MULTI-TRAIT CHARACTERIZATION OF SELECT EASTERN COTTONWOOD CLONES

By

LESLIE MARIE HITE

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Louisiana Tech University

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CHAPTER I

INTRODUCTION

Eastern cottonwood (*Populus deltoides* Bartr.) is a valuable tree species as a source of raw material. It's wood is utilized in the production of a wide range of products worldwide including veneer, containers, composite panels, structural composite lumber, match splints, chop sticks, crates, plywood corestock, flakeboard particles, excelsior, mulch, insulation, fuelwood, lumber, pulp, paper, pallets, boxes, foliage chemicals, energy, and animal feed supplements (Crist et al., 1979). The species is also useful in windbreaks to reduce soil erosion.

Maximum growth of eastern cottonwood is achieved on rich bottomland soils. Trees of eastern cottonwood are often found with other bottomland species or in pure even-aged stands on sandy loam sites. Eastern cottonwood is a pioneer species colonizing new sandbars and bare flood plains (Knopf, 1997). The range of eastern cottonwood extends across North America and can be found from south Alberta east to Quebec and New Hampshire, south to Florida, west across most of Texas and north to central Montana (Knopf, 1997).

In 1979 eastern cottonwood constituted the largest volume of growing stock of all species in the central Great Plains (Lovett 1979). Rainwater (1998), a representative of Westvaco's fine papers mill at Wickliffe, KY, reported growth of up to 30.48 meters in height in ten-year rotations. The demand for energy and fiber in relation to the productivity that cottonwood could bring to the industry has been realized for over a decade. Energy supplies and costs have been a major issue in the past and continue to be of great importance. Many *Populus* hybrids demonstrate hybrid vigor by out-performing their parents in terms of productivity. Hybrid vigor has become an important tool utilized in tree improvement in increasing biomass production within the genus *Populus*. Many species of the genus *Populus* are easily manipulated and hybridize readily. Certain F1 genotypes result in heterotic growth (Hinckley et al. 1989), which can be easily captured in *Populus* by cloning.

Limited funding and time has lead to early selection of clones or trees based on first or second-year growth combined with other selection criteria such as resistance to disease. Potlach Corporation in the Boardman, Oregon area works with hybrids which are crosses between any two of four poplar species: *P. trichocarpa* Torr. & Gray, *P. deltoides* Bartr., *P. nigra* L. (black poplar), and *P. maximawiczii* Henry (Japanese poplar) (Eaton, 1998). Various clones of those species are crossed and the offspring screened for two years to identify the top 10-15% for growth, which are moved into a three-year trial to evaluate suitability to the environment, wood quality, and growth. The top 10% of clones from the three-year trial are moved into a final test. The final test lasts 4-7 years and volume growth, stem form, environmental suitability, wood quality, and disease and pest resistance are evaluated. Selected clones are then compared to exceptional clones known to be highly productive and of exceptional quality and selected ones moved to clone banks for "rapid scale up".

With DNA technology, new strategies for selection and improvement exist. Species within the genus *Populus* are model trees to study different selection and breeding methods for various reasons including: high genetic variation and heterozygosity and because most species hybridize readily (Stanton and Villar 1996). According to Bradshaw and Stettler (1995), the nuclear genome is small (2C=1.1 pg) and the chromosome number is the same in all species (2n = 38).

It is a challenge to recognize desirable traits related to productivity in the first few years of growth in any woody species. It is also challenging to recognize traits for selection of parents that perform well in hybrid production. As early as the 17^{th} century, farmers and tree breeders selected individual trees for desirable traits (Cerevera et al. 1997). According to Bisoffi and Gullberg (1996), the following criteria for poplar selection, although over 60 years old, are still largely applicable: fast growth (especially juvenile), wide adaptability, resistance to diseases and frost, straight and cylindrical stems, and homogeneous, white wood suitable for pulp, boards, beams and peeling. Desirable attributes linked to overall production in many woody species includes rooting ability; stem features relating to form; branch characteristics such as few branches; leaf characteristics related to overall productivity such as larger leaf area; phenology including time of bud flush and bud set; and leaf retention, which is important in optimizing the growing season; and resistance to various diseases such as leaf rust (Stettler et al. 1996).

Methods of parental selection for hybrid vigor among tree species are not known. Oklahoma State University (OSU) clones have served as a source of *P. deltoides* clones for many crosses used in research and industry. Both above average OSU clones such as 20-1 and below average clones such 17-10 have been used to produce hybrid offspring that not only demonstrated hybrid vigor, but yielded operational clones.

Previous research with *P. deltoides* at OSU has resulted in a collection of over 300 clones. All of these clones have been tested in replicated field trials on sites known to be favorable for *P. deltoides*. The tests have yielded 12 to 20 years of growth data. Performance of a few OSU clones used in hybridization with *P. trichocarpa* is known. OSU clones have been used as parents in hybridization work with the University of Washington, Washington State University, Potlatch Corporation, Boise Cascade, Greenwood Resources, and Westvaco.

In the first few years of growth, it is a challenge to recognize desirable traits related to overall productivity in any woody species. There is limited information on how clone characteristics such as crown architecture, morphology, photosynthesis, water use efficiency, heterozygosity, and root characteristics relate to hybrid performance. In this study, clone characteristics listed in the measurement section were examined in 12 selected clones in their first growing season and compared to twelve-year volume to identify traits related to overall performance. Clones were selected based on mean twelve-year volume in replicated clonal field trials. Molecular markers will be utilized to compare phenotypic variation with genetic variation. Simple sequence repeats (SSRs) and random amplified polymorphic DNA (RAPDs) will be used to estimate heterozygosity to compare genetic variation with field productivity.

Further research is needed to determine which traits are limiting and which are preferred in parents used in hybrid production. There is limited theory to predict how hybrids will perform compared to their parents when dealing with crossing tree species. Evaluation of clones that demonstrate poor, average, and excellent growth should aid in understanding and identifying *P. deltoides* parents which result in heterotic offspring in crosses with other *Populus* spp. This research will not answer questions concerning hybrid production or performance, but will be utilized to establish a baseline of clonal charateristics relating to growth.

CHAPTER II

LITERATURE REVIEW

Multiple Trait Studies

Wilcox and Farmer (1967) studied heritability for growth, form, and phenological characters of juvenile eastern cottonwood. Measurements were taken on 1- and 2-year old propagules from unrooted cuttings of 49 randomly selected seedlings in a 2-year old natural stand near Rosedale, MS. Measurements taken included height, diameter, number of branches, incidence of leaf rust, and date of bud flush and leaf fall. Wilcox and Farmer (1967) found height growth in the second year was not correlated with the first year and they felt second year height and diameter were better indicators of future performance. The highest individual and clone heritability estimates were found for phenological characters and for incidence of leaf rust. They found the scores for rust were similar for both years measured. The heritability of number of branches was high also, 0.82 (clone-mean basis), but not as high as rust score and phenological characters. The lowest heritabilities were for the growth traits (diameter and height).

Farmer and Wilcox (1968) evaluated 100 clones grown for one season on two sites in the Mississippi flood plain. One site was located on a dark and poorly drained soil, subject to severe moisture stress. The other site was a loam soil, a better site for growth. Total heights were measured in June, July, August, and October. Stem diameters were measured in October. In November, plants were rated for *Melampsora* leaf rust.

Stem sections were taken from one tree in each plot from clones on the clay site and from two trees per plot on the loam site. Specific gravity was determined from green volume and ovendry weight. Samples varied from 10 to 40 cubic centimeters (cc). Mean clone height ranged between 2.96 to 4.57 m on the loam site and 2.90 to 4.24 m on the clay. Mean clone diameter ranged between 3.3 to 5.6 cm on the loam and 2.8 to 4.8 cm on the clay. There was no correlation found between clone and site. Mean volume was 0.0021 m^3 on the loam site and 0.0016 m^3 on the clay site. Heritability for volume was the same as for diameter. Mean specific gravity ranged from 0.32 to 0.41 grams/cc. No differences in specific gravity of the stem sections were found between sites.

Posey (1969) collected vegetative cuttings from eastern cottonwood trees sampled along the Red, South Canadian, and Cimarron rivers across Oklahoma and planted these cuttings near Norman, Oklahoma. Measurements were taken on height, diameter, number of branches, specific gravity and fiber length after one growing season. Stand means for specific gravity and number of limbs increased east to west, with no significant differences among rivers. Diameter and stand mean height decreased from east to west. The number of branches increased and size of leaves decreased with longitude as water supply was decreasing.

Ying and Bagley (1976) conducted a seven year common-garden test of 498 eastern cottonwood clones from 116 families in eastern Nebraska (40°N). The test included material from the northern half of the range, and established a genetic basis to the southeast to northwest decrease in leaf size. Total number of branches increased from southeast to northwest in this study. Variation in crown architecture was shown to be a function of genetic and environmental influences. Mean provenance height increased from north to south. Thirty-three percent of the genetic variance in height was estimated to be associated with provenance, 27% with families within provenances, and 40% with clones within families. A trend in spring leaf flush was found occurring from northwest to southeast provenances. Northern trees dropped leaves earlier in the fall than southern ones.

Friend (1981) conducted a two-year replicated test of eastern cottonwood at Stoneville and Starkville, MS. The test included open-pollinated seedlings collected from parent trees in 15 locations throughout the southern (30-35°N) United States. During the second year, date of budbreak , height, root collar diameter, leaf dimensions and weight, and *Melampsora* leaf rust incidence were measured. Friend (1981) found southern provenances (30°N) began growth on average 6 days earlier than northern (35°N). Northern families exhibited slower shoot elongation than southern families during the months of August and September, but all grew into October. Southern provenances, particularly those from the southwest, exhibited more overall growth in height for both years. Friend (1981) observed a decrease in leaf size east (82°W) to west (96°W) and the incidence of *Melampsora* leaf rust to be normally distributed. Southern latitude sources were found to be more rust resistant than middle and northern latitude sources.

Nelson (1984) studied genetic variation in juvenile characters of eastern cottonwood from the southwestern part of its range. He collected various data for seedlings: date of leaf fall, height and diameter growth, survival, leaf rust incidence, and number of branches. He found that each character showed a pattern of geographic variation. A northwest to southeast pattern was observed for growth. Northwestern stands and families were smaller in height and diameter compared to southeastern stands and families. Dates of leaf fall followed a northwest to southeast trend. Leaves from northern stands and families fell earlier than southern stands and families. Leaves fell earlier in western stands and families compared to eastern. A northwest to southeast pattern was observed for leaf rust. Northwestern stands and families had higher incidence of leaf rust than southeastern stands. Western stands and families had more branches per unit of main stem than eastern stands and families.

Pauley and Perry (1954) studied variation of the photoperiodic response in *P. trichocarpa* and *P. deltoides.* Branch or stem cuttings were collected at various latitudes along the species natural ranges. The cuttings were propagated and tests were conducted in Weston, Massachusetts and Jamaica Plain, Massachusetts. Significant variation in date of cessation of height growth was inversely correlated with the latitude of origin of each clone. They concluded that adaptation of a species to various habitats with variation in number of frost-free days is affected by a genetic mechanism which controls duration of the seasonal period of growth. They also concluded that a large number of genes controlled photoperiod responses.

Ceulemans et al. (1992) studied the physiology and morphology of 12 clones, including three *P. trichocarpa* Torr. & Gray, three *P. deltoides* Bartr., and six of their F1 hybrids, for 4 years. The parental clones were selected for fast growth. The female parents (*P. trichocarpa*) originated between 46.5 to 49°N latitude and the male parents (*P. deltoides*) orginated between 30 to 39°N latitude. The six F1 hybrids were selected for vigor, branching, and latitude of origin of the parent clones. The study was located near Puyallup, WA (47°12′N, 122°19′W). Measurements included date of bud flush and bud set, leaf development (number of leaves and leaves lost biweekly), height, diameter, stem volume, number of branches, and date of leaf fall during three growing seasons. Ceulemans et al. (1992) found highly significant differences in mean tree height, diameter, and stem volume between parents and hybrids, and between *P. trichocarpa* and *P. deltoides*. Hybrids had the greatest growth, followed by *P. trichocarpa* and then *P. deltoides*. Bud flush and set dates were variable between species and among clones within species. *Populus trichocarpa* clones had the longest growing period (196 days), and *P. deltoides* clones had the shortest (171 days); hybrids ranged in between. Dates of leaf initiation and leaf fall varied among clones, but seasonal patterns were nearly similar for all clones during the first two growing seasons. Leaf density on the current terminal was not different among clones, species, or hybrid groups during the 1st and 2nd years. The number of sylleptic branches on the current terminal was different among clones. Clones of *P. trichocarpa* had the most sylleptic branches, *P. deltoides* had the fewest, and hybrids were intermediate. There was a north to south geographic trend in the number of sylleptic branches on the current terminal of two-year old *P. deltoides* and *P. trichocarpa* clones.

Orlovic et al. (1998) measured net photosynthesis, dark respiration, leaf area, and assimilation tissue of rooted cuttings of eight poplar clones (four *Populus* x *euramericana* and four *Populus deltoides*) in three field experiments on different soil types. Diameter, height, and biomass were recorded at the end of the growing season. Most traits resulted in significant variability within and among clones implying traits measured were regulated by genetic elements specific to individual clones. A large genotype x environment interaction was observed between clone and location for all parameters.

Leaf area was positively related to height growth. In taller clones, leaf area was greater, stomates closed faster in drought conditions, and there were more epidermal cells compared to shorter clones.

Leaf Physiology

Rhodenbaugh and Pallardy (1993) studied photosynthetic characteristics, leaf area, and root growth in three poplar clones under limited water availability. Clones studied included balsam poplar (*P. balsamifera* L.), black cottonwood (*P. trichocarpa* Torr. & Gray), and a hybrid clone (*P. nigra* var. *charkowiensis* Schroed. X *P. nigra* L.). They found rapid leaf and root growth were associated with productivity.

Ridge et al. (1986) reported that rate of individual leaf growth, rate of leaf production and duration of leaf growth determine leaf area. They studied the relationship between components of leaf and stem volume growth in *P. trichocarpa, P. deltoides*, and their hybrids from several sources of material. One of the clones used in their study, ST-70, was a clone selected for this study. Material was grown in irrigated plots near Sumner, Washington. Leaf length and width, and tree height, and diameter were recorded weekly. They found stem volume was related to total and individual leaf area and that leaf growth rate and leaf area should be utilized in selection for high-yielding poplar.

Branch Physiology

Ceulemans et al. (1990) studied branch characteristics in five poplar clones (*P. deltoides, P. trichocarpa* and *P. trichocarpa* x *P. deltoides* hybrids) grown in the Pacific Northwest. Traits measured included orientation of proleptic and sylleptic branches and number, size, angle, and biomass of branches. They observed that genotype has a significant influence on branching patterns. There was significant variation among clones for branch angle. Current terminals had higher leaf area, density, and larger leaves than branches. Length and diameter of branches were found to be correlated (r >0.9) and length was correlated with leaf area.

Gas Exchange Studies

Poplars exhibit some of the highest CO_2 exchange rates and photosynthetic capacities among woody plants. Kelliher et al. (1980) compared stomatal resistance, transpiration, and growth of eastern cottonwood in three different watering regimes. Two clones from Texas were selected and grown in pots. Results from this study suggested that environmental differences cause differences in transpiration rate, which is dependent on water available. They also found that total leaf area change was sensitive to stress. Height growth was less sensitive than leaf area and was found to stop at stomatal resistance between 30 and 40 $s \cdot cm^{-1}$. Stomatal resistance was found to control transpiration and determine the point at which moisture stress caused cessation of leaf and plant growth.

Bassman and Zwier (1991) studied gas exchange characteristics of *P. trichocarpa*, *P. deltoides*, and their hybrids. Measurements were taken of net photosynthesis, dark respiration, photorespiration, transpiration, and stomatal conductance to irradiance, temperature, leaf-to-air vapor pressure deficit (VPD) and plant water stress. Clones with greater WUE had higher rates of net photosynthesis, stomatal conductance, and transpiration. Stomates closed at –2.0 MPa in the eastern Washington clone of *P. trichocarpa* and at –1.25 MPa in the *P. deltoides* and hybrid clones. Transpiration rates were highest in the hybrids and lowest in the western Washington clone of *P.*

trichocarpa. The *P. deltoides* clone and the eastern Washington clone of *P. trichocarpa* had the highest WUE and the western Washington clone of *P. trichocarpa* had the lowest. Hybrids were intermediate. Differences in water use efficiency under adequate water supply were not correlated with stomatal conductance, but were correlated with net photosynthesis rates.

Blake et al. (1984) studied genetic variation in WUE in 17 poplar clones and hybrids of the genus *Populus*. Variance in WUE and amount of dry matter production was observed in different clones of the genus and within species. In clones of several species, including balsam poplar (*P. maximowiczii*) and white poplar (*P. alba*), twice the dry matter production (leaves, stem, and roots) per unit of transpiration was observed compared to other clones of balsam poplar and black cottonwood (*P. nigra*), which exhibited relatively lower WUE and higher productivity. Most water-use-efficient clones exhibited lower transpiration rates compared with less-efficient clones, but transpiration rates varied among genotypes. In water-use-efficient clones, lower transpiration rates were associated with higher stomatal resistance found on leaves with more stomates on lower leaf surface compared with upper leaf surface. Less stomatal control was observed in less-efficient clones, as well as lack of adaptations that increase resistance to water loss including raised cuticular ledges and buried stomata, absence of stomata on upper leaf surface, and presence of hairs on the lower surface.

Rooting Behavior

Heilman et al. (1994) examined root development of *P. trichocarpa, P. deltoides* and their hybrids during their first growing season near Sumner, WA. All plants were grown in the field and destructively sampled at the end of the growing season. Mean number of roots per plant was 50 for hybrid clones, 31 for *P. trichocarpa* clones and 45 for *P. deltoides* clones. Above-ground biomass was positively correlated with root biomass (R^2 = 0.66 to 0.86). Location and size of roots varied. Mean root biomass of hybrids was higher than that of the parental species. Mean root biomass for all clones ranged from 1 to 33 g. Mean above-ground biomass of hybrids was higher than that of the parental species. Mean above-ground biomass of all clones ranged from 7 to 315 g.

Khurana et al. (2000) studied rooting behavior in poplars. They reported survival, growth, and development of poplars depend on the root system. Poplars had a variable type of root system that consisted of strong horizontal surface roots from which plunging vertical roots developed. The development of plunging roots appeared to be under strong genetic control and was clone specific. Cloned progeny of a single family exhibited different rooting behavior.

Wood Quality

Posey et al. (1969) studied variation in specific gravity, fiber length, and growth rate in eastern cottonwood from the southern Great Plains. Plots were established along the Red, Canadian, and Cimarron rivers of Oklahoma and Arkansas. Twenty-four stands were chosen along the three major rivers for measurements. Posey et al. (1969) observed an east to west increase in specific gravity along rivers. There were significant differences in specific gravity among stands and trees within stands. They found as rainfall increased, specific gravity decreased. There was a decrease in diameter growth rate from east to west and differences in diameter growth among rivers were due to variation in soil moisture capacity. Trees grown on soils with more sand than silt content resulted in less diameter growth compared to trees grown on soil with higher percentage of silt than sand.

