	1.4	1.6	0.2	0
Ont	122	4	11.8	7.5	2.0	1.8	0.5	0
	125	2	4.7	2.7	2.0	0	0	0
	126	5	4.0	3.2	0.8	0	0	0

NW	161	4	32.8	23.5	4.0	4.0	1.2	0
VT	162	5	7.8	6.4	0.8	0.2	0.2	0.2
	163	3	21.0	15.7	1.7	1.3	2.3	0
	165	4	59.0	36.6	10.4	7.2	3.2	1.6
Cen	131	5	12.0	9.2	1.8	0.6	0.4	0
Ont	132	4	5.2	4.2	0.6	0.4	0	0
	133	4	13.2	7.4	5.2	0.6	0	0
	134	3	6.2	3.5	1.8	0.5	0.5	0
Significance[z]			**	**	**	**	*	ns
5% t-test[y]			30.33	19.41	7.02	4.88	3.06	
1% t-test			40.09	25.65	9.27	6.45		
Border Row Trees[x]								
S IL	043	4	36.4	27.0	5.0	2.4	1.8	0.2
	044	4	74.2	46.2	13.0	9.2	4.8	1.0
	045	4	37.8	23.8	7.6	4.4	1.2	0.8
	046	4	98.2	68.0	14.2	8.2	5.8	2.0
S Cen	192	5	51.6	41.2	5.2	3.0	2.0	0.2
MN	193	5	25.8	21.0	2.6	1.4	0.6	0.2
	195	4	25.4	17.8	2.0	3.8	1.6	0.2
	196	5	39.4	18.6	8.4	7.4	3.2	1.8

N = approximate number of clonal trees

[z]Significant at the 5% (*) or 1% (**) level or nonsignificant (ns) according to the F-test.

[y]t-test for paired comparisons.

[x]Border row trees were excluded from statistical analysis.

Table 29. Phenotypic (upper) and genetic (lower) correlation values (r) among branch architecture characteristics for the Carbondale lowland plantation.

	Total number of 1° branches	Number of 1° branches formed on wood from: The top 1m	1993	1992	1991
Number of:					
Basal branches	0.016	0.808**	0.301	-0.316	-0.142
	0.035	0.801**	0.311	-0.293	-0.111
Secondary branches	0.696**	0.932**	0.811**	0.508	0.311
	0.624*	0.901**	0.750**	0.436	0.246
Tertiary branches	0.253	0.618*	0.405	0.069	0.022
	0.187	0.596*	0.354	-0.002	-0.049
Length of wood formed during:					
1993	-0.017	-0.012	0.168	-0.314	0.104
	-0.051	-0.009	0.123	-0.342	0.115
1992	0.487	0.108	0.382	0.656*	0.068
	0.422	0.107	0.322	0.594*	0.014

Lowland = 12, 35, and 143 df for provenance, clone within provenance, and error, respectively.

Table 30. Phenotypic (upper) and genetic (lower) correlation values (r) among branch architecture characteristics for the Carbondale upland plantation.

	Total number of 1° branches	Number of 1° branches formed on wood from: The top 1 m	1993	1992	1991
Number of:					
Basal branches	0.540*	0.154	0.517	0.555*	0.116
	0.497	0.137	0.484	0.566*	0.030
Secondary branches	0.740**	0.488	0.763**	0.376	0.421
	0.708**	0.451	0.762**	0.358	0.323
Tertiary branches	0.666**	0.334	0.696**	0.399	0.295
	0.689**	0.316	0.721**	0.442	0.272
Length of wood formed during:					
1993	0.586*	0.374	0.715**	0.313	0.046
	0.546*	0.311	0.641*	0.346	0.050
1992	-0.023	-0.336	-0.259	0.230	0.315
	-0.099	-0.357	-0.305	0.052	0.338

Upland = 12, 39, and 172 df for provenance, clone within provenance, and error, respectively.

Table 31. Phenotypic (upper) and genetic (lower) correlation values (r) among branch architecture characteristics for the Carbondale lowland plantation.

	Total number of 1° branches	Number of 1° branches formed on wood from: The top 1 m	1993	1992	1991
Number of:					
Nodes in the top 1m	-0.533*	-0.574*	-0.512	-0.498	-0.344
	-0.552*	-0.575*	-0.510	-0.532*	-0.386
Total 1° branches		0.002	0.941**	0.958**	0.656*
		-0.066	0.803**	0.754**	0.564*
1° branches in the top 1m			0.533*	0.262	0.100
			0.440	0.225	0.085
Number of 1° branches formed on wood from:					
1993				0.820**	0.410
				0.734**	0.398
1992					0.711**
					0.616*

Lowland = 12, 35, and 143 df for provenance, clone within provenance, and error, respectively.

Table 32. Phenotypic (upper) and genetic (lower) correlation values (r) among branch architecture characteristics for the Carbondale upland plantation.