Specific gravity is directly related to strength and pulp yield and is utilized to measure the physical and mechanical properties of wood (Reddy and Jokela, 1982). Reddy and Jokela (1982) measured specific gravity of 15 clones of eastern cottonwood located in the Pottsville bottoms of southern Illinois. One of the clones selected in this study, ST-240, was a clone that they reported on. Cross sections of 3.5cm were taken at different heights from felled trees in the fifth growing season. Two wood specimens of each growth ring were utilized and cross sections in each were obtained for measurement of specific gravity. Mean specific gravity of trees ranged from 0.331 to 0.436 and of clones from 0.343 to 0.427. There was a significant increase in mean specific gravity from 0.36 to 0.39 from the outer to the inner ring at the lower heights of 0.3, 1.5, and 2.5 m, but at the other heights (5, 7.5, and 10 m) there was no significant difference. The large variation found within trees suggested small wood samples are subject to large errors and variation occurs due to age, crown class, position within tree, and tree vigor.

Pathological Studies

Some of the many diseases and insects that affect poplars include leaf spots and cankers caused by *Marssonina brunnea* and *Septoria musiva*, leaf rust caused by *Melampsora medusae*, and *Cytospora chrysosperma* canker (Ostry, 1979). Many of these diseases can cause premature defoliation and reduced growth. Through selection and screening of clones, resistance to diseases such as leaf rusts, bacterial canker, and shoot blight can be found (Ostry, 1979). The incidence, distribution and severity of diseases of poplar varies by area and clone (Ostry, 1979). Nelson (1984) reported a northwest to southeast pattern for variation in the incidence of leaf rust caused by *Melampsora* leaf rust. Seedlings that originate from the north and west are more susceptible to *Melampsora* leaf rust than those originating from the south and east. This report agreed with Friend (1981) who also found northern seedling more susceptible than southern ones.

SSR and RAPD Technology

Simple sequence repeats (SSRs) can be used to examine the heterozygosity level of plants. The level of heterozygosity within a genome may be linked to hybrid vigor. Cerevera et al. (1997) defined SSRs or microsatellites, as "tandem repeats of sequence units, which can be as short as 4, 3, 2, or even 1 nucleotide". SSR-based markers can be generated by PCR amplification of the SSR using specific primers (20 to 25 bases) complementary to their flanking regions. The number of repeat units at a locus is highly variable and can be easily detected as polymorphisms when the amplified DNA fragments are electrophoretically separated on polyacrylamide or high-resolution agarose gels. Bands are visualized by ethidium bromide staining or by autoradiography or silver staining when labeled primers are used in the PCR reaction. One locus can be analyzed per specific primer combination. SSR-based markers are codominant and detect many different allele sizes per locus.

Powell et al. (1996) listed established methods for development of SSRs: construction of a genomic library, screening for inheritence of markers by controlled crosses, DNA sequencing of positive clones, creation of primers and locus-specific PCR analysis, and detection of polymorphisms.

Sun et al. (1999) examined genetic diversity in 33 individual *Elymus caninus* (awned wheat grass or bearded coach) utilizing isozymes, SSRs, and random amplified polymorphic DNA (RAPDs). They found differences in the amount of polymorphism observed and SSRs produced the highest amount of diversity. All three methods gave different degrees of variation, but produced high amounts of variation.

This summary of reported research was useful as a guide for determining appropriate traits to measure in the selected eastern cottonwood clones in this study. The objectives for this research are to measure the selected traits the first season and compare them to twelve-year volume to determine if a relationship exists to identify traits that would predict clone performance at an early age.

CHAPTER III

MATERIALS AND METHODS

Material Selection and Collection

Twelve *P. deltoides* clones from the collection of OSU clones were selected for study: four of the best, four average, and four poor performers. Clone selection was based on height and diameter growth at age 12. All clones selected originated from the southern half of the natural range of eastern cottonwood. Table I includes the clones selected, their origin, rank, and average height and diameter after twelve years in a clonal replicated field test.

TABLE I

CLONES SELECTED BASED ON TWELVE YEAR PERFORMANCE

State of Origin	Clone	Mean dbh (cm)	Mean ht (m)	Why Selected	Rank (out of 100)
SE OK	1-8	29.59	26.6	Best overall	1
MS	111232	28.42	25.67	One of best	2
MS	ST-70	25.88	24.04	One of best	3
AL	2433	22.2	20.81	One of best	34
SE OK	117	19.08	20.28	Average, Used in hybrid work	51
TX	9-8	17.86	19.67	Average	57
TX	S7C21	16.36	17.18	Average	70
OK	11-3	13.92	16.45	Average, Used in hybrid work	79
MS	ST-240	13.39	14.41	Poor	83
OH	64-217-01	12.83	13.60	Poor	86
C. OK	22-4	10.21	12.80	Poor	90
TX	82-18-2-1	10.06	10.09	Poor	93

Experimental Design for Pot and Field Study

Pot Study

Unrooted ten-inch cuttings of each clone were taken from stool beds located near Idabel, OK and transported to Stillwater, OK in a cooler. Twenty-four hours before planting in pots, ten cuttings from each of the twelve selected clones were soaked in tap water, weighed to obtain green weight, and planted in a two gallon pot with a volume of 1:1 peat moss and vermiculite soil mix with 39 g lime and 30 g osmocote. The pots were perforated to allow for drainage and watered as needed. The ten cuttings from the selected twelve clones were arranged in a completely randomized design in the greenhouse until the last day of frost, April 15. Seven of the ten were selected based on survival to be further evaluated during the rest of the season.

On April 16, 2001, the potted plants were moved out of the greenhouse and under a plastic canopy where pots were arranged in a randomized complete block design (Table II). There were seven replicates with one cutting of each of the 12 clones per replicate. Clones were assigned to replicate based on size of plant to decrease heterogeneity within replications. The plants were sprayed with an insecticide, Diazinon, because of presence of defoliators on the day they were moved outside. During the month of June, the trees showed significant damage to the leaves and stems because of inadequate nutrients, pot size, and possibly over-heating under the plastic canopy.

The first week of July, the trees were transplanted into 10 gallon plastic pots perforated for drainage in a 2:1:1 volume of growth substrate consisting of peat moss, vermiculite, and sand. The pots were transported out from under the canopy and arranged in the same randomized complete block design. Once a week, the pots were fertilized with a water-soluble solution of 20-20-20 NPK plus micronutrients.

TABLE II

Experimental Design for Pot Study

Row/ Rep	1	2	3	4	5	6	7
1	ST-240*	82-18-2-1	ST-240	2433	9-8	117	117
2	1-8	ST-240	117	ST-240	ST-240	11-3	22-4
3	2433	11-3	S7C21	117	82-18-2-1	ST-70	ST-70
4	22-4	S7C21	9-8	ST-70	22-4	9-8	2433
5	64-217-1	ST-70	1-8	1-8	2433	64-217-1	S7C21
6	117	22-4	2433	111232	111232	22-4	64-217-1
7	11-3	111232	82-18-2-1	82-18-2-1	S7C21	82-18-2-1	1-8
8	82-18-2-1	64-217-1	111232	11-3	11-3	ST-240	82-18-2-1
9	S7C21	117	64-217-1	64-217-1	117	S7C21	ST-240
10	111232	2433	ST-70	S7C21	ST-70	2433	111232
11	9-8	1-8	22-4	22-4	64-217-1	1-8	9-8
12	ST-70	9-8	11-3	9-8	1-8	111232	11-3

*Clone Numbers

Field Study

On March 20, 2001, eighteen-inch cuttings of the twelve selected clones were planted in a randomized complete block design (Table III) in the field on the Forestry Research Station near Idabel, OK. The area where the cuttings were planted was sprayed with two applications of Roundup at 3 oz/gallon (88.72 ml/3.78 liter), once two weeks prior to planting and then prior to planting on March 20. Each planting spot was hoed and grass removed in a 61cm diameter. Each spot was planted initially with two cuttings spaced 30.48 cm apart and later, on May 15, the non-dominant cutting of the two was removed. The spacing of the planting was 2.44 m by 2.44 m. There was one cutting of each clone in each of seven replications. There was one border row planted.

TABLE III

Experimental Design for Field Study

Row/Rep	1	2	3	4	5	6	7
1	82-18-2-1*	117	22-4	82-18-2-1	117	ST-70	9-8
2	9-8	11-3	64-217-1	2433	ST-240	82-18-2-1	1-8
3	ST-240	S7C21	82-18-2-1	ST-240	1-8	9-8	64-217-1
4	1-8	64-217-1	S7C21	11-3	9-8	ST-240	2433
5	22-4	ST-70	11-3	64-217-1	2433	1-8	111232
6	111232	82-18-2-1	ST-240	117	22-4	22-4 82-18-2-1	
7	ST-70	2433	117	9-8	ST-70	2433	22-4
8	11-3	ST-240	ST-70	22-4	S7C21	117	11-3
9	117	22-4	9-8	ST-70	111232	111232	ST-240
10	64-217-1	9-8	2433	1-8	64-217-1	11-3	S7C21
11	S7C21	1-8	1-8	111232	11-3	S7C21	ST-70
12	2433	111232	111232	S7C21	82-18-2-1	64-217-1	117

* Clone Numbers

Note: Planting surrounded by one border row of mix of some of the same clones

Measurements

Measurements taken at both locations for the first growing season included height and diameter, length of growing season, gas exchange measurements (water use efficiency and maximum photosynthetic activity), leaf and branch characteristics (size and density), and *Melampsora* leaf rust incidence. The following characters were observed or measured for the potted study only: total shoot, root, and tree weight; cutting weight when planted and when removed, and number of first order lateral roots. An estimate of heterozygosity of each clone was made using SSR and RAPD markers.

Date of bud flush was recorded on cuttings in both locations as the day the first visible leaf protruded from an active bud. Date of bud set was recorded in the fall as the first day bud formation on the tip of the main stem became apparent. The days between bud flush and set were counted and the length of time considered the length of season for height growth for each clone. The date when one or no leaves remained on each cutting was recorded following bud set and was used to examine leaf retention.

Height and diameter measurements were taken every two weeks at both study sites beginning May 15 and ending at bud set. Height measurements were taken using a meter stick and measuring from the soil surface to the apex of the highest active meristem. Measurements for height were recorded to the nearest centimeter. Diameter was measured to the nearest millimeter on the upper side of the main stem five centimeters from the point of origin from the cutting.

Leaf density was obtained by counting the number of fully developed leaves on the upper meter of the stem. Measurements for leaf size were obtained by measuring length and width of all leaves in the upper meter of stem excluding immature leaves. Using a protractor, leaf angle was measured from the petiole to the stem for all leaves in the upper meter of stem, excluding immature leaves. Internode length was measured by dividing one meter by the total number of leaves in the upper meter of the main stem. Total leaf area was measured using the LI-3000 portable leaf area meter (LI-COR, Inc., Lincoln, NE). At both locations, seven leaves on the main stem in the upper meter of main stem were randomly selected from each clone and seven leaves were randomly chosen from any branches in the upper meter of stem from each clone. Length and width of each selected leaf was measured before using the LI-3000 to obtain leaf area. A regression equation was fit for each clone utilizing PROC REG in SAS software seperately for main stem leaves and leaves on branches in the upper meter at each location to estimate total leaf area in the upper meter.

Maximum photosynthesis (A_{max}) at light saturated conditions was obtained for each clone to estimate differences in efficiency and utilization for growth throughout the season. A_{max} and water use efficiency (WUE) were measured using the LI-COR 6400, an open gas exchange system, during the last week of the months of July and August and twice during the month of September. In an open system photosynthesis and transpiration are based on differences in CO_2 and H_2O in an air stream before and after it flows through the leaf cuvette where the sample leaf is held (LI-COR, Inc., 1998). All measurements were taken under light-saturated conditions (1500 $\mu mol\ m^{-2}\ s^{-1}$) and ambient CO_2 (360 $\mu l\ l^{-1}\ CO_2$). Measurements were taken on the fourth fully expanded leaf from the growing tip of the main stem. WUE was obtained from the ratio of photosynthesis to stomatal conductance and divided by vapor pressure deficit.

Sylleptic branches, branches derived from nondormant buds on the current year's shoot, were counted at the end of the growing season. Any limb that could be traced back to the main stem was counted as a sylleptic branch. The length of each branch was measured to the nearest millimeter and the diameter of each branch to the nearest millimeter at 2.54 cm from the point of origin of the branch. The angle of each branch was measured with a protractor using the main stem as a reference point and measuring the angle at which the branch grew away from the main stem.

Specific gravity (SG), weight of each cutting, total root and shoot weight, and number of first order lateral roots were measured or counted for each clone in the potted study. The maximum moisture content method described by Smith (1954) was utilized to estimate specific gravity. Stem cross-sections were taken 24.5 cm up the main stem. The cross-sections were placed in a vacuum container with distilled water to allow maximum saturation (sat wt) and then weighed to the nearest 0.01 g. They were then dried in an oven until a constant weight was obtained (od wt). Smith's formula (1954) was used to estimate specific gravity (SG):

SG = 1/((sat wt – od wt/od wt) + (1/1.53))

SSR and RAPD markers were utilized to estimate heterozygosity and genetic variation of the clones at the DNA level. Material for DNA work was collected from newly emerged leaves from extra potted cuttings of the clones in Stillwater. Primers utilized for SSR work were obtained from Dr. Jerry Tuskin at the Oak Ridge national Laboratories in Oak Ridge, TN. Primers for RAPD's were supplied by the University of British Columbia.

Melampsora leaf rust was observed at both locations and recorded. The percentage of leaf area covered with urediospores was estimated utilizing criteria outlined by Nelson (1984). Table IV outlines these criteria.

TABLE IV

Scoring Criteria for *Melampsora* Leaf Rust (MLR)

MLR	Approximate % of Upper Leaf Surface Area Covered with Urediospores
0	Less than 10
20	Greater than 10 but less than 30
40	Greater than 30 but less than 50
60	Greater than 50 but less than 70
80	Greater than 70 but less than 90
100	Greater than 90

Data Analysis

Means and standard errors for each measurement were obtained for each of the twelve clones for each location utilizing SAS procedures. Dr. Mark Payton from the OSU Department of Statistics was consulted to ensure utilization of the best procedure available to analyze the measurements and heterozygosity levels and to determine which traits best explained the variance observed in twelve-year volume. A stepwise regression procedure was used to fit the best equation that would explain this variance utilizing the measurements observed over the first season as independent variables and the twelve-year volume as the dependent variable.

CHAPTER IV

RESULTS AND DISCUSSION

SECTION 1. MEASUREMENTS

Growth Measurements

Field Study

Clonal height at the end of the first growing season, Oct 16 (HT 12) in the field study, ranged from 1.46 m to 3.06 m. The average height at the end of the season in the field was 2.48 m. The average diameter in the field was 30.63 mm. All clones followed a similar trend in growth illustrated by the height and diameter curves in Figures 1 and 2. The majority of height growth occurred from May 29 (HT 2) to Sep 18 (HT 10). Clone 9-8 shows a decrease in height from Oct 16 (HT 12) to Oct 30 (HT 13). This decrease may be due to grasshopper damage or wind damage to some of the terminals. Clone 117 showed the greatest one-year height, averaging 3.06 m. Most clones began rapid height growth after May 29 (HT 2). Clones 111232, S7C21, ST-240, ST-70, 82-18-2-1, and 64-217-01 did not slow growth until Oct 2 (HT 11) while all the others slowed growth by Sep 18 (HT 10). Clone 22-4 delayed height growth until after July 26 (HT 4) and slowed growth after Sep 18 (HT 10), resulting in less height growth than all other clones.

Diameter growth at the end of the first year, Oct 16 (DIA 12), ranged from 14.43 mm to 40 mm. Most diameter growth occurred from June 12 (DIA 3) to Oct 2 (DIA 11). Clones 9-8 and 22-4 appear to delay diameter growth until July 10 (DIA 5) and were the smallest in diameter when measurements began. Clone 22-4 produced a much lower

Figure 1. Mean Height by Date, Field Study

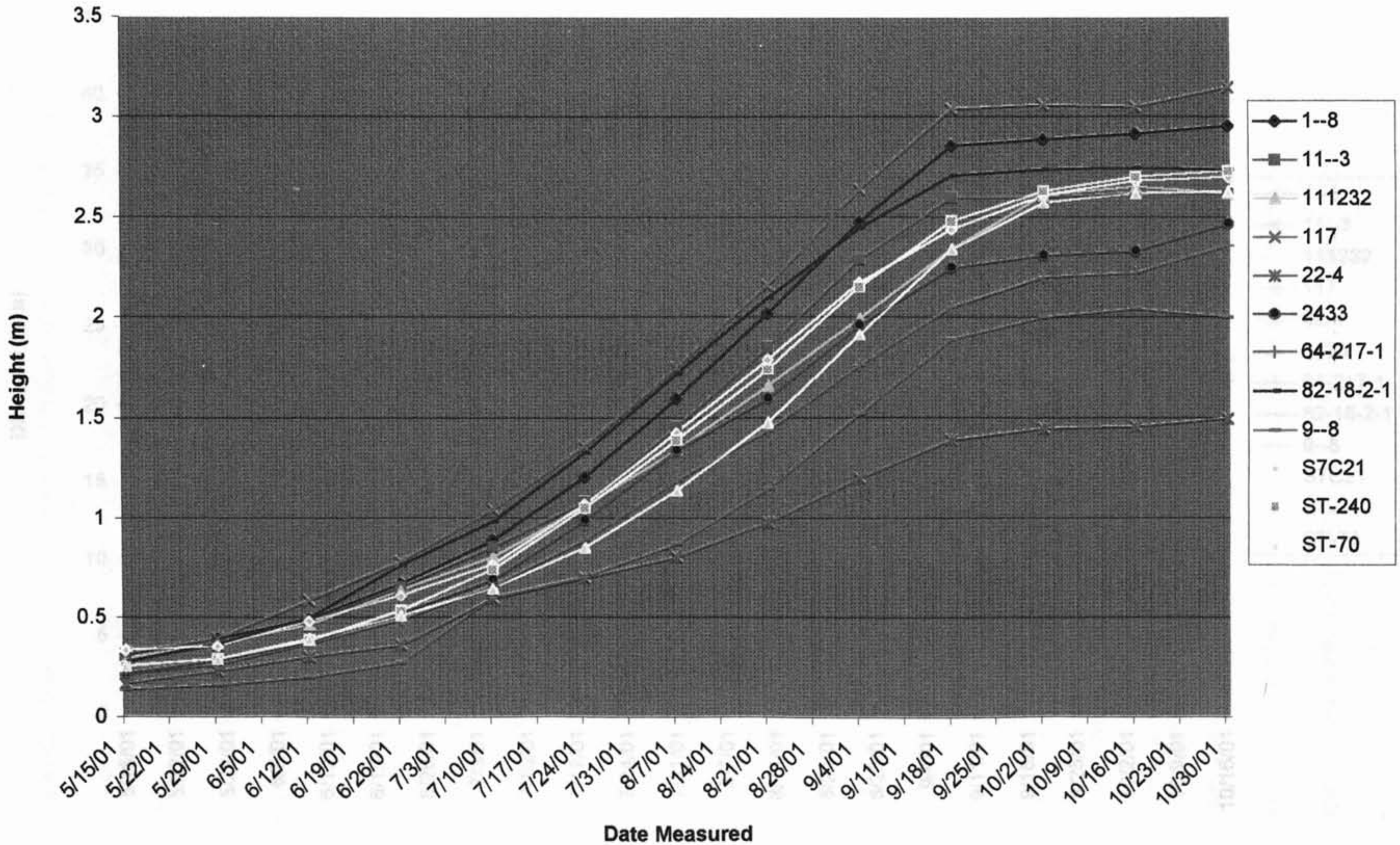
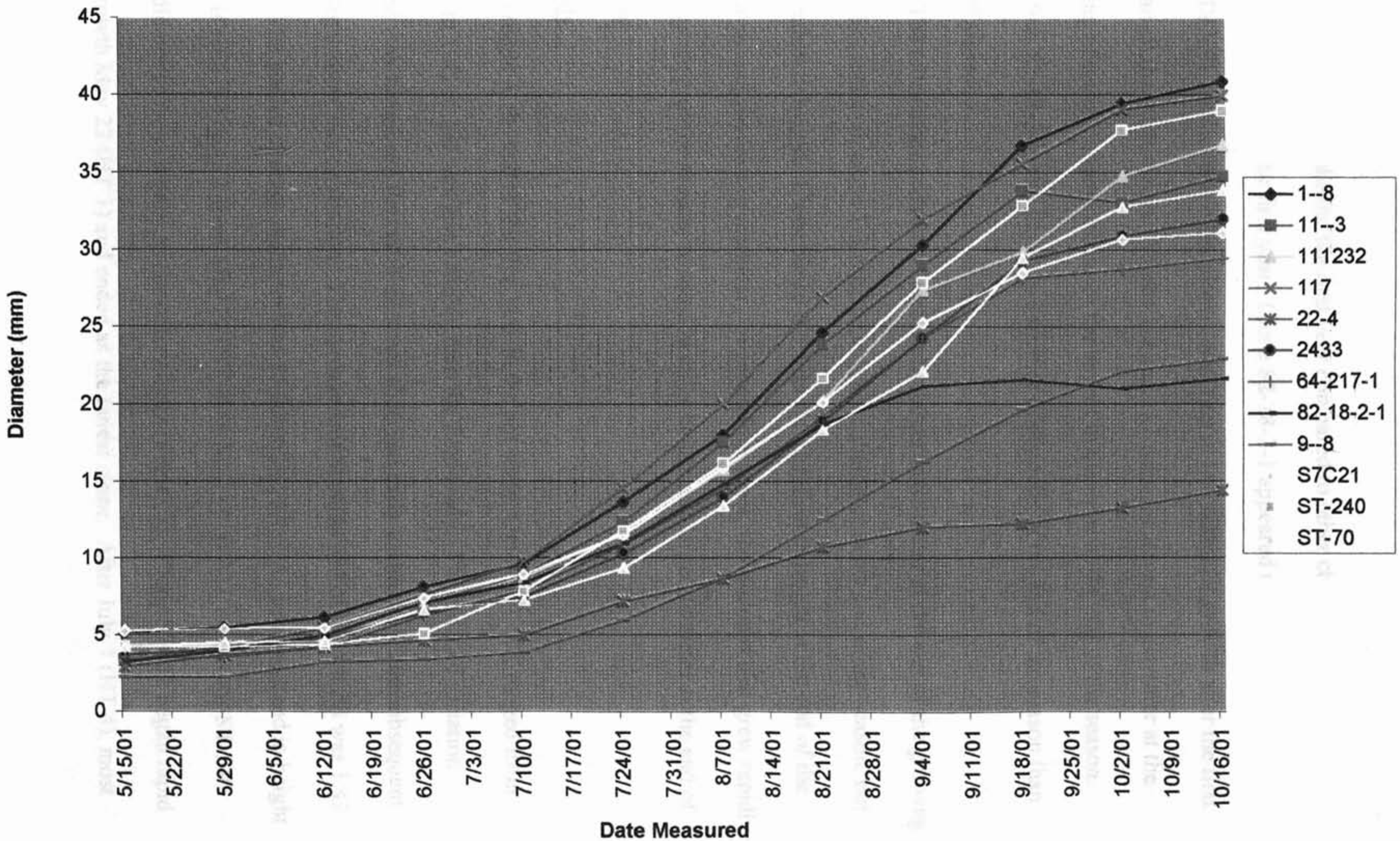


Figure 2. Mean Diameter by Date, Field Study



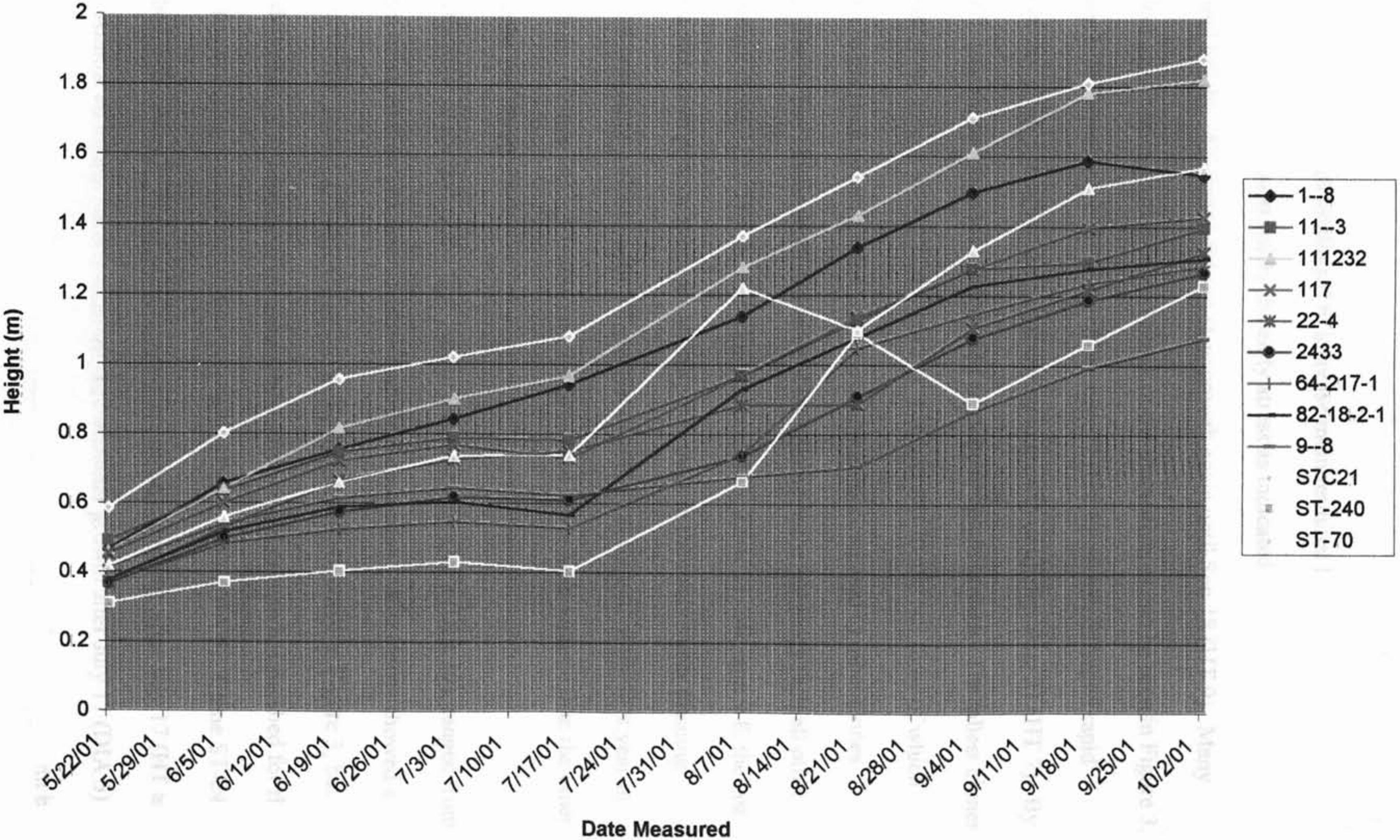
diameter growth curve during the first year compared to other clones and resulted in less diameter at the end of the first year. Clone 82-18-2-1 appeared to slow diameter growth Sep 4 (DIA 9), earlier than other clones, resulting in less diameter growth after the first year than all the other clones. Clones 1-8 and 117 were the largest in diameter at the beginning of measurements and were the largest in diameter at the end of the season. Clones 9-8, 82-18-2-1, and 22-4 were smaller in diameter at the end of the season than the other clones.

The taller clones were not necessarily larger in diameter at the end of the growing season. For instance, clone 1-8 was the largest in diameter at the end of the season, but second tallest in height. Clone 82-18-2-1 was fourth tallest in height at the end of the year, but second smallest in diameter. In general however, those clones that grew rapidly at the beginning of the season, resulted in taller height and larger diameter at the end of the season.

Pot Study

Height at the end of the first year in the pot study, Oct 2 (HT 10), ranged from 1.08 m to 1.88 m and was less variable than the field study. The reduced variation observed may have been the result of stress observed early in the study and subsequent years might show more variation. The average height at the end of the season was 1.43 meters. The pooled average diameter was 25.82 millimeters. An upward trend in height growth is seen in Figure 3 from May 22 (HT 1) to June 19 (HT 3), except for ST-240 which did not grow as rapidly as the other clones (Figure 3). Clone S7C21 began rapid early growth May 22 (HT 1) and ended as the tallest clone. After July 3 (HT 4), most clones showed loss of height to the main terminals as shown in Figure 3 except clones

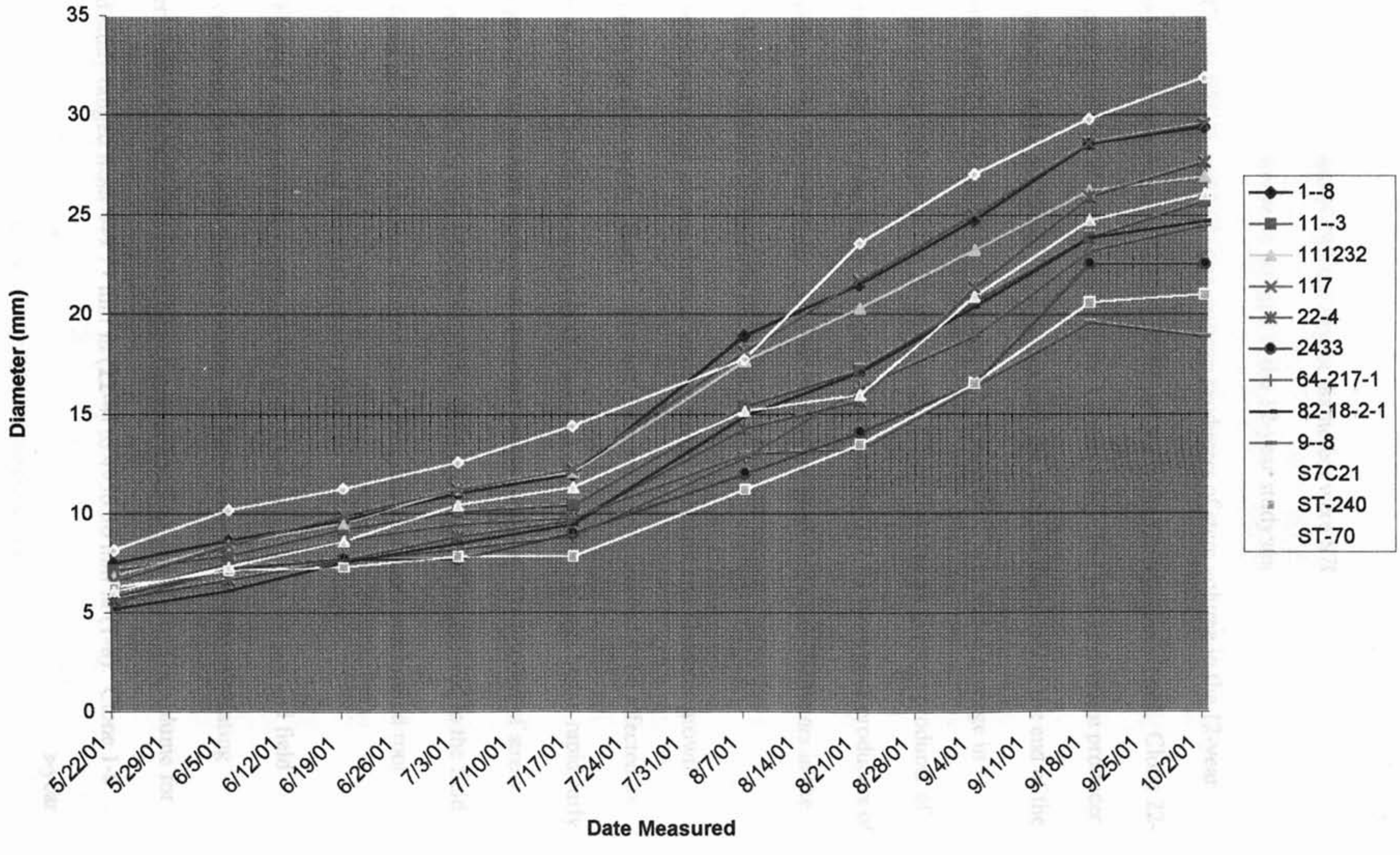
Figure 3. Mean Height by Date, Pot Study



S7C21 and 111232 which continued to increase main terminal height slowly, but steadily. Clone 1-8 did not seem affected by the early stress as indicated by a continuous increase in terminal height. All clones did not slow growth again until Sep 18 (HT 9). Many clones lost terminals or experienced dieback of the main stem, as can be seen in Figure 3, from July 3 (HT 4) to July 17 (HT 5). After July 17 (HT 5), all clones began rapid growth except clone 9-8 which did not show rapid growth until after Aug 21 (HT 7). By Oct 3 (HT 10), almost all clones had slowed or stopped height growth. The tallest clones at the end of the season were S7C21, 111232, 1-8, and ST-70, the last three of which produced larger stem volume in the twelve-year planting compared to other clones selected. These four clones produced more stem volume in the pot study than all other clones except clone 117. The shortest clones were 2433, 22-4, ST-240, and 9-8, the last three of which were poor or average volume performers in the twelve-year planting. Clone 22-4 was among clones with the greatest diameters at the end of the first year in the pot study. Clones 2433, ST-240, and 9-8 produced lower stem volume than the other clones in the pot study.

Diameter at the end of the first year in the pot study, Oct 2 (DIA 10), ranged from 18.94 mm to 31.90 mm; also less variable than field diameters. Most clones showed a trend in diameter growth (Figure 4) similar to the height growth curve in Figure 3, but slightly delayed since diameter growth continues after height growth has finished for the season. Rapid diameter growth did not occur until after July 17 (DIA 5). Clone ST-240 did not begin diameter or height growth until after re-transplanting, after July 17 (HT and DIA 5). Almost all clones show a steep upward diameter growth after July 17 (DIA 5) and continue growth until Sep 18 (DIA 9). Most clones had stopped diameter growth by

Figure 4. Mean Diameter by Date, Pot Study



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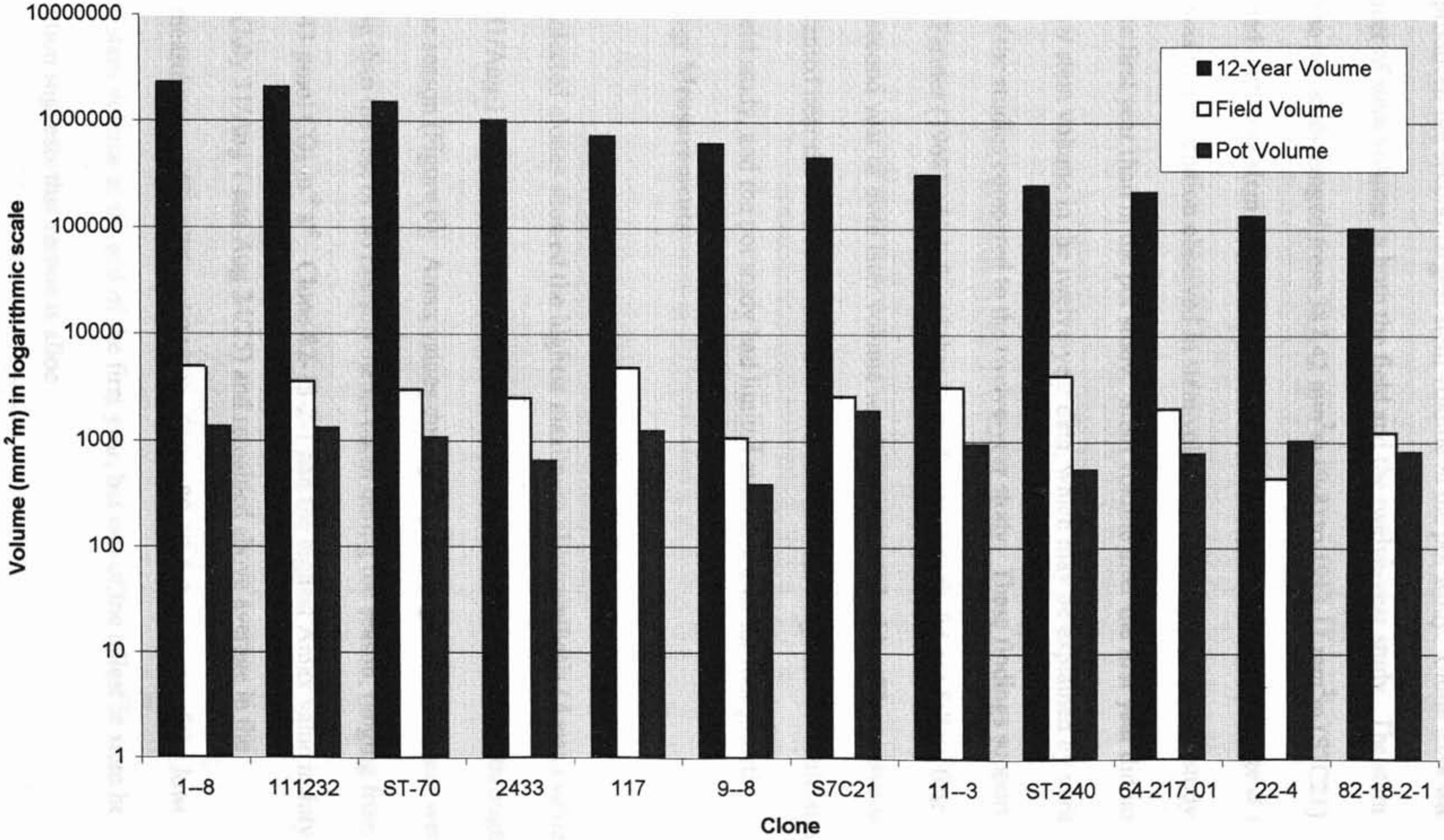
Oct 2 (DIA 10). The clones with the largest diameters were S7C21, 1-8, 117, and 22-4. Clone 1-8 had the greatest stem volume in the 12-year study and one of the best in the pot study. Clones S7C21 and 117 were average producers of stem volume in the 12-year study and both produced more volume in the pot study than most other clones. Clone 22-4 was a poor producer of stem volume in the 12-year study, but was an average producer of stem volume in the pot study. The clones with the smallest diameters at the end of the season were 64-217-01, 2433, ST-240, and 9-8. Clone 2433 was above average in production of stem volume in the 12-year study. Clone 9-8 was an average producer of stem volume in the 12-year study. Clones ST-240 and 64-217-01 were poor producers of stem volume in the 12-year study. All four clones that produced small diameters in the pot study had poor stem volumes in the pot study.

In the pot study, clones showed similar trends in height and diameter growth compared to the field study. Both height and diameter were observed to be affected by the early stress of the pots as seen in both Figures 3 and 4 where clones began rapid early growth and slowed growth during the observed period of stress. This period of stress may have accounted for the reduced variation observed in growth compared to the field study. Trees planted in pots have limited space for growth of roots and limited root growth may have affected terminal growth observed in the pot study.