	Total number of 1° branches	Number of 1° branches formed on wood from: The top 1m	1993	1992	1991
Number of:					
Nodes in the top 1m	0.168 0.139	-0.070 -0.062	0.026 0.000	0.365 0.335	0.172 0.161
Total 1° branches		0.720** 0.642*	0.902** 0.742**	0.807** 0.526	0.580* 0.433
1° branches in the top 1m			0.776** 0.685**	0.394 0.397	0.297 0.235
Number of 1° branches formed on wood from:					
1993				0.562* 0.468	0.233 0.191
1992					0.519 0.473

Upland = 12, 39, and 172 df for provenance, clone within provenance, and error, respectively.

Table 33. Phenotypic (upper) and genetic (lower) correlation values (r) among branch architecture characteristics for the Carbondale lowland plantation.

	Number of			Length of wood formed during:	
	Basal branches	Secondary branches	Tertiary branches	1993	1992
Number of:					
Nodes in the top 1m	0.020 0.010	0.247 0.283	0.334 0.354	-0.202 -0.188	0.100 0.111
Basal branches		0.306 0.326	0.269 0.289	0.000 0.012	-0.076 -0.059
Secondary branches			0.698** 0.620*	-0.143 -0.160	0.389 0.325
Tertiary branches				-0.278 -0.279	0.335 0.277
Length of wood formed during:					
1993					-0.062 -0.094

Lowland = 12, 35, and 143 df for provenance, clone within provenance, and error, respectively.

Table 34. Phenotypic (upper) and genetic (lower) correlation values (r) among branch architecture characteristics for the Carbondale upland plantation.

	Number of			Length of wood formed during:	
	Basal branches	Secondary branches	Tertiary branches	1993	1992
Number of:					
Nodes in the top 1m	0.309 0.326	0.218 0.219	0.162 0.199	-0.334 -0.333	0.075 0.064
Basal branches		0.605* 0.450	0.557* 0.500	0.380 0.404	-0.019 0.080
Secondary branches			0.819** 0.719**	0.530 0.515	-0.140 -0.122
Tertiary branches				0.537* 0.548*	-0.235 -0.248
Length of wood formed during:					
1993					0.208 0.234

Upland = 12, 39, and 172 df for provenance, clone within provenance, and error, respectively.

Table 35. Correlations between provenance environmental factors and branch architecture on the Carbondale lowland plantation.

Provenance environmental factor	Total number of 1° branches	Number of 1° branches formed on wood from: The top 1m	1993	1992	1991
Latitude	-0.302	-0.082	-0.284	-0.243	-0.147
Longitude	0.118	0.065	0.096	0.130	0.054
Elevation	-0.125	-0.016	-0.039	-0.142	-0.148
Mean annual temperature	0.308	0.122	0.284	0.254	0.143
Mean January temperature	0.282	0.118	0.271	0.216	0.141
Mean July temperature	0.269	0.072	0.240	0.235	0.109
Mean annual precipitation	0.333	0.122	0.288	0.264	0.253
Mean number of frost-free days	0.338	0.112	0.305	0.279	0.166
Mean number of heating-degree days[z]	-0.008	-0.109	-0.278	-0.242	-0.130
Mean number of cooling-degree days[z]	0.316	0.146	0.268	0.274	0.182

[z]Heating and cooling degree days relate to the number of degree days homes would need to be heated or air conditioned in a given region.

Table 36. Correlations between provenance environmental factors and branch architecture on the Carbondale lowland plantation.

Provenance environmental factor	Number of Nodes in the top 1m	Basal branches	Secondary branches	Tertiary branches
Latitude	0.032	-0.023	-0.310	-0.302
Longitude	0.050	-0.068	0.168	0.187
Elevation	0.035	0.070	-0.110	-0.184
Mean annual temperature	0.014	0.035	0.337	0.333
Mean January temperature	-0.002	0.034	0.287	0.275
Mean July temperature	0.082	-0.004	0.314	0.320
Mean annual precipitation	-0.085	-0.007	0.304	0.319
Mean number of frost-free days	0.006	0.007	0.363	0.363
Mean number of heating-degree days[z]	-0.008	-0.042	-0.322	-0.316
Mean number of cooling-degree days[z]	0.038	0.008	0.356	0.366

[z]Heating and cooling degree days relate to the number of degree days homes would need to be heated or air conditioned in a given region.

Table 37. Correlations between provenance environmental factors and branch architecture on the Carbondale upland plantation.

Provenance environmental factor	Total number of 1° branches	Number of 1° branches formed on wood from: The top 1m	1993	1992	1991
Latitude	-0.245	-0.075	-0.247	-0.137	-0.128
Longitude	0.285	0.188	0.201	0.165	0.263
Elevation	-0.046	-0.047	-0.084	-0.033	0.049
Mean annual temperature	0.298	0.132	0.308	0.175	0.126
Mean January temperature	0.192	0.069	0.232	0.100	0.047
Mean July temperature	0.350	0.146	0.321	0.226	0.187
Mean annual precipitation	0.216	0.032	0.218	0.146	0.066
Mean number of frost-free days	0.331	0.078	0.289	0.215	0.209
Mean number of heating-degree days[z]	-0.264	-0.107	-0.282	-0.152	-0.108
Mean number of cooling-degree days[z]	0.369	0.185	0.355	0.232	0.166

[z]Heating and cooling degree days relate to the number of degree days homes would need to be heated or air conditioned in a given region.

Table 38. Correlations between provenance environmental factors and branch architecture on the Carbondale upland plantation.

Provenance environmental factor	Number of Nodes in the top 1m	Basal branches	Secondary branches	Tertiary branches
Latitude	-0.180	-0.003	-0.340	-0.229
Longitude	0.039	0.109	0.259	0.170
Elevation	0.039	0.038	-0.004	-0.162
Mean annual temperature	0.188	0.011	0.354	0.258
Mean January temperature	0.190	-0.055	0.254	0.171
Mean July temperature	0.164	0.077	0.378	0.300
Mean annual precipitation	0.116	-0.002	0.263	0.247
Mean number of frost-free days	0.166	0.043	0.394	0.310
Mean number of heating-degree days[z]	-0.190	0.003	-0.342	-0.240
Mean number of cooling-degree days[z]	0.167	0.050	0.359	0.302

[z]Heating and cooling degree days relate to the number of degree days homes would need to be heated or air conditioned in a given region.

LITERATURE CITED

Ashby, W.C., D.F. Bresnan, C.A. Huetteman, J.E. Preece, and P.L. Roth. 1991. Chilling and bud break in silver maple. J. Environ. Hort. 9:1-4.

Ashby, W.C., D.F. Bresnan, R.K. Kjelgren, P.L. Roth, J.E. Preece, and C.A. Huetteman. 1993. Coppice Growth and water relations of silver maple. Biomass and Bioenergy 5:317-323.

Ashby, W.C., J.E. Preece, C.A. Huetteman, D.F. Bresnan, and P.L. Roth. 1987. Silver maple tree improvement for biomass production. In: Proceedings of the Fifth North Central Tree Improvement Conference. Sponsored by: North Central Tree Improvement Association. pp. 6-23.

Cody, R. P. and J. K. Smith. 1991. Applied statistics and the SAS programming language. 3rd Edition 1991. Elsevier Science Publishing Co., Inc. New York, New York.

Ellis, D. D. and B. H. McCown. 1988. The potential of biotechnology in the biomass production program. Oak Ridge National Laboratory, Oak Ridge, TN. ORNL/M-606, Environmental Sciences Division Pub. No. 3172. 60 p.

Fowells, H. A., Compiler. 1965. Silvics of forest trees of the United States. USDA For. Serv. Agric. Hdbk. 271. 762 pp.

Gabriel, W.J. 1990. Acer saccharinum L. Silver maple pp. 70-77. In: Burns, R.M. and B.H. Honkala (Tech. Coord.) Silvics of North America Vol.2, Hardwoods. USDA Forest Service. Agricultural Handbook 645. Washington, D.C.

Geyer, W. A. 1978. Spacing and cutting cycle influence on short rotation silver maple yield. Tree Plant. Notes 29:209-215.

Kopp, R. K., W. A. Geyer, and W. R. Lovett. 1988. Silver maple seed sources for increased biomass production. Northern J. Applied For. 5: 180-184.

Libby, W. J. 1983. The clonal option. As, Norway: Norwegian Forest Research Institute. 32 pp.

Libby, W. J. 1974. The use of vegetative propagules in forest tree improvement. New Zealand Journal of Forest Science 4:440-447.

National Climatic Center. 1983. Climate Normals for the U.S. (Base: 1951-1980), Bale Research Co., Detroit, MI.

Meridian Corporation. n.d. (about 1986). Short-rotation intensive culture of woody crops for energy, principles and

practices for the Great Lakes Region. Falls Church, VA. 85 p. plus appendices.

Preece, J.E., C.A. Huetteman, W.C. Ashby, and P.L. Roth. 1991a. Micro- and cutting propagation of silver maple. I. Results with adult and juvenile propagules. J. Amer. Soc. Hort. Sci. 116:142-148.

Preece, J.E., C.A. Huetteman, W.C. Ashby, and P.L. Roth. 1991b. Micro- and cutting propagation of silver maple. II. Genotype and provenance affect performance. J. Amer. Soc. Hort. Sci. 116: 149-155.

Ranney, J. W., A. R. Ehrenshaft, P. A. Layton, W. A. McNabb, and L. L. Wright. 1988. Short rotation woody crops program annual progress report for 1987. Oak Ridge National Laboratory, Oak Ridge, TN. ORNL-6440, Environmental Sciences Division Pub. No. 3030. 99 p.

Ranney, J. W., L. L. Wright, and P. A. Layton. 1987. Hardwood energy crops: the technology of intensive culture. J. For. 85: 17-28.

Roth, W. B., I. M. Cull, R. A. Buchanan, and M. O. Bagby. 1982. Whole plants as renewable energy resources: Checklist of 508 species analyzed for hydrocarbon, oil, polyphenol, and protein. Trans. Ill. State Acad. Sci. 75:217-231.