Figure 5 shows clonal volume at the end of the first year in the pot and field studies compared to the twelve-year volume. Volume was obtained by calculating diameter^2 (mm) X height (m) for both twelve-year and first year data. The volume for the field study ranged from 449.77 mm^{2}m (22-4) to 4956.36 mm^{2}m (1-8). Clone 1-8 produced the greatest stem volume in both the first year in the field and the twelve-year

Figure 5. Comparison of Volume in Year One and Twelve



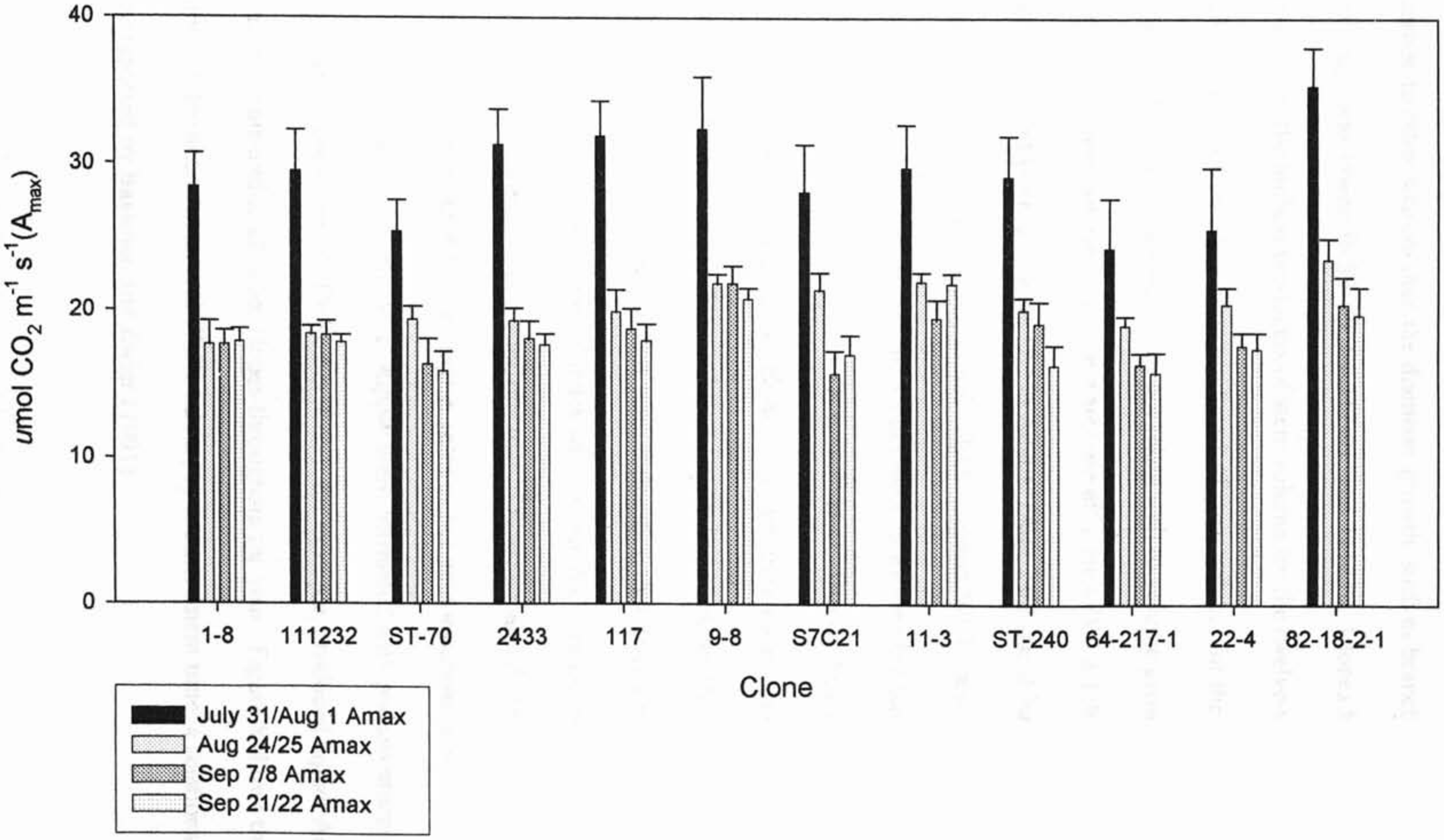
study and produced the second largest stem volume in the pot study. Clone 22-4 was a poor producer of stem volume in both the field and the twelve-year study. The stem volume in the pot study ranged from 387.42 mm^2m (9-8) to 1913.11 mm^2m (S7C21). Clone 9-8 had very low stem volume in both the field and pot study, but average at age 12. There was more variation observed in stem volume production in the field study at the end of the first year than in the pot study. Stem volume after the first year did not closely follow stem volume in the twelve-year data, which may be explained by variable conditions of the studies compared to the twelve-year study. These findings support Wilcox and Farmer (1968) which found that second year growth did not follow first year growth and second year or even later volume would be more valuable. The twelve-year study was planted near the Red River on favorable soil without irrigation or fertilization unlike the field study, and the pot study had limited available area for root growth.

Gas Exchange Measurements

<u>Field Study</u>

All selected clones showed the highest maximum photosynthesis (Amax) values on the July 31/Aug 1 measurement and Amax progressed in a downward trend through the rest of the season (Figure 6). Amax values during July 31/Aug 1 measurement were more variable than the rest of the measurements taken during the season, ranging from 24.33 to 32.43 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$. Clone 82-18-2-1 had the highest Amax value in July and August (July 31/Aug 1 and Aug 24/25) and remained above average in the September measurements (Sep 7/8 and 21/22). Clone 82-18-2-1 was one of the lowest producers of stem volume at the end of the first year, but one of the tallest in stem height. This observation suggests that carbon is allocated to stem height more than to diameter.

Figure 6. Means with Standard Errors for Maximum Photosynthetic Activity (A_{max}), Year One, Field Study



Perhaps clones with higher Amax values throughout the season, but lower stem volume, allocated carbon to other sources than the diameter growth, such as branch, leaf, height or root growth. A_{max} was lowest in ST-70, 64-217-01, and 111232. Clones ST-70 and 111232 were two of the highest producers of stem volume for the twelve-year study. Clone 64-217-01 was one of the poorest producers of stem volume for the twelve-year study. These results suggest that A_{max} does not relate well to volume growth.

All clones showed similar trends in water use efficiency (WUE) throughout the season (Figure 7). Measurements were low in August (Aug 24/25) and least variable, with an overall mean of 1.04 μmol CO_2 $mmol^{-1}$ H_2O. Highest WUE values were observed in late September (Sep 21/22) and values were more variable than at other times, with an overall mean of 2.28 μmol CO_2 $mmol^{-1}$ H_2O. During August when temperatures were highest in the field, the clones required more water resulting in lower WUE than at cooler times. Clones that produced greater stem volume the first year generally showed less WUE during the first year, suggesting that more water was required to produce more stem volume. Clones with higher WUE values resulted in higher Amax values. This information confirms that of Bassman and Zwier (1991) who found that clones with greater WUE had higher rates of net photosynthesis and differences in WUE under adequate water supply were correlated with photosynthesis rather than stomatal conductance. Clone 82-18-2-1, for example, produced higher Amax and WUE values compared to all other clones throughout the year. Figure 8 shows the linear relationship between Amax and WUE values, by measurement time; a relationship that was also reported by Bassman and Zwier (1991).

Figure 7. Means with Standard Errors for Water Use Efficiency (WUE), Year One, Field Study

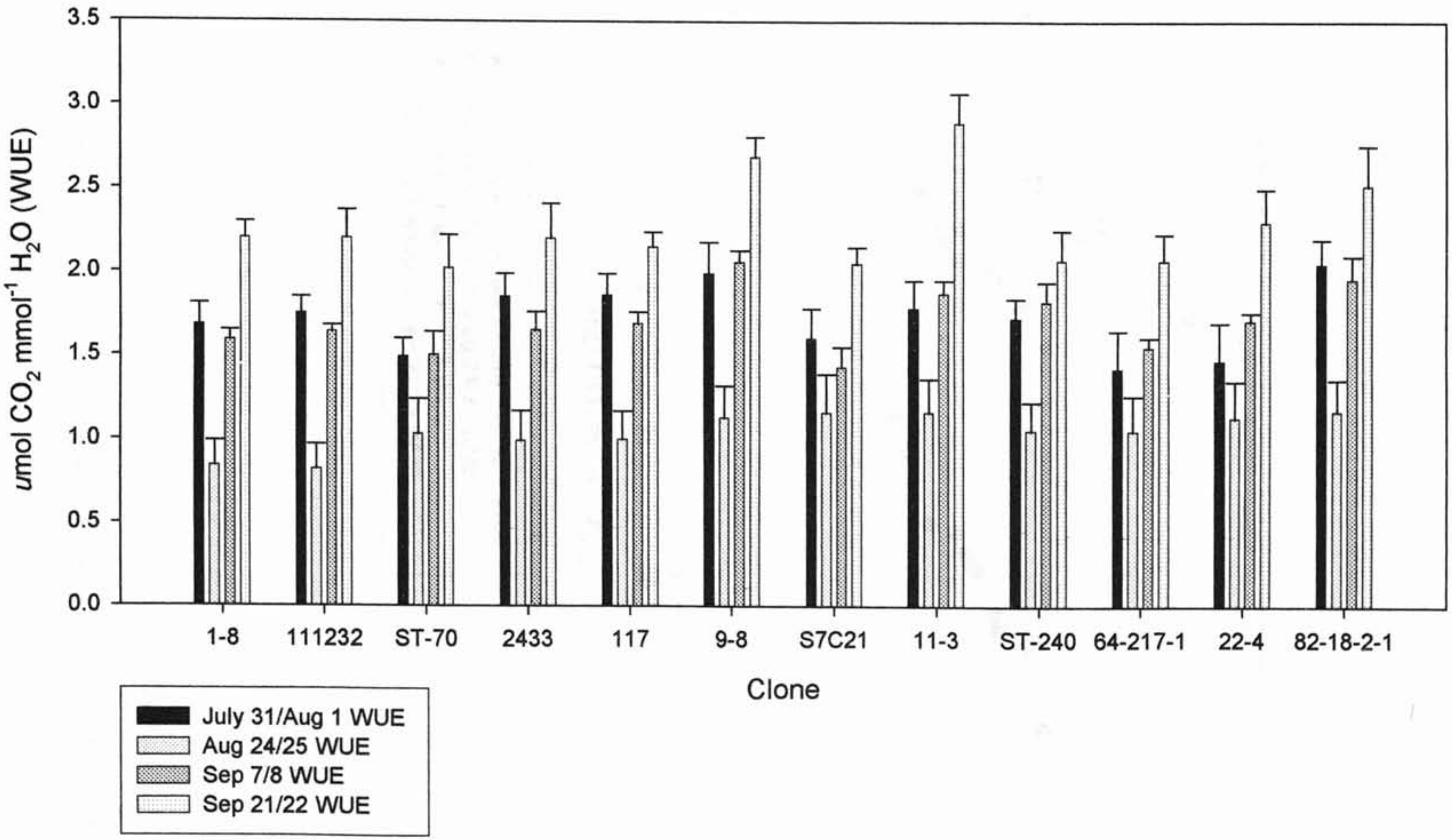
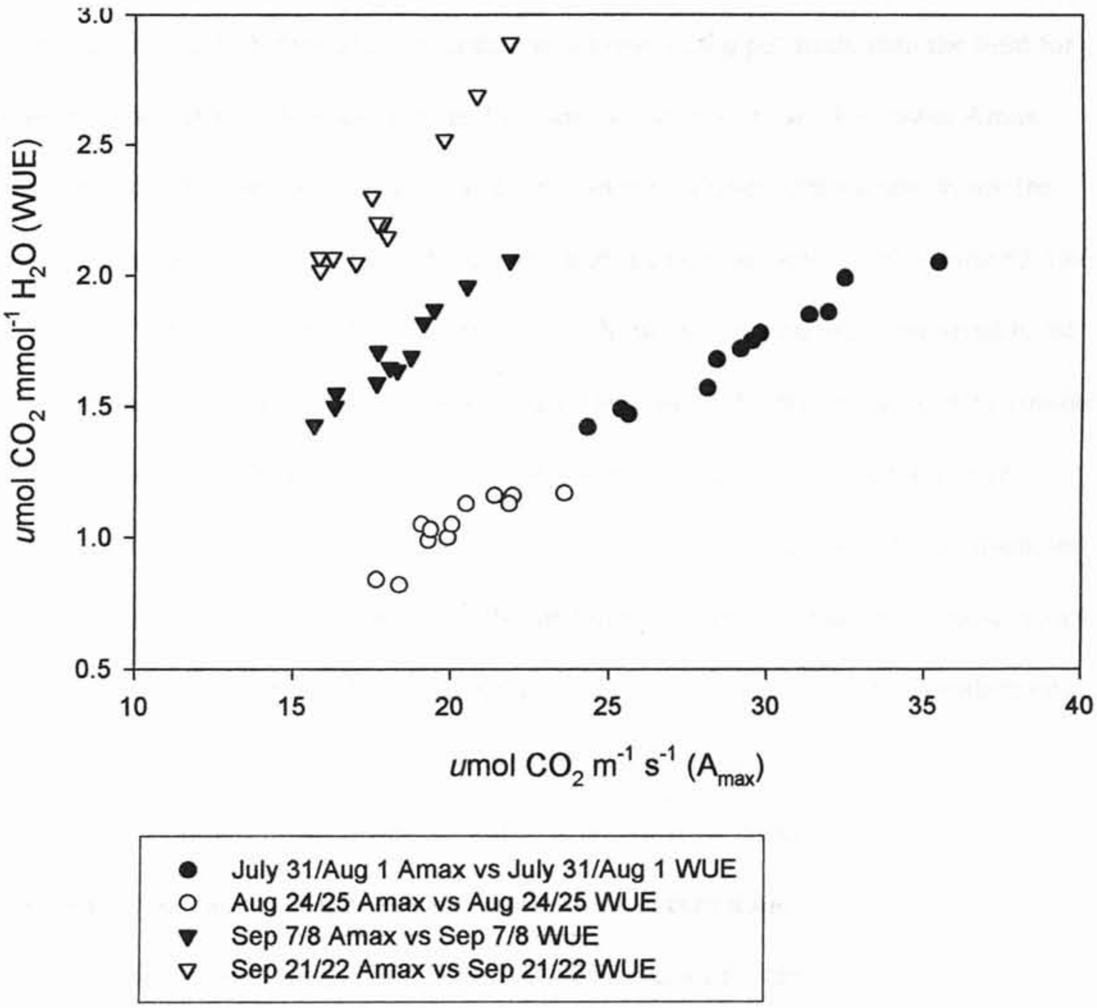


Figure 8. Plot of Maximum Photosynthetic Acitivity (A_{max}) and Water Use Efficiency (WUE), Year One, Field Study

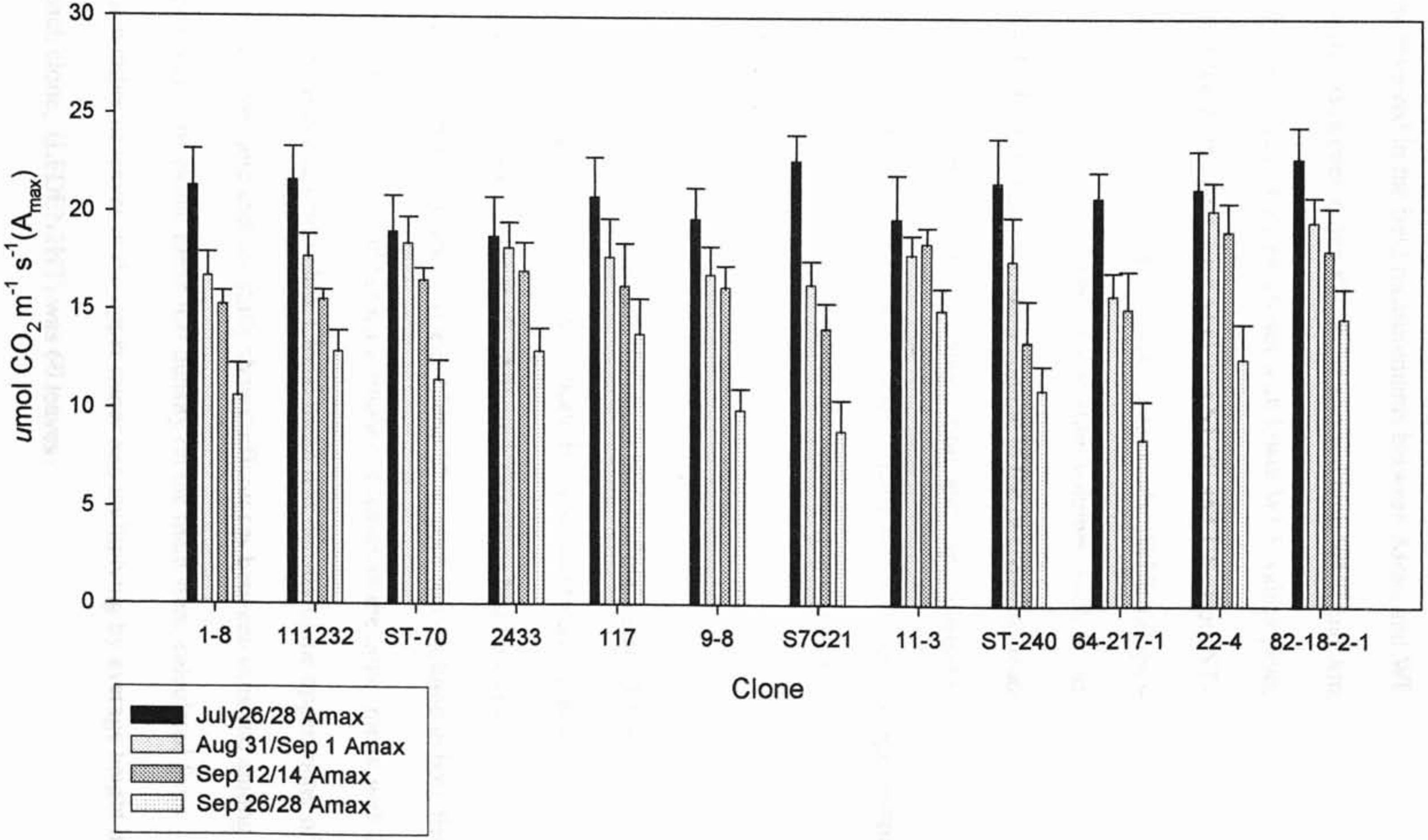


Pot Study

The highest photosynthetic values for all clones during the season occurred in July (July 26/28) and decreased throughout the rest of the year. There was less variation observed in Amax values in the pots than in the field. Amax values were lower in the pot study than the field. Stomatal conductance was lower in the pot study than the field for measurements taken in July and September, but similar in August. The lower Amax values observed in the pot study may be due to several biochemical signals within the clones relative to the limited space for growth and the early season stress. Clone 82-18-2-1 showed highest photosynthetic activity in both the pot and the field compared to all other clones. This clone produced average stem volume in the pot and poor stem volume in the field study in the first year and was the poorest of these clones in twelve-year volume. This clone was one of the tallest in the field study, but produced little diameter compared to other clones. Clone 82-18-2-1 had more branches compared to most clones and high leaf area during the first year, suggesting that high photosynthetic productivity is allocated to leaf, branch, or root growth instead of main stem growth. Several factors affect rate of photosynthesis including light, carbon dioxide concentration, available water, and temperature. Light and carbon dioxide concentration during measurements were controlled in both the pot and field study, but available water and temperature may have affected photosynthetic rate and resulted in different values than obtained under different conditions such as by controlling temperature or limiting available water. Mean clonal Amax values throughout the season are presented in Figure 9.