Ruffner, J.A. and F.E. Blair. 1984. The Weather Almanac. Gale Research Co. Detroit, MI.

SAS Institute, Inc. 1990. SAS/STAT User's Guide, Version 6, Fourth Edition. Cary, NC.

Sinclair, W.A., H.H. Lyon, and W.T. Johnson. 1987. Diseases of trees and shrubs. Cornell University Press, Ithaca. 574 pp.

Van Sambeek, J.W., J.E. Preece, C.A. Huetteman, and P.L. Roth. 1995. Use of plastic films for weed control during field establishment of micropropagated hardwoods. In: Proceedings of the Tenth Central Hardwood Forest Conference. pp. 496-506.

LIST OF PROJECT PUBLICATIONS

Ashby, W.C., J.E. Preece, A.G. Hilen, C.A. Huetteman, and P.L. Roth. 1987. Silver maple tree improvement for biomass production. 5th North Central Tree Improvement Conference. (Abstr.)

Ashby, W.C., J.E. Preece, C.A. Huetteman, D.F. Bresnan, and P.L. Roth. 1987. Silver maple tree improvement for biomass production. In: Proceedings of the Fifth North Central Tree Improvement Conference. Sponsored by: North Central Tree Improvement Association. pp. 6-23.

Preece, J.E., C.A. Huetteman, C.H. Puello, and M.C. Neuman, 1987. The influence of thidiazuron on in vitro culture of woody plants. HortScience. 22(5): 259. (Abstr.)

Bresnan, D.F., W.C. Ashby, J.E. Preece, P.L. Roth, and C.A. Huetteman. 1988. Geographic variation in silver maple. Transactions of the Illinois State Academy of Science, Supplement to Vol. 81: 10. (Abstr.)

Preece, J.E., C.A. Huetteman, W.C. Ashby, D.F. Bresnan, and P.L. Roth. 1988. Provenance tests for biomass production using micropropagated clonal silver maple. HortScience 23(3): 603. (Abstr.)

Bresnan, D.F., W.C. Ashby, J.E. Preece, C.A. Huetteman, and P.L. Roth. 1989. First-year seed source variation in silver maple. Abstracts of Kansas Academy of Science. 8:5 (Abstr.)

Preece, J.E., C.A. Huetteman, W.C. Ashby, and P.L. Roth. 1989. Site of origin affects micropropagation and rooting of cuttings of silver maple (Acer saccharinum L.). ASHS Annual Meeting/Program and Abstracts. No. 196 (Abstr.)

Preece, J.E. and E.G. Sutter. 1990. Acclimatization of micropropagated plants to the greenhouse and field. In Vitro cellular & developmental biology 26(3) Part II: 66. (Abstr.)

Preece, J.E. and E.G. Sutter. 1990. Acclimatization of micropropagated plants to the greenhouse and field. In: Debergh, P. and R.H. Zimmerman (eds.). Micropropagation. Kluwer, Dordrecht, The Netherlands. pp 71-93.

Preece, J.E., C.A. Huetteman, W.C. Ashby, and P.L. Roth. 1990. Research to production: laboratory scale-up with micropropagated Acer saccharinum L. HortScience 25(9): 317 (Abstr.)

Ashby, W.C., D.F. Bresnan, C.A. Huetteman, J.E. Preece, and P.L. Roth. 1991. Chilling and bud break in silver maple. J. Environ. Hort. 9(1):1-4.

Ashby, W.C., D.F. Bresnan, J.E. Preece, P.L. Roth, and C.A. Huetteman. 1991. Provenances and phenology in silver maple. 1991 Southern Biomass Conference Program and Abstracts. p. VI.A.2. (Abstr.)

Huetteman, C.A., J.E. Preece, W.C. Ashby, and P.L. Roth. 1991. Research to production: rooting and acclimatization strategies for micropropagated Acer saccharinum L. HortScience 26(6):480. (Abstr.).

Preece, J.E., C.A. Huetteman, W.C. Ashby, and P.L. Roth. 1991. Micro- and cutting propagation of silver maple. I. Results with adult and juvenile propagules. J. Amer. Soc. Hort. Sci. 116(1): 142-148.

Preece, J.E., C.A. Huetteman, W.C. Ashby, and P.L. Roth. 1991. Micro- and cutting propagation of silver maple. II. Genotype and provenance affect performance. J. Amer. Soc. Hort. Sci. 116(1): 149-155.

Ashby, W.C., D.F. Bresnan, P.L. Roth, J.E. Preece, and C.A. Huetteman. 1992. Nursery establishment, phenology and growth of silver maple related to provenance. Biomass and Bioenergy. 3:1-7

Huetteman, C.A., J.E. Preece, W.C. Ashby, and P.L. Roth. 1992. First-year field performance of 60 micropropagated silver maple clones in southern Illinois. HortScience 26(6):228. (Abstr.).

Huetteman, C.A. and J.E. Preece. 1993. Thidiazuron: A potent cytokinin for woody plant tissue culture. Plant Cell Tissue and Organ Culture. 33:105-119.