WUE showed an upward trend from July (July 26/28) through late September (Sep 26/28) in the pot study. The air and leaf temperatures observed were highest in July

Figure 9. Means with Standard Errors for Maximum Photosynthetic Activity (A_{max}), Year One, Pot Stuc



(July 26/28) and in most clones lowest in late September (Sep 26/28). The linear relationship observed in the field measurements between Amax and WUE was not seen in the pot study. However, clone 82-18-2-1 showed high WUE and Amax values in the pot study. In some circumstances, clones with lower WUE values produced larger stem volumes at the end of the year, such as clones ST-70 and 1-8. Both ST-70 and 1-8 were producers of high stem volume in the twelve-year study. WUE values were found to be lower in several clones that produced smaller stem volumes, such as clones ST-240 and 64-217-01, both of which had poor stem volume in the twelve-year study. WUE was calculated by utilizing photosynthetic, transpiration, and vapor pressure values obtained from the LI-Cor. In the pot measurements, transpiration was lower on average compared to the field values. Mean clonal WUE values are presented in Figure 10.

Leaf Measurements

Field Study

The average number of leaves in the upper meter of main stem (LEAFDENS) was 23. Clone 64-217-01, poor stem volume in both first-year and twelve-year studies, had the most leaves in the upper meter at 29. Although this clone had low stem volume, it produced more branches than other clones. Clone 22-4, poor stem volume in both first and twelve-year field studies, had the least number of leaves in the upper meter with 20, but did not produce as many branches. Clonal mean leaf density in the upper meter of main stem in both the field and pot study shows differences between sites and among clones (Figure 11). The clonal mean leaf density on the main stem, calculated from counting the number of leaves in the upper meter and multiplying by average height in meters of each clone, (LFDEN2HT) was 60 leaves per stem. Clone 117 had the highest

Figure 10. Means with Standard Errors for Water Use Efficiency (WUE), Year One, Pot Study

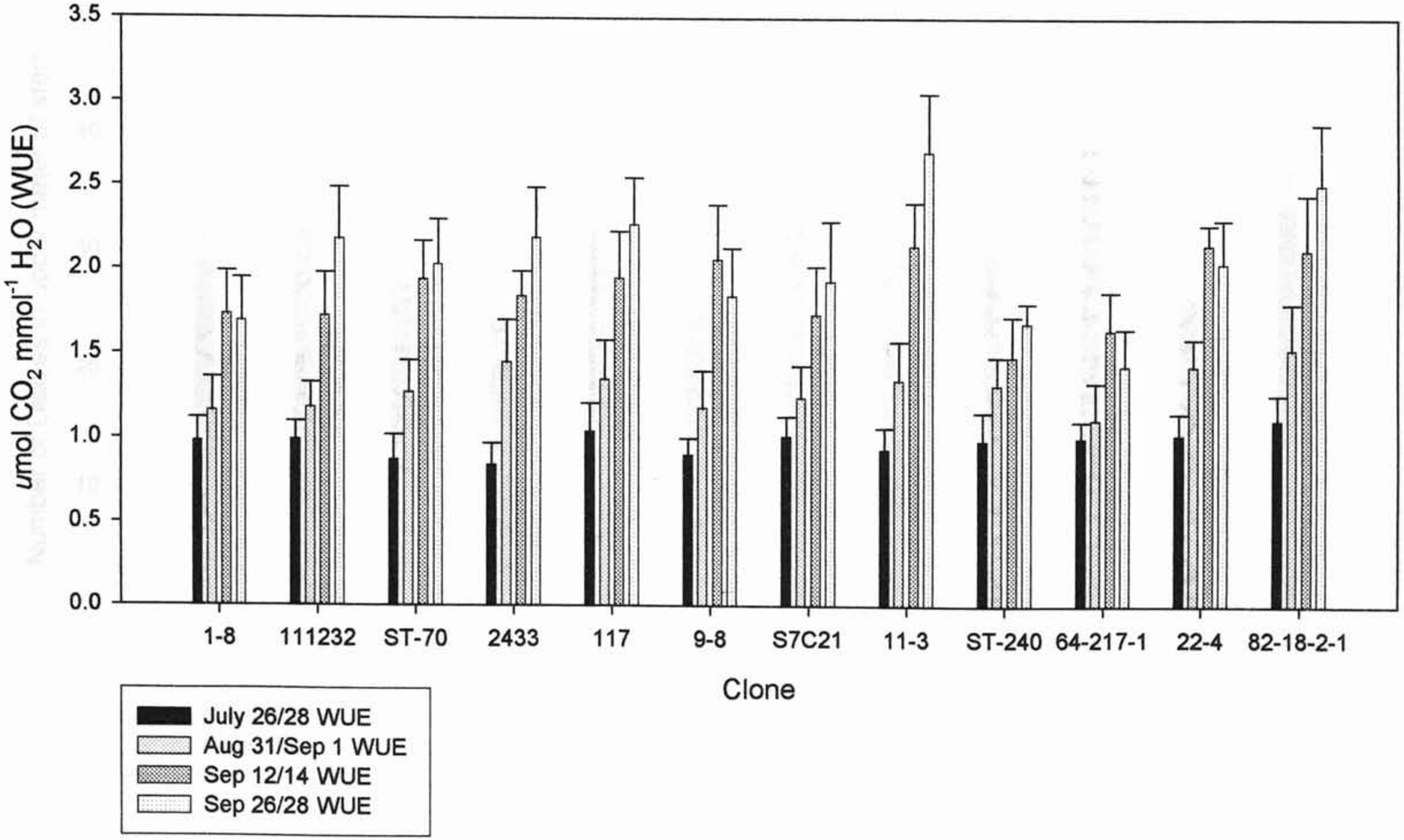
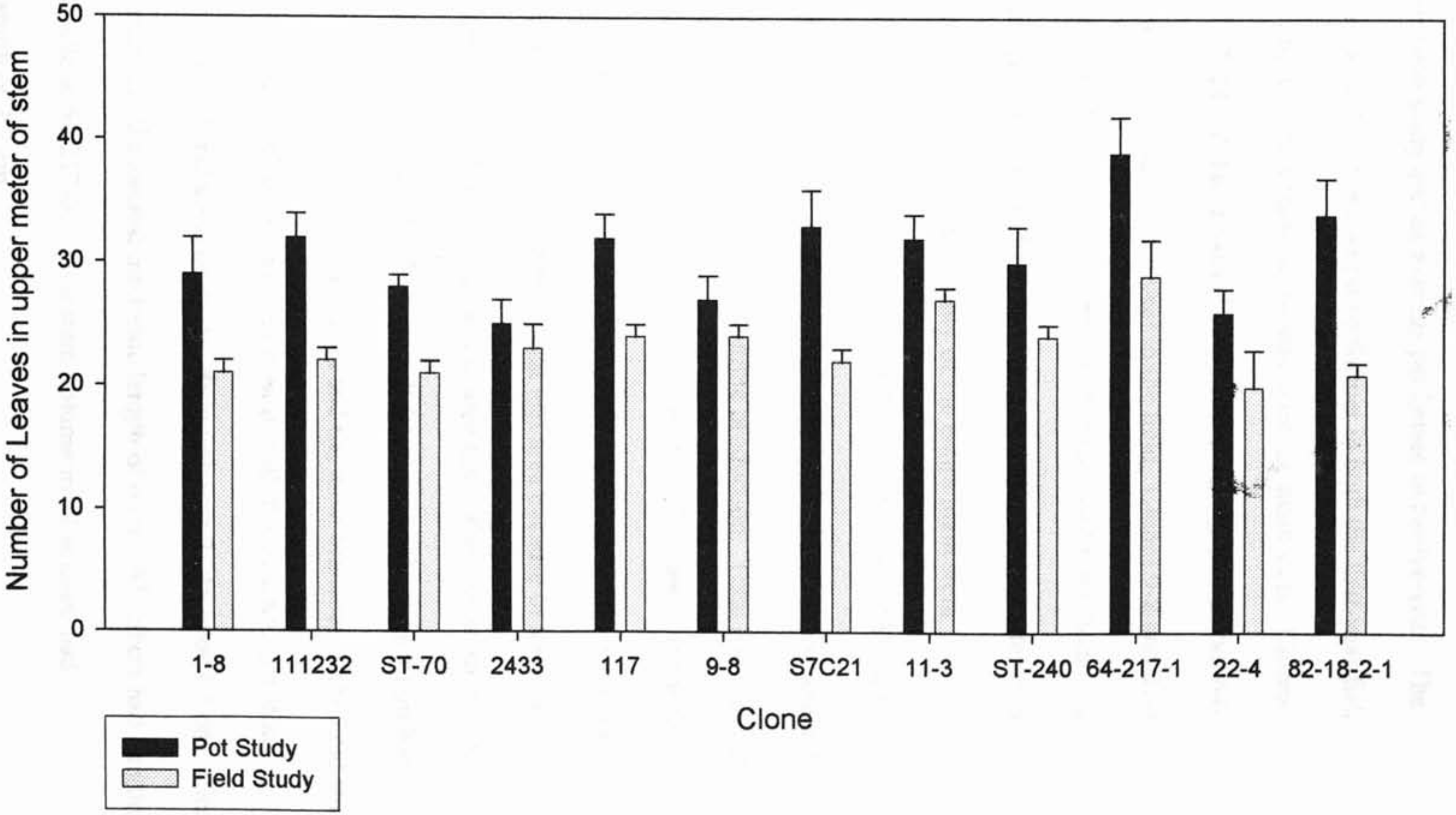


Figure 11. Means with Standard Errors for Leaf Density in Upper Meter of Stem, Field and Pot Study

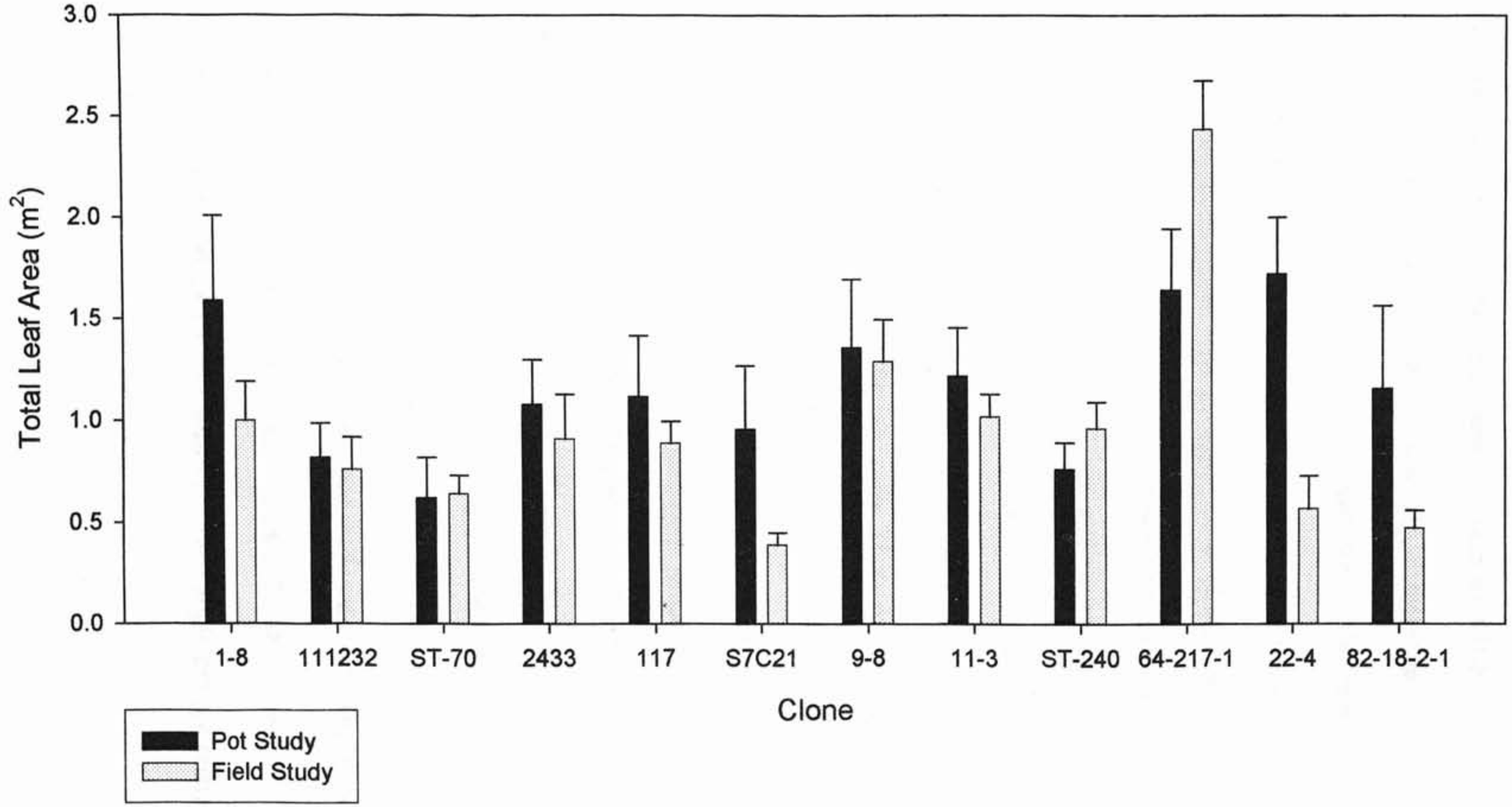


mean leaf density on the main stem at 72. Clone 117 was one of the best performers in the one-year field study and an average performer in twelve-year. The clone with the fewest leaves was 22-4, the poorest performer in both the first-year field study and the twelve-year study, with a mean of 44 leaves on the main stem. Clones 117, 11-3, 1-8, 64-217-01, and ST-240 all had relatively high leaf densities and all but 64-17-01 produced high stem volume during the first year in the field. Clones 9-8 and 22-4 had the lowest leaf densities, both less than 50 leaves, and both showed poor stem volume in both one-year field and twelve-year studies. Leaf density in the upper meter of main stem is more accurate than the estimated leaf density of the entire main stem.

Leaf angle in the field ranged from 43° (111232 and 2433) to 62° (9-8). The mean leaf angle for the field study was 53°. The differences in leaf angle did not seem to reflect differences in growth or stem volume production. Total leaf area ranged from 0.39 m^2 (S7C21) to 2.44 m^2 (64-217-01). Ten out of 12 clones in the field had higher leaf area on branches than on the main stem, 111232 and S7C21 being the exceptions. Clone S7C21 may have had a smaller total leaf area because of less branch leaf area, however, clone 111232 had more total leaf area than other clones such as ST-70, 22-4, and 82-18-2-1. Both clones 111232 and S7C21 also had the fewest number of branches. Clone 64-217-01 had the highest leaf area and the most branches in the field study. Figure 12 shows a bar chart of total leaf area in both the field and pot study.

The overall clonal average internode length was 0.045 m or 4.5 cm. Clone 22-4, a poor performer, had the longest internode length of 6 cm. All others had lengths between 4 and 5 cm. Clone 64-217-01, poor stem volume in all studies, had the shortest internode length of 3.7 cm.

Figure 12. Means with Standard Errors for
Total Leaf Area, Field and Pot Study



Pot Study

The average leaf density in the upper meter of main stem (LEAFDENS) over all clones was 31 leaves. The average leaf density in the upper meter multiplied by average clone height (LFDENS2HT) was 44 leaves on the main stem. The clones with the least leaves in the upper meter of main stem included 2433 with 25 leaves and 22-4 with 26 leaves. The clones with the most leaves in the upper meter of main stem were 64-217-01 with 39 leaves and 82-18-2-1 with 34 leaves. Clones with the most leaves on the entire main stem (LFDEN2HT) were S7C21 with 61 leaves and 111232 with 58 leaves, both of which produced greater stem volume than all other clones in the pot study. The clones with the least leaves on the main stem were 9-8 with 31 leaves and 2433 with 33 leaves, and both produced poor stem volumes in the pot study. These results suggest that leaf density on the main stem is related to stem volume production. The leaf density in the in the upper meter of main stem was higher in the pot study than in the field (Figure 11). The higher density in the pot was a result of less internode length between leaves. Leaf internode length in the pot study was between 2.6 cm (64-217-01) to 4.3 cm (22-4) while those in the field were between 4 and 5 cm. Clone 64-217-01 also had the shortest internode length in the pot study and 22-4 had the longest. There was no correlation between stem volume and leaf internode length.

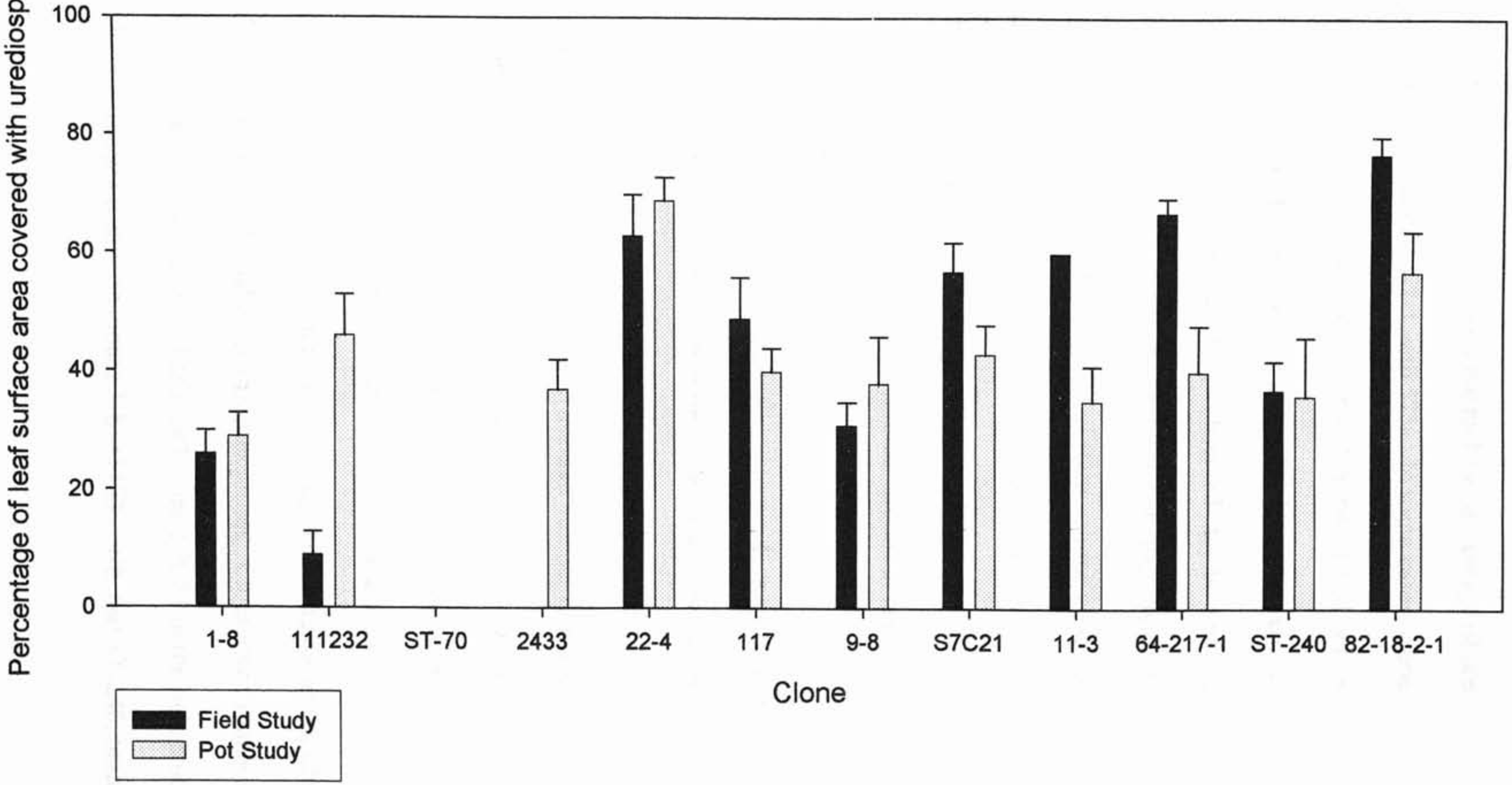
The average leaf angle for all clones in the pot study was 51°. The clones with the largest angles included 1-8 with 56°, 11-3 with 55°, and 82-18-2-1 with 56°. The clone with the smallest angle was 64-217-01 with 47°. Leaf angle did not relate to stem volume production.