Preece, J.E., C.A. Huetteman, W.C. Ashby, and P.L. Roth. 1993. Clonal Propagation of Biofuel Trees with Emphasis on Silver Maple. Comb. Proc. Intl. Plant Prop. Soc. 42:483-487.

Ashby, W.C., D.F. Bresnan, R.K. Kjelgren, P.L. Roth, J.E. Preece, and C.A. Huetteman. 1993. Coppice growth and water relations of silver maple. Biomass and Bioenergy 5:317-323.

Huetteman, C.A. and J.E. Preece. 1993. Simple improvements for increased efficiency of research micropropagation laboratories. HortScience 28(5):413. (Abstr.).

Preece, J. 1993. Studies of DNA polymorphism in silver maple (Acer saccharinum L.). Poster Directory, C.P.B.R. p. 23.

Preece, J.E., C.A. Huetteman, W.C. Ashby, P.L. Roth, and R.G. Adams. 1994. Genotypic and phenotypic field growth correlations of micropropagated silver maple. HortScience 29(5):030. (Abstr.).

Freire, A.V., J.E. Preece, and D.A. Lightfoot. 1994. DNA

polymorphism in silver maple (Acer saccharinum L.). HortScience 29(5):665. (Abstr.).

Van Sambeek, J.W., J.E. Preece, C.A. Huetteman, and P.L. Roth. 1995. Use of plastic films for weed control during field establishment of micropropagated hardwoods. In: Proceedings of the Tenth Central Hardwood Forest Conference. pp. 496-506.

Preece, J.E., C.A. Huetteman, R.G. Adams, W.C. Ashby and P.L. Roth. 1995. Branching architecture of 3-year-old plantation-grown micropropagated silver maple. HortScience 30(4):862. (Abstr.).

APPENDIX

Appendix Table 1. Environmental factors of the 15 silver maple provenances in the biofuel plantations.

Provenance	Latitude	Longitude	Elevation (m)	Mean Temperature (°C) Annual	January	July
E Cen MS	33.27	88.50	110.34	16.9	6.1	26.7
SW VA	36.54	82.47	290.00	11.4	0.4	21.7
S Cen WV	37.23	81.06	752.55	11.2	-0.3	21.3
S IL	37.43	89.12	126.80	13.4	-0.2	25.6
S Cen IN	38.50	86.06	164.29	12.1	-1.6	24.4
NE KS	39.12	96.35	324.61	13.0	-2.7	26.6
NE PA	41.49	75.53	475.49	6.9	-6.4	19.6
Cen IA	42.02	93.39	281.02	9.0	-8.3	23.3
S Cen NY	42.10	74.04	291.69	8.3	-4.7	21.0
Cen WI	43.04	89.22	262.13	7.3	-9.1	21.4
Cen NH	43.21	71.40	81.69	7.4	-6.7	18.2
S Cen Ont	43.21	82.45	178.61	9.2	-4.7	22.2
NW VT	44.28	73.14	34.14	6.7	-8.6	20.9
S Cen MN	44.43	93.06	289.56	6.6	-12.2	21.9
Cen Ont	46.32	84.20	219.76	4.3	-10.4	17.5

Provenance	Mean Annual Precipitation (cm)	Frost-free days	Heating degree days[z]	Cooling degree days[z]
E Cen MS	142.0	241	2783	1883
SW VA	95.1	187	5074	576
S Cen WV	97.6	187	5217	525
S IL	108.2	233	4563	1395
S Cen IN	108.5	193	5166	1096
NE KS	83.5	200	5119	1525
NE PA	107.0	174	7697	238
S Cen IA	80.5	183	6874	792
S Cen NY	84.1	154	6927	411
Cen WI	78.3	177	7642	467
Cen NH	92.8	142	7482	353
S Cen Ont	77.8	181	6611	621
NW VT	85.6	148	7953	379
S Cen MN	77.9	166	8235	535
Cen Ont	85.0	138	9305	131

[z]Heating and cooling degree days relate to number of degree days homes would need to be heated or air conditioned in a given region.

Data compiled from: Ruffner and Blair (1984) and National Climatic Center (1983).

Appendix Table 2. Distribution of micropropagated plantlets, Calendar dates 1987 - 1995.

Plantation	State	Personnel	Dates	Number
USDA Forest Service	Illinois	Jerry Van Sambeek	11-May-87	150
KSU	Kansas	Wayne Geyer	21-Oct-88 28-Jun-89	240 65
Herbicide Study	Illinois	Maple Biomass	17-Aug-88	720
SIUC Forestry	Illinois	Dave Shenaut	18-Feb-89	360
Amana Project	Iowa	Rick Hall	2-May-89	52
Strip Mine Reclamation	Illinois	Clark Ashby	spring 1989	72
Biomass Test Site	Minnesota	Maple Biomass	1-Jun-89 29-May-90 3-Jun-91	845
Chilling Study	Illinois	Maple Biomass	3-Oct-89	666
Clonal Bank	Illinois	Maple Biomass	11-May-90	1112
Lining out Nursery	Illinois	Maple Biomass	Aug-90	2726 to UP/LW91
Herbicide Pot Study	Illinois	Maple Biomass	19-Mar-91	12
Lining out Nursery	Minnesota	Univ. of Minn.	3-Jun-91	1225 to MN92
Biomass Test Site	Illinois	Maple Biomass		
	Upland		21-May-91	1758
	Lowland		3-Jun-91	1334
USDA Forest Service	Wisconsin	Dan Netzger Ed Hansen	14-May-91	366
University of Georgia	Georgia	Kimberly Krahl	12-Aug-91	28

Appendix Table 2 (continued).

Plantation	State	Personnel	Dates	Number
Lining out Nursery	Illinois	Maple Biomass	1-Oct-91	1331 to KS92
USDA Forest Service	Wisconsin	Dan Netzger Ed Hansen	8-Mar-92 5-May-92	72 108
Biomass Test Site	Kansas	Maple Biomass	18-May-92	1694
Weed Control I	Illinois	Maple Biomass	Jun-92	90
Biomass Test Site	Minnesota	Maple Biomass	22-Jun-92 Oct-92	1737 60
Weed Control II	Illinois	Maple Biomass	13-Sept-93	105
USDA Forest Service	Wisconsin	Dan Netzger Ed Hansen	3-Mar-93	200
Intensive Study	Illinois	Maple Biomass	Jun-94	1550
Weed Control III	Illinois USFS NCFES	Maple Biomass William Heckrodt	20-June-95	720
TOTAL TREES DISTRIBUTED FOR FIELD PLANTING				21793

Appendix Table 3. Growth measurements and data collection protocols for nonharvested stems.

Basal caliper; measured up to several times yearly.

Caliper is measured at a point 10 cm above ground level. If there is any obstruction, the measurement is made at the nearest clear point above the 10 cm mark and a note is made to denote an altered diameter point. If more than one stem is available, the stem with the tallest height is designated as the main stem.

Crown; measured at the end of the second growing season.

The maximum possible volume of crown outreach filling an imaginary cube, centered on the stem with sides parallel and perpendicular to the mulch strip. May be collected either in leaf or when leafless.

1. Height-

The height of the tallest live bud of the tree is measured in a direct line straight up from the ground.

2. Crown start (in leaf)-

This height is measured from the ground straight up to the point on the stem at which leaves begin to hide the main stem (leaves either from the main stem or from branches). This measurement of the beginning of the crown is somewhat subjective, but should be consistent with the same observer.

3. Width of crown (parallel)-

The distance is measured between the furthest points (leaf or stem tip) in the plane parallel to the plastic mulch (E-W). This is not a measurement of the farthest distance between points (along a diagonal path) but the farthest reach in the E-W direction parallel to the mulch strip.

4. Depth of crown (perpendicular)-

The distance is measured between the furthest points (leaf or stem tip) extension in the plane perpendicular to the plastic mulch (N-S). This, also, is not a measurement of the farthest distance between points.

Date of bud break; collected weekly until completed as the # of days past 31 March.

This measurement is defined as the day when new stems (emerging leaf tissues) elongate to greater than 1 cm. Each tree is quickly examined on a weekly basis to determine whether any new stems are elongating.

Date of bud set; collected weekly until completed as the # of days past 31 August.

Because of the large amount of time required to examine a majority of the terminal buds for each tree, this measurement is more precisely defined as the day when new leaves are no longer produced and no longer elongate.

Each tree is quickly examined on a weekly basis to determine whether new leaves are actively growing. This can be most easily distinguished by:

1. light reddish-green color on very small leaves at the terminal bud.
2. clusters of small leaves at the terminal bud.
3. light green color of the stem below the terminal bud.

The presence of active growth anywhere on the tree is noted on the data sheets for each tree and bud set is considered as following the last date at which new growth was active. Frequently, trees remain with no new leaves being formed for several weeks and then resume growth late in the season. The last mark designating activity on the data sheets precedes the date of bud set.

Hard bud set is generally evidenced by reddish color of the bud scales and often a single small leaf (rather than a pair) is present at the terminal bud.

Date of leaf fall; collected weekly until completed as the # of days past 31 August.

The date at which the tree becomes leafless requires considerably less time in the field than does date of bud set and has been shown to be highly correlated with bud set. For practical purposes, a "leafless" tree is defined as having less than 10 leaves on the entire tree. Southern-source clones may retain their leaves well past a killing frost and may never actually go leafless. In this case, the date of the killing frost will be considered as the terminal date.

Diameter breast height (dbh); collected in years four and five.

DBH is a caliper measurement collected at a point 4.5 feet above ground level on the single largest main stem.

Height; measured several times yearly.

The height of the tallest live bud of the tree is measured in a direct line straight up from the ground.

Stem form; recorded at the end of the second growing season.

The current stem form classification will consist of 5 separate items.

1. Main stems-

The number of main stems will be counted as 1,2,3,4,5 or > 5.