The average total leaf area over all clones was 1.17 m^2. The clones with the most total leaf area included 22-4 with 1.72 m^2 . 64-217-01 with 1.65 m^2 and 1-8 with 1.59 m^2 (Figure 12). The clones with the least total leaf area included ST-70 with 0.62 m^2, ST-240 with 0.76 m^2, and 111232 with 0.82 m^2. The clones with the least leaf area had fewer branches than the other clones. The clones with the most leaf area also had large numbers of branches. Leaf area did not necessarily relate to branch production or stem volume, suggesting that growth may not be dependent on leaf area alone. In general, the clones in the pot study produced greater leaf area than in the field study. This observation suggests, as mentioned earlier, that greater leaf area and density may have been required to maintain survival of the clones in the pots and did not necessarily relate to growth of the main stem.

Leaf Rust

Premature defoliation was observed in clones infected with *Melampsora* leaf rust in both the field and pot study. Infection began one month earlier in the field, in July. After the first rainfall in August, the clones in the pot study also showed infection. One selected clone, ST-70, showed no infection at either location suggesting possible resistance. Presence of urediospores on the upper leaf surface varied by location and clone (Figure 13). The percentage of leaf surface area covered with urediospores was observed in the field in late August. The overall mean leaf rust score was 37% in the field study and 39% in the pot study. Clones 2433 and ST-70 had no urediospores on the upper or lower leaf surface in the field, however 2433 averaged 37% coverage of leaf surface with urediospores in the pot study. Clone 82-18-2-1 had the highest percentage of urediospores in the field with an average of 77% and 22-4 had an average of 63%.

Figure 13. Means with Standard Errors for *Melampsora* Leaf Rust (MLR) Score, Field and Pot Study

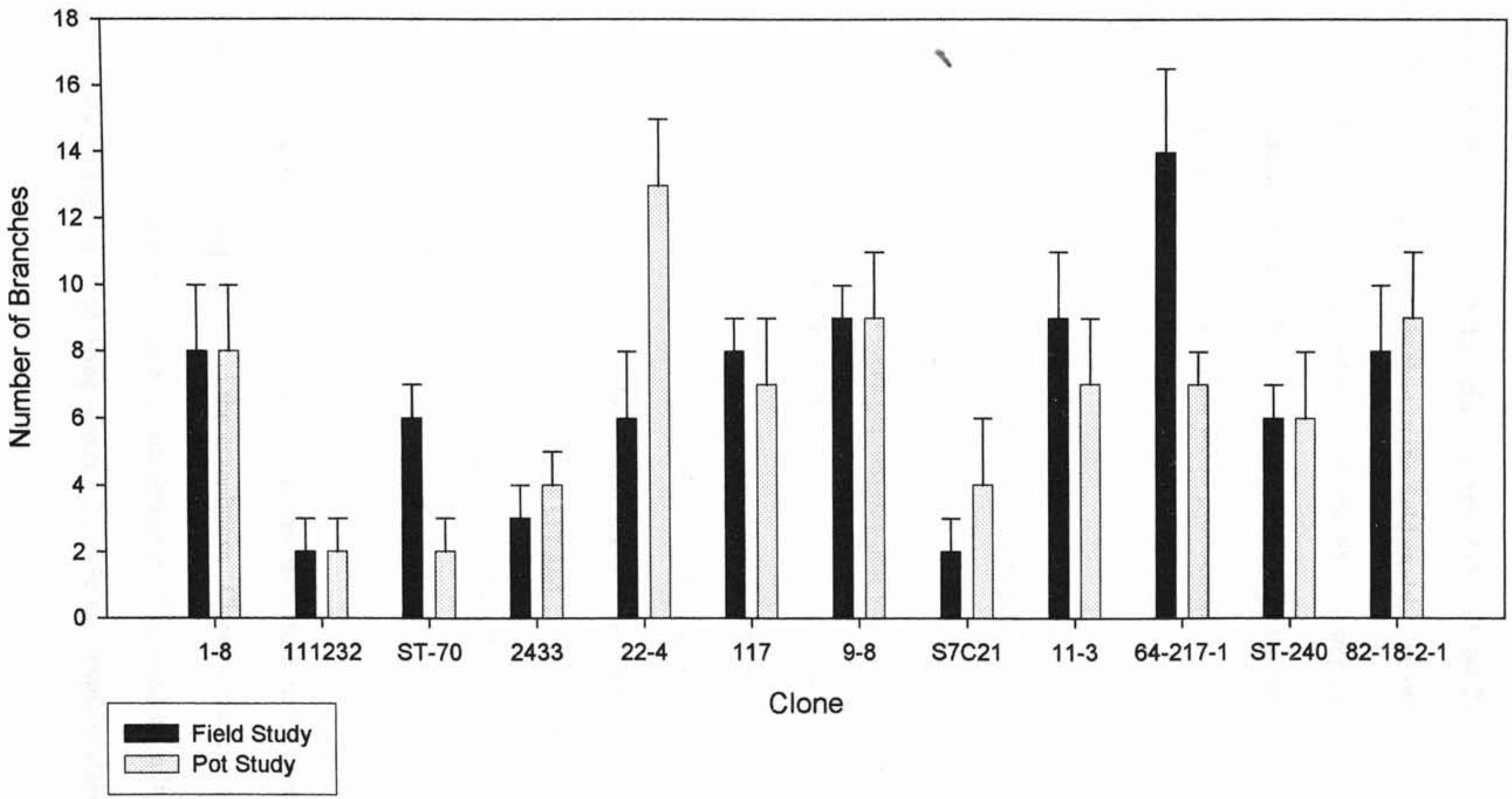


The clones with the least percentage of urediospores in the pot study included 1-8 with 29% and 11-3 with 35%. The clones with the highest percentage of urediospores included 22-4 with 69% and 82-18-2-1 with 57%. In some cases, clones exhibited similar scores in both field and pot study, such as 1-8, 64-217-01, and ST-240. In other instances, differences in scores between the pot and field study were apparent, such as in 111232, 2433, and 82-18-2-1. The difference observed may be due to different races of *Melampsora* leaf rust. Clones 22-4 and 82-18-2-1 which displayed high percentages of urediospores, were the poorest clones in terms of stem volume production, suggesting that perhaps, leaf rust has an effect on overall stem volume production not seen in the first year, but in subsequent years. Perhaps this same observation can explain why ST-70 produces larger stem volume compared to most other clones in later years.

Branch Characteristics

In both the field and pot study, clones found to produce more branches generally carried higher branch leaf area than the main stem. Some clones that exhibited higher photosynthetic activity (A_{max}) produced more branches. All selected clones produced branches during the first year (Figure 14). The average number of branches in the upper meter of main stem in the field and pot study was 7. There were smaller secondary branches produced from the main stem branches in the pot not measured in this study. The average length of a branch in the pot study was 64.46 cm and the average length in the field was 73.96 cm. Clones with longer branches had larger diameter branches and those with smaller branches had smaller diameter branches. Clones with longer branches usually had fewer branches, such as in 111232, 2433, and S7C21 in the field study and ST-70 and S7C21 in the pot study. In clones 1-8, 111232, 9-8, and ST-240, branch

Figure 14. Means with Standard Errors for Number of Branches in Upper Meter of Stem, Pot and Field Study



number was similar in both studies. Clones 22-4, 2433, 82-18-2-1, and S7C21 produced more branches in the pot study than in the field. Clones 11-3, 117, 64-217-01, and ST-70 produced fewer branches in the pot study than in the field study. The differences in the number of branches produced suggests that environment plays an important role in branch production. Branch number and size are important in clone form. Fewer branches in the main stem would be desired for wood production.

Length of Growing Season

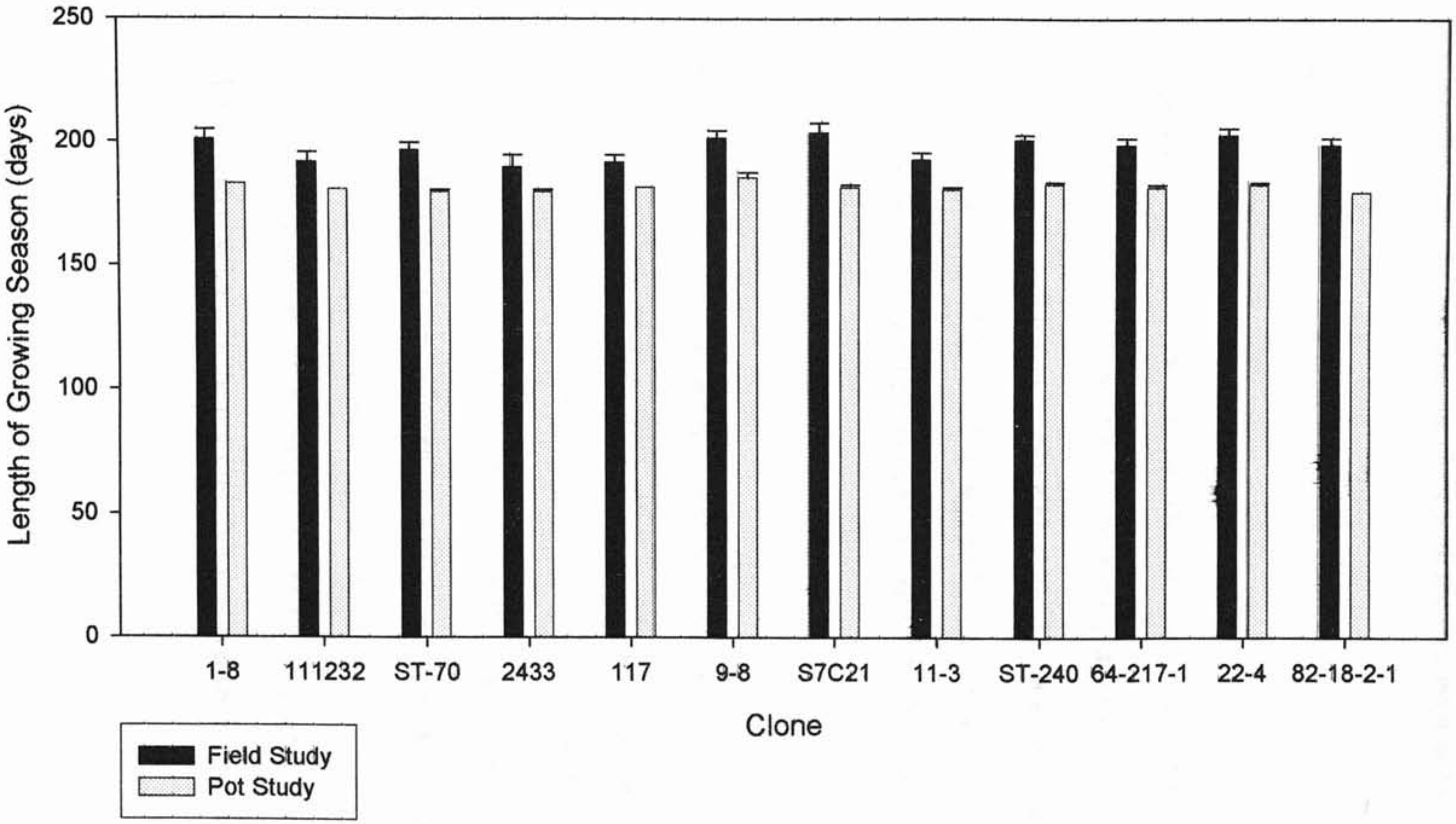
Field Study

Environmental conditions change from year to year and influence timing of bud flush and set. The dates of bud flush may not reflect true adaptations to the environmental conditions since cuttings were planted this first year. The clonal means for length of growing season for both the field and pot studies are presented in Figure 15. The average date of flush for all clones in the field was April 6. The average date of bud set for clones in the field was October 19. The average length of season from bud flush to bud set was 198 days. Clone S7C21 had the longest season in the field, 204 days. Clone 2433 had the shortest season, 190 days. Clones 117 and 111232 had relatively short growing seasons but were above average performers during the first year. Clones 22-4, 9-8, 1-8, and ST-240 had growing seasons over 200 days.

Pot Study

Clones in the greenhouse flushed a few days earlier than those in the field probably because of warmer temperatures in the greenhouse. Clones in the pot study all set bud October 1, 2001 in response to freezing temperatures. This resulted in little variation among clones for length of growing season. The average length of days

Figure 15. Means with Standard Errors for Length of Growing Season, Field and Pot Study



between bud flush and bud set was 182 days. The clone with the longest length of growing season was 9-8 with 186 days and the clone with the shortest was 2433 with 180 days.

Date of Leaf Fall

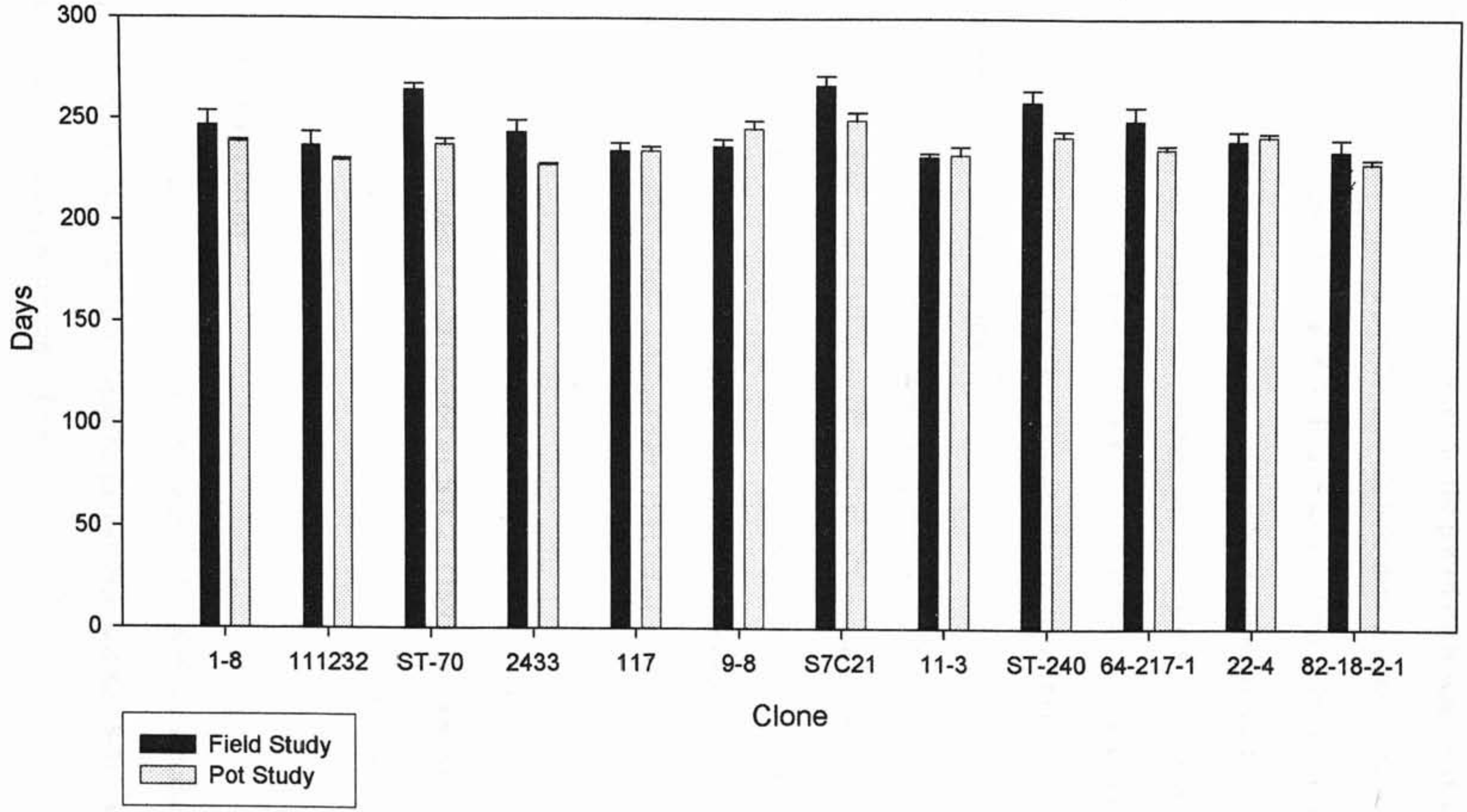
Field Study

The average date of leaf fall in the field was December 6 (Figure 16). Clones 111232, 117, ST-70, S7C21, 64-217-01, and ST-240 on average dropped leaves later into December. Clone 82-18-2-1 lost all leaves by November 19. The average date of leaf fall from bud flush for clones in the field was 246 days and 55 days past bud set. Clone 11-3 dropped leaves earliest, 232 days after bud flush. Clone S7C21 dropped leaves latest after bud flush, 247 days.

Pot Study

The average number of days past bud flush that the leaves fell was 237 days (Figure 16). The clones lost leaves 55 days past bud set, as did the field clones. Clones which lost leaves early included 2433 at 228 days, or 48 days past bud set. Clone 2433 resulted in low stem volume in the pot study, but was one of the largest in stem volume in the 12-year study. The longest average leaf retention was clone S7C21 at 250 days, or 68 days past bud set. Most clones dropped all leaves by November 25. Clone S7C21 dropped leaves later in both the pot study and field study compared to other clones. Clone S7C21 had the greatest volume in the pot study but was average in the field and 12-year study.

Figure 16. Means with Standard Errors for Leaf Fall (Days after Bud Flush),Field and Pot Study



Number of Roots in Pot Study

The average number of first order roots for the potted study was 33 (Figure 17). Clones with the most roots included S7C21, also the best stem volume in the pot study, with 46 roots on average, and 117, one of the best in stem volume, with 40 roots. Clones with fewer roots included ST-70, with average stem volume in the pot study, with 19 roots and 111232, one of the best for stem volume, with an average of 22 roots. The number of roots did not appear to relate to volume growth in first or twelve-year study. Growing the clones in pots may not represent root production under field conditions.

Biomass Partitioning in the Pot Study

The average above-ground biomass including stem and branches was 244.18 g, twice the amount of below-ground biomass (Figure 18). Clones with the most above-ground biomass included S7C21 (413.4 g) and 1-8 (318.85 g) and these clones resulted in higher stem volume in the pot study compared to all other clones selected. The clones with the least above-ground biomass included 2433 (153.99 g), 9-8 (160.26 g), and ST-240 (161.94 g). These three clones had small stem volumes in the pot study.

The average below-ground or root biomass was 122.27 g. Clones with the most below-ground biomass included ST-70 (166.64 g), S7C21 (159.81 g), and 11-3 (157.79 g). The clones with the least root biomass included those with poor stem volume: 2433 (91.51 g), ST-240 (50.3 g), and 9-8 (92.5 g).

Specific Gravity in Pot Study

Specific gravity ranged from 0.323 to 0.420 g/cm^3. The average specific gravity was 0.375g/ cm^3. Clones with the highest specific gravity included 82-18-2-1 with 0.420 g/ cm^3, S7C21 and 11-3 with 0.410 g/cm^3. Clone 82-18-2-1 resulted in average stem

Figure 17. Means with Standard Errors for Number of Roots, Pot Study

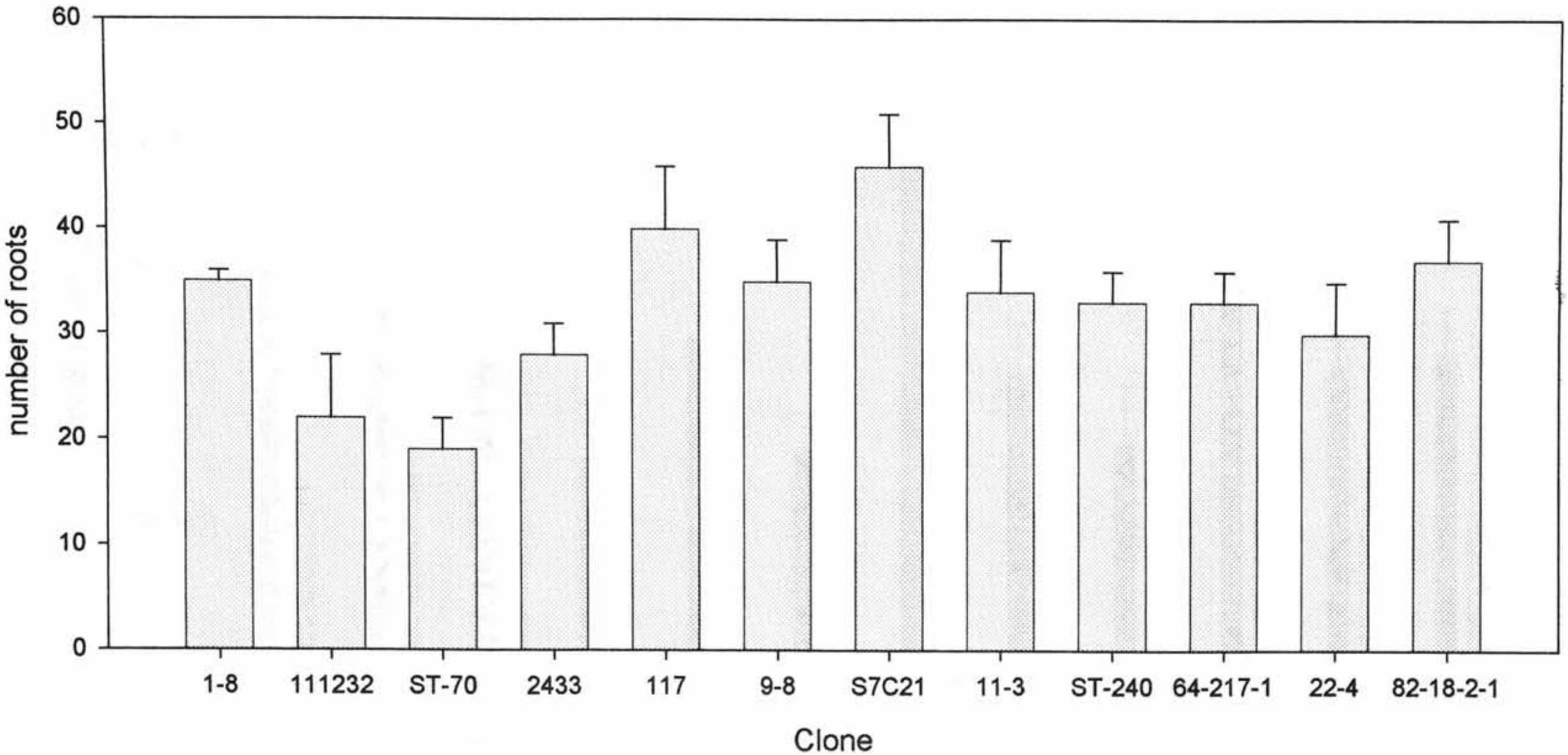
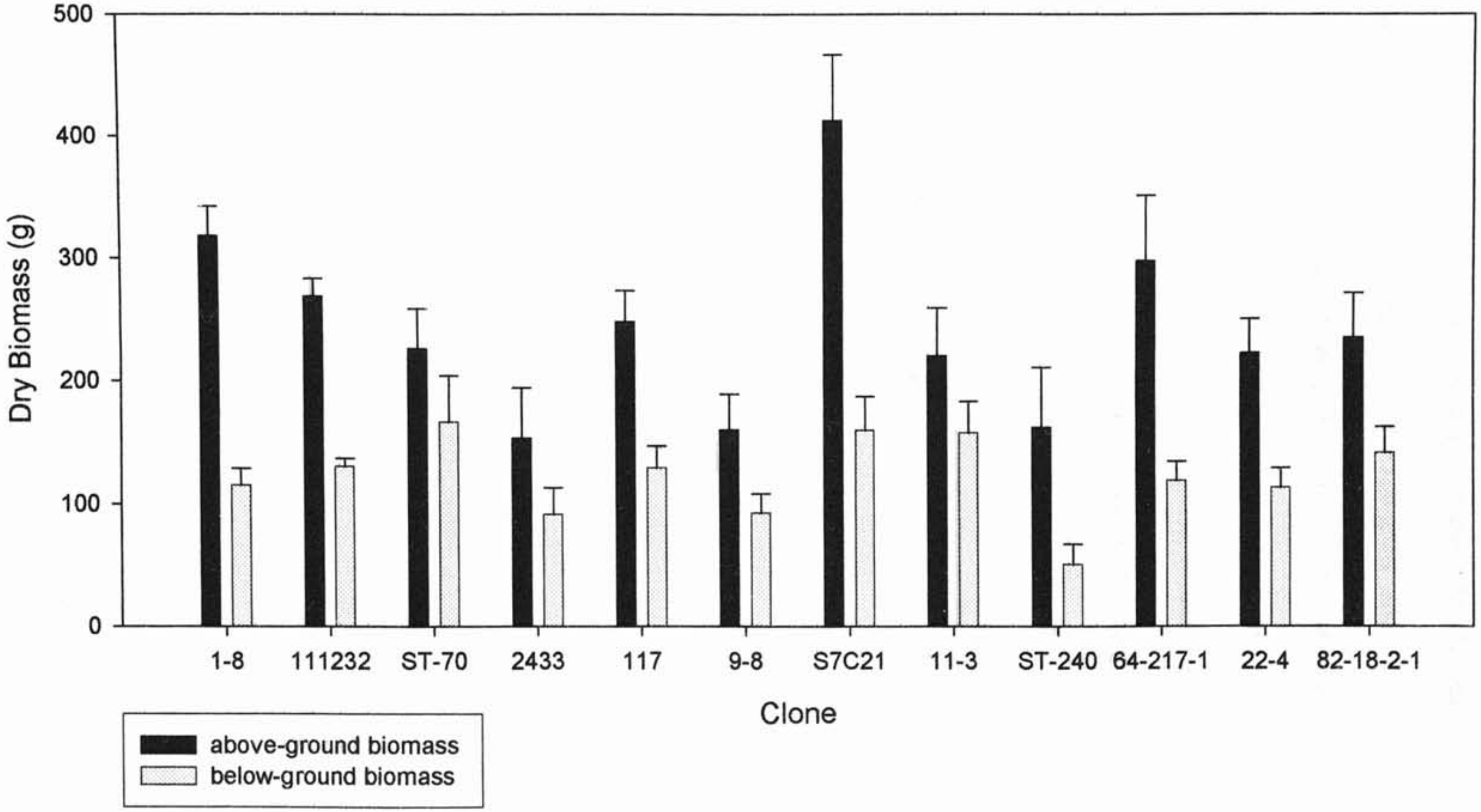


Figure 18. Means with Standard Errors for Above and Below-Ground Biomass, Pot Study



volume in the pot study and one of the poorest in the 12-year study. Clone S7C21 had the greatest stem volume in the pot study but was average in the 12-year study. Clones with the least specific gravity included 9-8 with 0.320 g/cm^3 and ST-240 with 0.330 g/cm^3. Clones 9-8 and ST-240 were lower in stem volume compared to all other clones in the pot study. Clone ST-240 had small stem volume in the 12-year study and clone 9-8 produced average stem volume in the 12-year study. The results from measurements of specific gravity does not appear to relate to low or high stem volume.

SECTION 2. RESULTS AND DISCUSSION OF STEPWISE REGRESSION

A forward stepwise selection procedure was utilized to identify the most significant year one variable, or measurement, that explains the twelve-year volume. Independent variables were added sequentially in the order of significance until no variables excluded were significant at the 0.15 level. The stem volume from the twelve-year data was used as the dependent variable in the procedure. All variables fitted made a significant contribution to the variation observed in the twelve-year volume, however, after 95% of the variance is explained the remaining variables fitted account for very little variability in the model and will not be discussed. The results obtained should be useful in determining which first-year traits are most closely related to 12-year volume.

Field Study

Table V lists the variables from the field study found to make significant contributions to the regression model. The first four variables listed in Table V explain over 95% of the 12-year volume. The first variable selected in the field data was Sep7/8 WUE (Sep7WUE), which as a one variable model explains 67% of the variation observed in the twelve-year volume. As mentioned in the section on gas exchange results from the field, WUE showed a simple linear correlation with Amax when water supply was not limited. In most instances clones that produced higher stem volume at the end of the year, had lower WUE values, indicating that greater growth requires more water.

TABLE V

Summary of Stepwise Regression, Field Study

Variable	Partial R-Square	Model R-Square	F Value	Pr > F
Sep7WUE	0.6720	0.6720	20.49	0.0011
DIA1	0.1909	0.8629	12.53	0.0063
DIA12	0.0529	0.9158	5.03	0.0552
HT11	0.0394	0.9552	6.15	0.0422
AUG(Amax)	0.0220	0.9772	5.78	0.0530
length of season	0.0138	0.9910	7.62	0.0399
DIA9	0.0054	0.9964	6.01	0.0704
HT4	0.0026	0.9990	7.64	0.0699
HT2	0.0010	1.0000	43.69	0.0221
DIA7	0.0000	1.0000	765.20	0.0230

The second variable selected for the field data was the first diameter measurement (DIA1) taken on May 15, 2001, and it accounted for an additional 19% of the twelve-year volume variability. The fit of this trait suggests that rapid early growth is associated with future volume production. The third variable selected, the last diameter measurement taken October 16 (DIA12), accounted for an additional 5% of the twelve-year volume variability. The fit of this trait suggests that diameter growth at the end of the first year is also a good indicator of future volume growth. Height taken late in the first year, (HT11) on October 2, accounted for an additional 4% of the twelve-year volume variability. This height trait combined with the significant diameter variables in the field study suggests that selection for growth (height and diameter) at the end of the first year is a viable approach to predicting volume in later years. Table VI presents the mean values for the first four significant variables from the model and how each clone in the first year compared to the 12-year data.

TABLE VI

Clones Ranked by 12-Year Volume with Mean Values and Ranks for the First Four Significant Year One Variables in the Stepwise Regression, Field Study

Clone	12-Year Volume (mm^2xm)	Sep7 WUE	Rank	DIA1 (mm)	Rank	DIA 12 (mm)	Rank	HT11 (m)	Rank
1-8	2293258	1.59	9	5.17	3	40.92	1	2.89	2
111232	2073648	1.87	3	4.35	5	36.77	4	2.63	4
ST-70	1510387	1.64	8	4.49	4	33.87	6	2.57	8
2433	1025508	1.69	6	3.76	7	32.08	7	2.31	9
117	737899	1.71	5	3.37	9	40.00	2	3.04	1
9-8	627151	1.65	7	2.30	12	22.93	10	2.00	11
S7C21	459653	1.55	10	5.43	2	31.12	8	2.61	6
11-3	318699	1.96	2	3.79	6	34.82	5	2.60	7
ST-240	258205	2.06	1	6.23	1	38.99	3	2.63	5
64-217-1	223763	1.43	12	3.60	8	29.50	9	2.20	10
22-4	133458	1.82	4	3.00	11	14.43	12	1.45	12
82-18-2-1	102073	1.50	11	3.29	10	21.67	11	2.74	3

Pot Study

Table VII summarizes the stepwise regression results in the pot study.

TABLE VII

Summary of Stepwise Regression, Pot Study

Variable	Partial R-Square	Model R-Square	F Value	Pr > F
HT4	0.4808	0.4808	8.33	0.0180
Aug(XPP)	0.4338	0.9146	40.63	0.0002
LFDEN2HT	0.0530	0.9676	11.46	0.0117
Internode Length	0.0218	0.9894	12.28	0.0127
Leaf Angle	0.0084	0.9977	18.33	0.0079
Aug Cond	0.0019	0.9996	17.61	0.0137
ABOVEBIO	0.0004	1.0000	49.19	0.0060
DIA5	0.0000	1.0000	122.46	0.0081
BELOWBIO	0.0000	1.0000	8822.62	0.0068

The first variable selected was the fourth height measurement (HT4), taken July 3, which as a one variable model accounts for 48% of the variation observed in the twelve-year volume. The plot of height by date in the pot study (Figure 3), shows that the HT4 measurement was taken during or preceding the occurrence of stem damage, suggesting that perhaps early height growth even in the pot study is a good indicator of future volume production. The variable AugXPP, water potential taken August 31/September 1, was the second variable selected and accounted for an additional 43% of the variation in 12-year volume. The fit of this variable may only suggest that the limited soil volume of the pots lead to some level of stress and affected not only the water uptake capacity of the clone, but also growth. The third variable fit was LFDEN2HT, total main stem leaf density, and it accounted for an additional 5% of the variation in 12-year volume. The fourth variable, leaf internode length, accounted for an additional 2% of the variation observed in the 12-year volume. Leaf internode length affects leaf density which was listed as the third variable. Less internode length results in greater leaf density. The variables listed in the stepwise regression from the pot study may only reflect the nature of the pot study, since the clones grown in pots developed and grew very differently from those in the field. It is not appropriate to ignore the results from the pot study, but the conditions observed suggest the reliability of the pot study relative to 12-year volume is questionable. Since the field study is similar to the 12-year study, the field study is a better test of the performance of the selected clones. Table VIII shows the mean values in the pot study for the first four significant variables in the stepwise regression and the rank of each clone in the first year compared to the 12-year data.

Table VIII

Clones Ranked by 12-Year Volume with Mean Values and Ranks for the First Four Significant Year One Variables in the Stepwise Regression, Pot Study

Clone	12-Year Volume (mm^2 x m)	HT4	Rank	Aug (XPP)	Rank	LFDEN 2HT	Rank	Internode length	Rank
1-8	2293258	0.85	3	-1.53	9	45	5	0.04	4
111232	2073648	0.90	2	-1.40	5	59	2	0.03	10
ST-70	1510387	0.74	6	-1.35	2	45	6	0.03	6
2433	1025508	0.62	9	-1.26	1	33	11	0.04	2
117	737899	0.77	5	-1.38	4	46	4	0.03	11
9-8	627151	0.65	8	-1.57	11	30	12	0.04	3
S7C21	459653	1.02	1	-1.42	7	61	1	0.03	8
11-3	318699	0.79	4	-1.54	10	44	7	0.03	7
ST-240	258205	0.43	12	-1.43	8	37	9	0.04	5
64-217-1	223763	0.55	11	-1.37	3	49	3	0.03	12
22-4	133458	0.73	7	-1.41	6	34	10	0.04	1
82-18-2-1	102073	0.61	10	-1.60	12	44	8	0.03	9

SECTION 3. RESULTS AND DISCUSSION OF MOLECULAR MARKER DATA

Simple Sequence Repeat (SSR) Data

Primers utilized for SSR data resulted in little variation among the clones. Thirty-seven primers were screened with DNA isolated from the 12 selected clones. Most primers utilized were developed for *P. trichocarpa* and many did not show positive amplification in the selected *P. deltoides* clones.

Random Amplified Polymorphic DNA (RAPD) Data

Twenty-five primers produced by the University of British Columbia were screened using DNA isolated from the 12 selected clones. Fifteen primers resulted in positive amplification (bands) in 1.5% agarose gel, stained with ethidium bromide and visualized under an ultraviolet light. Bands from each run were scored for their presence (1) or absence (0) in each selected clone. Eleven primers resulted in multiple bands and presence or absence of a band at a locus was variable among clones. PROC TTEST was utilized in SAS to test for a relationship between presence or absence of a band at each locus and 12-year volume. Significant differences were tested between mean volume of clones with absence of a band and mean volume of clones with a band present. Equality of variance was tested to decide which t-value to use (pooled or Satterthwaite). Statistical significance was found at a few loci (Table XIX).

TABLE XIX

T-Test for Significant Variation in Primer/Loci Absence or Presence in Relation to 12-Year Volume

Primer/ loci	+/-	Mean Volume+/Volume- (mm^2xm)	Method	DF	t-value	Pr>|t|
5/1	2/7	180140/ 700437	Satterthwaite (unequal)	6.94	-2.80	0.0270
5/2	4/5	905675/ 328128	Pooled (equal)	7	2.41	0.0466
55/1	2/10	2180000/ 539680	Pooled (equal)	10	4.95	0.0006
6/6	7/3	673221/ 1440000	Pooled (equal)	8	-1.49	0.1758
6/8	7/3	629910/ 1540000	Pooled (equal)	8	-1.87	0.0978
51/4	3/9	1400000/ 616947	Pooled (equal)	10	1.68	0.1244

+/- = number of selected clones showing presence/absence of band in agarose gel
DF = degrees of freedom
Vol+/Vol- = clonal mean volume for clones with a band present/clonal mean volume for clones with a band absent

Primer 55/loci 1 resulted in a highly significant difference in volume between clones with absence and presence of a band. Clones with absence of a band at that particular locus had a much lower volume than those with presence. Primer 5/loci 1 and loci 2 also show significant variation in volume between presence and absence of a band. Presence of a band did not necessarily mean higher volume. For instance, absence of a band at primer 5/loci 1 resulted in higher volume compared to presence of a band. The last three primer/loci shown in Table XIX suggest biologically significant volume differences between those with presence and absence of a band and suggests that if the sample size was larger, the results may show significant t-values.

These results from the RAPD work are very preliminary. However, the t-test for a relationship between absence and presence of bands and 12-year volume did result in a several significant primers/loci volume associations. The objective was to test for a possible relationship. From these results showing several primers absence or presence significantly related to volume, it is reasonable to conclude that relating volume to genetic diversity by use of molecular markers such as RAPD may be useful, and deserves further study.

CHAPTER V

SUMMARY AND CONCLUSIONS

Multiple traits were measured in the first year of growth on twelve selected eastern cottonwood clones planted in the field or in pots in two different locations. The objective was to determine which traits are related to stem volume estimated from twelve-year growth data. A forward stepwise regression procedure was utilized to relate traits to volume. Significant variables found in the field study included WUE in early September, first and last diameter measurements, and late height measurements. These four variables explained over 95% of the variation observed in the twelve-year growth data. In most clones, those with rapid early growth resulted in higher stem volume at the end of the first year and most clones with higher volume at age one produced higher stem volume at age 12. This suggests that selection at age one based on growth variables is a viable approach to ensure improved performance in future years.