2. Stem location-

The point at which the terminal stem or stems separate from the main stem if forking has occurred. This can happen from the bottom (B), middle (M) or top (T) portion of the main stem, or a combination of these locations.

3. Lateral branching-

The location of lateral branching is determined as originating from the bottom, middle or top portions (B,M,T) of the main stem, or a combination of these locations.

4. Basal branches-

Basal branches originate less than 10 cm from the ground level and are classified as strong (S) greater than 1/2 of the total height or weak (W), less than 1/2 the total height.

Appendix Table 4. Growth measurements and data collection protocols for harvested stems.

Stem harvest of the five coppice blocks required cutting the trees at approximately 10 cm from ground level with a chain saw during the winter. The cut trees were generally removed from each site to collect data.

Basal caliper;

Mean stem caliper was calculated at the cut stump level. Minimum and maximum measurements were made for all trees as the trunks are not round due to basal branching.

Coppice stem growth;

Coppice stems that result from tree harvest are counted and classified by basal caliper as being <10, 10-20, and >20 mm. All stems were measured 10 cm above ground level and characterized as having either horizontal or vertical orientation. Horizontal stems were those having the terminal bud a greater distance horizontally from the stem base than vertically from the ground-line. Horizontal stems are recorded in <20 and >20 mm basal caliper size categories.

Stem disks;

Cross section disks were removed from the main stem of 1 tree in each clonal plot. Disks approximately 2.5 cm thick were cut from the single-most dominant stem using two pruning saws clamped together. Disk selection begins with a clean basal cut and moves toward the stem apex at 1 m intervals. The disks were placed in plastic bags in the field and then stored in a freezer until measured. These measurements include the determination of specific gravity (using fresh volume displacement) bark and stem fresh and dry weights, bark and stem relationships, and stem caliper for stem taper estimates.

Weight;

All trees from the three-tree reps were individually chipped and collected in plastic mesh bags (onion bags). They were stored temporarily in a greenhouse prior to being placed in a drying oven at 70°C for three days prior to weighing.

Alternately, trees are harvested during the dormant season and weighed while they are whole and green. A subsample is oven dried to determine a multiplier to calculate the dry weight of all trees.

Tree architecture;

Branching growth was collected on the center tree in each clonal plot or from the tree with east and west neighbors if the plot had only 2 clonal trees.

(1) 1 m Sylleptic Branching

Recent-season branching outgrowth was characterized by measuring the sylleptic branches in the top 1 m of the tallest

main stem. All branches were counted and categorized by length as <10 cm, ≥10 to <25 cm, ≥25 cm, from the point of attachment to the main stem to the terminal bud on the branch. All nodes were counted in the top 1 meter of the main stem.

(2) Branching Habit

All stems and branches were counted and categorized according to length as <10 cm, ≥10 to <25 cm, ≥25 to <50 cm, ≥50 to 1 m, ... (in 0.5 m increments). The single most dominant main stem (M1) was measured in total length. A second large stem (M2) could be measured for total length if it is approximately equal in size to the designated main stem and it originates above the cut stump but less than 2 m from ground level. All other branches were categorized by length and ordered as primary branches (first order branches off the main stem), secondary (branches from the primary), and tertiary (branches from the secondary). All basal stems originating from below the cut stump were designated as primary basal branches.

Additional Supportive Activities.

A project titled "Plastic mulches and their effects on microclimate changes during establishment of hardwoods" is currently being funded by the USFS NCFES and the Community Foundation for the Fox Valley Region (William Heckrodt in Wisconsin). This weed control study was established in June 1995 at the NCFES Tree Improvement Center in Carbondale IL. The focus is to evaluate plastic mulch efficacy and document soil and air microclimate changes during plantation establishment of silver maple and poplar in southern Illinois. It consists of 4 silver maple and 3 poplar clones planted in a split-split plot design. The main plots are either tilled- or untilled-sod site preparation treatments. Three subplots are solid white-on-black mulch, porous black mulch or herbicide-treated plots. Approximately 720 clonal silver maple trees were used for this study which had been cold stored since from excess production prior to 1993. The duration of this study is tentatively scheduled for 2 years.

GENETIC BIOMASS AND GROWTH ANALYSIS OF CLONAL SILVER MAPLE (Acer saccharinum L.) IN SEVERAL LOCATIONS

RENEWAL PROPOSAL

1996

Report Prepared by

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under

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for

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Oak Ridge, Tennessee 37831
operated by
Martin Marietta Energy Systems, Inc.
for the
U. S. Department of Energy
Contract No. DE-AC05-840R21400

SUMMARY STATEMENT

The proposed continuation of our research project will contribute to meeting the goals of the Biofuels Feedstock Development Program by providing genetic and phenological information about a promising woody biomass species that has potential for use in the midwest and northeast as an alternative or companion to Populus. Silver maple has excellent potential as a biofuel species because it grows rapidly, sprouts (coppice growth) well from stumps, can be repeatedly harvested thus avoiding costly replanting, grows reasonably well on less desirable secondary farm lands that may be available for the energy plantations of the future (lowland and upland sites), is generally free from serious pest problems, and is relatively easy to propagate asexually or by seeds.

The focus of this year will be to complete harvest, data collection, analysis, and manuscript preparation related to the silver maple project. These will be the final harvests of the Illinois, Kansas, and Minnesota silver maple biofuel plantations. Yield and growth data will collected on all sites.

These data will help us to understand interactions between the silver maple genotype and environment on growth and yield. They will also help us to make selections of genotypes that perform well on a variety of sites, as well as those that are more site specific. Recommendations will be made as to where silver maple germplasm should be collected for future studies.

DESCRIPTION OF THE PROPOSED ACTIVITIES

SUMMARY OF TASKS AND SUBTASKS

Task 1. Production of Planting Stock for Field Tests.

There will be no activity in this task. It is complete.

Task 2. Plantation Establishment.

There will be no activity in this task. It is complete.

Task 3. Plantation Maintenance.

Maintenance of the biofuel plantations during this year will be limited to fertilization, pest and disease monitoring, and upkeep of the deer exclusion fences. The intensive study area will be mowed between the plastic mulch strips on a regular basis during this second season after establishment to control excessive weed growth. Generally, serious weed competition has been reduced or eliminated at all biofuel sites by a combination of factors including polyethylene mulch strips, judicious application of glyphosate, and canopy closure.

Deer fencing will be removed and all maintenance will cease on the Illinois plantations after this last harvest. Decisions will be made about disposal of the Illinois plantations.

Task 4. Data Collection and Analysis.

This will be the focus of this year's actives. During the beginning of this funding cycle, data collection on the harvested trees from the Illinois Upland and Lowland plantations will be completed.

Much time will be required to enter and analyze data that have been and will be collected. We will focus on completing this by the end of this funding cycle.

Site visits during the growing season to Kansas and Minnesota will be necessary for maintenance and collection of growth data. Both sites will be visited twice during the growing season.

During the dormant season, all trees and coppice growth will be measured and similar data to those collected on the Illinois plantations during 1995 will be collected on the trees at the Kansas and Minnesota plantations. Since the Kansas and Minnesota plantations were established one year later than the Illinois plantations, these data will be necessary to provide site comparisons for the various genotypes.

During the dormant season, all trees in the Kansas and Minnesota plantations will be harvested and weighed. This will be the same as is being done to the Illinois plantations this winter. The previously non-harvested trees will have completed 5 growing seasons, and the coppice growth will be two years old. This will simulate two harvest cycles.

Additional activities will include manuscript and report preparation.

Task 5. Additional Supportive Activities.

Other activities that are funded by other sources will include the mulching study. Mulching materials were laid out during autumn 1995. In addition to mulching materials, there are till and no-till treatments. *Populus* cuttings will be stuck into the soil through the mulching treatments. This is similar to a study implemented during early summer, 1995.

Year 1: April 1, 1996--Mar. 31, 1997

A. Professional Staff	Salary Rate	# Hrs./ # Mos.	%	Person Months	Agency Request	# Hrs./ # Mos.	%	Person Months	SIU
1. John Preece, P.I.	4973.00					3.00	0.20	0.60	2984.00
	5221.65					9.00	0.20	1.80	9399.00
2. Paul Roth	4817.00					3.00	0.20	0.60	2890.00
	5057.85					9.00	0.20	1.80	9104.00
Subtotal:				0.00	0.00			4.80	24377.00
B. Other Personnel									
1.									
Subtotal:					0.00			0.00	0.00
C. Graduate Assistants/Student Workers									
1. Grad. Asst. (12 mos @ 50%)	1740.00	3.00	0.50	1.50	2610.00	0.00	0.00	0.00	0.00
	1827.00	9.00	0.50	4.50	8222.00				
2. Grad. Asst. (10 mos @ 50%)	1740.00	1.00	0.50	0.50	870.00				
	1827.00	9.00	0.50	4.50	8222.00				
3. Student Worker					4500.00				
Subtotal:					24424.00				0.00
D. Subtotal Personnel					24424.00				24377.00
E. Fringe Benefits									
1. For Professional Staff									
a. Retirement/Medicare @10.3%					0.00				2511.00
b. Medical/Dental/Life @$535/per.mo.					0.00				2568.00
2. For B1 @ 7.65% of salary					0.00				0.00
Subtotal:					0.00				5079.00
F. Equipment									
1.					0.00				
Subtotal:					0.00				0.00
G. Travel					3000.00				
Subtotal:					3000.00				0.00
H. Commodities					745.00				
Subtotal:					745.00				0.00
I. Contractual Services									
1. Phone					0.00				
2. Postage					0.00				
3. Duplicating					0.00				
Subtotal:					0.00				0.00
J. Other									
Subtotal:					0.00				0.00
K. Direct Costs					28169.00				29456.00
L. Indirect Costs (42% of MTDC)					11831.00				12372.00
M. Total Project Costs					40000.00				41828.00