Measurements of significance in the pot study included height measured the first of July, August water potential, and leaf density on the main stem. Growing trees in pots resulted in different development of stems, leaves, and branches in terms of size and number compared to the field study. In the pot study, clones in pots had slowed growth by the end of June and some stems died back as a result of root: shoot imbalances, inadequate nutrition, and perhaps other environmental factors. Therefore, the results from the stepwise regression on pot study measurements may not be as useful as the field data. Rapid early growth, water potential, and leaf density were shown to be significant contributors to twelve-year volume. All three variables contribute toward survival and growth in the first year, so perhaps concentration on growth, as suggested by the field study, remains a reasonable conclusion.

Some characteristics worth noting in the 12 selected high volume clones at age 12 compared to low volume clones includes: low incidence of leaf rust, rapid early growth, moderate to many branches, larger height and diameter at the end of the season, moderate total leaf area, moderate to late-growing season, average to low WUE and A_{max} values. Clones that produced lower volumes at age 12 displayed higher incidence of leaf rust, slow growth, few to moderate branches, variable leaf area, short growing season, and higher WUE and A_{max} values in the first year.

The nature of the pot study suggests that growing eastern cottonwood in pots for a full year should not be practiced. Some of the differences in performance and characteristics of the clones in the two studies included leaf and branch morphology. Leaves from the field study were larger than those from the pot study. Clones in the pot study produced more secondary branches than clones in the field.

Gas exchange measurements were taken under artificially-induced light saturated conditions and values obtained may not reflect values under normal atmospheric conditions. Several clones that produced lower stem volumes during the first year and twelve-year study exhibited higher WUE and A_{max} values in both studies. These results suggests that some clones allocate carbon to other tissues such as branch, leaf, and root growth instead of the main stem volume.

The first year following planting is considered the "establishment phase" and some measurements may need to be taken for the next few years to acquire additional information concerning performance of the selected clones.

Preliminary molecular work involving use of RAPD primers to compare 12-year volume in clones with a band present and a band absent at various loci resulted in a few primer/loci volume associations. Further research involving more RAPD primers is needed to research this relationship further.

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APPENDIX A

RANKING OF CLONES WITH MEANS AND STANDARD ERRORS FOR ALL MEASURED TRAITS, FIELD STUDY

TABLE X

Ranking of Clones with Means and Standard Errors of the Mean for May 15 (HT1 and DIA1) and May 29 (HT2 and DIA2), Field Study

Clone	HT1 (m) X±se	Rank	DIA1 (mm) X±se	Rank	HT2 (m) X±se	Rank	DIA2 (mm) X±se	Rank
1-8	0.32±0.05	3	5.17±0.67	2	0.40±0.05	1	5.52±0.78	1
111232	0.29±0.04	5	4.35±0.51	3	0.37±0.03	3	4.38±0.54	5
ST-70	0.26±0.04	7	4.22±0.38	5	0.29±0.05	7	4.49±0.67	3
2433	0.22±0.03	10	3.76±0.36	7	0.28±0.03	9	4.10±0.16	7
117	0.32±0.04	2	3.37±0.57	9	0.40±0.05	1	4.27±0.55	6
9-8	0.14±0.02	12	2.30±0.34	12	0.16±0.02	12	2.31±0.28	12
S7C21	0.34±0.03	1	5.26±0.42	1	0.36±0.04	6	5.43±0.57	2
11-3	0.29±0.02	4	3.79±0.28	6	0.36±0.03	5	4.00±0.30	9
ST-240	0.25±0.04	8	4.23±0.51	4	0.29±0.06	8	4.41±0.83	4
64-217-1	0.22±0.02	9	3.57±0.15	8	0.26±0.03	10	3.60±0.26	11
22-4	0.17±0.02	11	3.00±0.41	11	0.23±0.04	11	3.73±0.46	10
82-18-2-1	0.28±0.04	6	3.29±0.36	10	0.37±0.06	4	4.01±0.54	8

TABLE XI

Ranking of Clones with Means and Standard Errors of the Mean for June 12 (HT3 and DIA3) and June 26 (HT4 and DIA4), Field Study

Clone	HT3 (m) X±se	Rank	DIA3 (mm) X±se	Rank	HT4 (m) X±se	Rank	DIA4 (mm) X±se	Rank
1-8	0.50±0.09	3	6.19±1.16	1	0.67±0.12	3	8.17±1.68	1
111232	0.46±0.05	6	4.70±0.43	8	0.64±0.08	5	7.01±0.82	5
ST-70	0.39±0.06	7	4.63±0.55	9	0.51±0.08	9	6.65±0.92	7
2433	0.38±0.04	9	4.81±0.44	7	0.53±0.06	8	6.50±0.46	8
117	0.59±0.08	1	5.53±0.85	2	0.78±0.11	1	7.68±1.18	2
9-8	0.20±0.03	12	3.28±0.63	12	0.27±0.04	12	3.46±0.39	12
S7C21	0.49±0.04	4	5.48±0.43	3	0.61±0.07	6	7.41±0.65	3
11-3	0.48±0.05	5	4.88±0.62	6	0.65±0.07	4	7.01±0.84	6
ST-240	0.39±0.08	8	5.09±0.70	4	0.54±0.10	7	6.23±2.36	10
64-217-1	0.37±0.05	10	4.25±0.32	11	0.49±0.07	10	6.35±0.86	9
22-4	0.30±0.06	11	4.27±0.97	10	0.36±0.08	11	4.68±1.07	11
82-18-2-1	0.50±0.08	2	5.02±0.74	5	0.77±0.15	2	7.17±1.39	4

TABLE XII

Ranking of Clones with Means and Standard Errors of the Mean for July 10 (HT5 and DIA5) and July 24 (HT6 and DIA6), Field Study

Clone	HT5 (m) X±se	Rank	DIA5 (mm) X±se	Rank	HT6 (m) X±se	Rank	DIA6 (mm) X±se	Rank
1-8	0.89±0.16	3	9.69±1.71	2	1.21±0.21	3	13.70±2.67	3
111232	0.80±0.11	5	8.74±1.30	5	1.06±0.14	6	11.54±1.60	5
ST-70	0.65±0.11	10	7.26±1.14	10	0.85±0.13	10	9.32±1.70	10
2433	0.69±0.08	8	7.54±0.76	9	0.99±0.10	8	10.34±0.95	9
117	1.04±0.15	1	9.83±1.68	1	1.36±0.18	1	14.61±2.23	2
9-8	0.60±0.10	11	3.89±0.54	12	0.71±0.29	11	6.02±0.81	12
S7C21	0.77±0.11	6	8.96±1.12	4	1.07±0.15	5	11.53±1.55	3
11-3	0.86±0.10	4	8.99±0.95	3	1.08±0.16	4	12.42±1.77	4
ST-240	0.74±0.13	7	7.83±1.20	8	1.05±0.18	7	16.14±2.83	1
64-217-1	0.66±0.10	9	7.94±1.14	7	0.89±0.14	9	10.92±0.86	8
22-4	0.60±0.15	12	5.03±1.11	11	0.70±0.22	12	7.23±2.13	11
82-18-2-1	0.98±0.20	2	8.44±1.72	6	1.33±0.24	2	11.00±2.38	7

TABLE XIII

Ranking of Clones with Means and Standard Errors of the Mean for August 7 (HT7 and DIA7) and August 21 (HT8 and DIA8), Field Study

Clone	HT7 (m) X±se	Rank	DIA7 (mm) X±se	Rank	HT8 (m) X±se	Rank	DIA8 (mm) X±se	Rank
1-8	1.60±0.25	3	18.05±3.34	3	2.02±0.28	3	24.66±4.35	3
111232	1.34±0.17	8	15.73±2.30	6	1.66±0.18	7	20.17±2.72	5
ST-70	1.14±0.16	10	13.41±2.34	10	1.48±0.17	9	18.32±3.38	10
2433	1.34±0.11	7	14.00±1.46	9	1.60±0.11	8	18.90±1.79	8
117	1.75±0.20	1	20.05±2.76	2	2.16±0.21	1	26.94±3.57	1
9-8	0.87±0.13	11	8.769±1.21	11	1.15±0.14	11	12.54±1.73	11
S7C21	1.43±0.21	5	15.92±2.58	5	1.79±0.25	5	20.11±3.36	6
11-3	1.46±0.17	4	17.60±2.38	4	1.85±0.18	4	23.91±3.01	4
ST-240	1.39±0.23	6	21.64±3.89	1	1.74±0.24	6	26.78±15.84	2
64-217-1	1.19±0.19	9	14.57±2.58	8	1.44±0.23	10	19.26±3.36	7
22-4	0.80±0.22	12	8.70±2.77	12	0.98±0.25	12	10.77±3.46	12
82-18-2-1	1.72±0.24	2	14.82±2.88	7	2.10±0.25	2	18.71±3.29	9

TABLE XIV

Ranking of Clones with Means and Standard Errors of the Mean for September 4 (HT9 and DIA9) and September 18 (HT10 and DIA10), Field Study

Clone	HT9 (m) X±se	Rank	DIA9 (mm) X±se	Rank	HT10 (m) X±se	Rank	DIA10 (mm) X±se	Rank
1-8	2.48±0.30	2	30.33±5.07	2	2.86±0.32	2	36.80±6.03	1
111232	2.06±0.19	7	27.43±3.67	5	2.48±0.18	5	29.97±3.67	5
ST-70	1.91±0.19	9	22.06±3.71	9	2.34±0.22	8	29.50±4.96	6
2433	1.96±0.09	8	24.30±2.57	8	2.25±0.11	9	29.34±1.98	7
117	2.64±0.22	1	32.00±3.56	1	3.04±0.26	1	35.60±4.43	2
9-8	1.52±0.15	11	16.28±1.95	11	1.89±0.18	11	19.70±2.35	11
S7C21	2.17±0.28	5	25.23±4.07	6	2.44±0.29	7	28.51±4.61	8
11-3	2.29±0.19	4	29.03±3.28	3	2.60±0.25	4	33.11±4.37	3
ST-240	2.15±0.25	6	27.82±4.38	4	2.48±0.24	6	32.84±5.19	4
64-217-1	1.76±0.28	10	24.33±4.29	7	2.05±0.33	10	28.23±5.02	9
22-4	1.20±0.29	12	12.06±3.61	12	1.39±0.31	12	12.29 ±3.52	12
82-18-2-1	2.45±0.24	3	21.04±3.50	10	2.71±0.23	3	21.14±3.55	10

TABLE XV

Ranking of Clones with Means and Standard Errors of the Mean for October 2 (HT11 and DIA11) and October 16 (HT12 and DIA12), Field Study

Clone	HT11 (m) X±se	Rank	DIA11 (mm) X±se	Rank	HT12 (m) X±se	Rank	DIA12 (mm) X±se	Rank
1-8	2.89±0.28	2	39.47±5.49	1	2.92±0.28	2	40.92±5.98	1
111232	2.63±0.18	4	34.83±3.65	4	2.65±0.18	6	36.90±4.00	4
ST-70	2.57±0.26	8	32.78±5.26	6	2.62±0.25	7	33.87±5.35	6
2433	2.31±0.11	9	30.95±2.64	8	2.33±0.11	9	32.08±2.83	7
117	3.15±0.16	1	39.14±4.98	2	3.05±0.26	1	40.00±5.16	2
9-8	2.00±0.18	11	22.15±2.95	10	2.00±0.18	11	22.93±2.91	10
S7C21	2.61±0.28	6	30.70±4.62	7	2.68±0.29	5	31.12±4.69	8
11-3	2.60±0.26	7	33.86±3.98	5	2.62±0.26	8	34.82±3.8	5
ST-240	2.63±0.22	5	37.70±5.87	3	2.70±0.22	4	38.99±6.00	3
64-217-1	2.20±0.36	10	28.80±5.09	9	2.22±0.37	10	29.50±5.17	9
22-4	1.45±0.32	12	13.29±3.72	12	1.46±0.32	12	14.43±4.12	12
82-18-2-1	2.74±0.24	3	21.60±3.89	11	2.74±0.24	3	21.67±3.57	11

TABLE XVI

Ranking of Clones with Means and Standard Errors for Maximum Photosynthetic Activity (A_{max}), *u*mol CO_2 m^{-2} s^{-1}, Field Study

Clone	July31/Aug 1 X±se	Ran k	Aug 24/25 X±se	Rank	Sep 7/8 X±se	Rank	Sep 21/22 X±se	Rank
1-8	28.39±2.30	8	17.64±1.62	12	17.64±1.00	9	17.83±0.91	5
111232	29.50±2.79	6	18.37±0.57	11	18.29±1.01	6	17.81±0.52	6
ST-70	25.38±2.17	11	19.37±0.09	8	16.32±1.73	11	15.84±1.34	11
2433	31.32±2.44	4	19.29±0.87	9	18.05±1.21	7	17.64±0.76	7
117	31.92±2.42	3	19.91±1.56	7	18.74±1.41	5	17.96±1.14	4
9-8	32.43±3.56	2	21.87±0.66	3	21.87±1.21	1	20.79±0.77	2
S7C21	28.11±3.29	9	21.40±1.25	4	15.67±1.60	12	16.98±1.33	9
11-3	29.77±2.96	5	21.97±0.68	2	19.46±1.31	3	21.83±0.71	1
ST-240	29.14±2.84	7	20.04±0.89	6	19.12±1.54	4	16.25±1.44	10
64-217-1	24.33±3.41	12	19.07±0.64	10	16.36±0.83	10	15.80±1.44	12
22-4	25.62±4.23	10	20.50±1.17	5	17.69±0.90	8	17.46±1.13	8
82-18-2-1	35.39±2.62	1	23.59±1.43	1	20.51±1.91	2	19.76±1.95	3

TABLE XVII

Ranking of Clones with Means and Standard Errors for Water Use Efficiency (WUE), µmol CO_2 mmol H_2O , Field Study

Clone	July31/Aug 1 X±se	Rank	Aug 24/25 X±se	Rank	Sep 7/8 X±se	Rank	Sep 21/22 X±se	Rank
1-8	1.68±0.13	8	0.84±0.15	11	1.59±0.06	9	2.20±0.10	5
111232	1.75±0.10	6	0.82±0.15	12	1.64±0.04	8	2.20±0.17	6
ST-70	1.49±0.11	10	1.03±0.21	8	1.50±0.14	11	2.02±0.20	12
2433	1.85±0.14	4	0.99±0.18	10	1.65±0.11	7	2.20±0.21	7
117	1.86±0.13	3	1.00±0.17	9	1.69±0.07	6	2.15±0.09	8
9-8	1.99±0.19	2	1.13±0.19	4	2.06±0.07	1	2.69±0.12	2
S7C21	1.57±0.18	9	1.16±0.23	3	1.43±0.12	12	2.05±0.10	11
11-3	1.78±0.17	5	1.16±0.20	2	1.87±0.08	3	2.89±0.18	1
ST-240	1.72±0.12	7	1.05±0.17	6	1.82±0.12	4	2.07±0.18	10
64-217-1	1.42±0.23	11	1.05±0.21	7	1.55±0.06	10	2.07±0.16	9
22-4	1.47±0.23	11	1.13±0.22	5	1.71±0.05	5	2.30±0.20	4
82-18-2-1	2.05±0.15	1	1.17±0.19	1	1.96±0.14	2	2.52±0.24	3

TABLE XVIII

Ranking of Clones with Means and Standard Errors for Leaf Characteristics, Leaf Density in Upper Meter of Stem (LFDENS), Leaf Density in Branches in Upper Meter of Stem (BRLFDENS), Leaf Angle (LFANGLE), and Leaf Internode Length (NODELGTH),Field Study

Clone	LFDENS X±se	Rank	LFDENS BR X±se	Rank	LFANGLE X±se	Rank	NODELGTH (cm) X±se	Rank
1-8	21±1	10	40±9	7	56±3	5	0.05±0.00	2*
111232	22±1	8	23±11	11	43±3	11	0.05±0.00	3
ST-70	21±1	9	39±8	8	52±4	8	0.05±0.00	2
2433	23±2	6	31±9	10	43±3	12	0.04±0.00	3
117	24±1	3	44±8	6	52±1	9	0.04±0.00	3
9-8	24±1	4	65±12	3	62±3	1	0.04±0.00	3
S7C21	22±1	7	16±5	12	47±3	10	0.05±0.00	2
11-3	27±1	2	69±12	2	53±2	7	0.04±0.00	3
ST-240	24±1	5	47±10	5	58±3	4	0.04±0.00	3
64-217-1	29±3	1	146±30	1	59±3	3	0.04±0.00	3
22-4	20±3	12	38±16	9	60±3	2	0.06±0.01	1
82-18-2-1	21±1	11	60±18	4	54±2	6	0.05±0.00	2

*Rank of Internode length results in only 1-3 due to same lengths in several clones.

TABLE XIX

Ranking of Clones with Means and Standard Errors for Leaf Characteristics, Main Stem Leaf Area(MSAREA), Branch Leaf Area (BRAREA), and Total Leaf Area(TOTALAREA),Field Study

Clone	MSAREA (cm^2) X±se	Rank	BRAREA (cm^2) X±se	Rank	TOTALAREA (cm^2) X±se	Rank
1-8	3853.12±598.17	5	6144.65±1464.07	5	9997.77±1913.11	3
111232	3900.80±523.52	4	3713.23±1861.17	9	7614.03±1594.43	8
ST-70	2873.99±317.32	8	3571.78±766.98	10	6445.77±931.78	9
2433	2698.73±479.25	9	6373.35±2198.92	4	9072.08 ±2234.31	6
117	4223.11±298.94	3	4699.89±819.27	7	8923.00±1083.73	7
9-8	3339.17±295.78	7	9602.45±1833.28	2	12941.62±2059.55	2
S7C21	2175.09±453.32	10	1687.53±535.91	12	3862.62±669.95	12
11-3	3741.11±224.37	6	6485.94±1120.39	3	10227.05±1075.4	3
ST-240	4333.07±420.76	2	5217.30±1062.18	6	9550.37±1273.51	5
64-217-1	4651.94±159.47	1	19724.35±2337.95	1	24376.30±2358.44	1
22-4	1487.97±545.60	12	4209.58±1573.07	8	5697.55±1641.86	10
82-18-2-1	2028.79±256.66	11	2665.23±824.15	11	4694.02±931.48	11

TABLE XX

Ranking of Clones with Means and Standard Errors for Length of Season Between Bud Flush and Bud Set (LENGTHSEASON) and Leaf Fall, Days between bud flush and Leaf Fall (LEAFALL), Field Study

Clone	LENGTHSEASON (days) X±se	Rank	LEAFALL (days) X±se	Rank
1-8	201±4	5	247±7	5
111232	192±4	11	237±7	9
ST-70	197±3	8	265±3	2
2433	190±5	12	244±6	6
117	192±3	10	235±4	10
9-8	202±3	3	237±4	8
S7C21	204±4	1	267±5	1
11-3	193±3	9	232±2	12
ST-240	201±2	4	259±6	3
64-217-1	199±3	6	250±7	4
22-4	203±3	2	240±5	7
82-18-2-1	199±3	7	235±6	11

TABLE XXI

Ranking of Clones with Means and Standard Errors for Branch Characteristics, Number of Branches in Upper Meter of Stem (BRNUMUM), Average Length of Branches in Upper Meter (AVGLENBR), Average Diameter of Branches in Upper Meter (AVGDIABR), and Average Branch Angle from Main Stem (AVGANGLEBR), Field Study

Clone	BRNUM UM X±se	Rank	AVGLEN BR (cm) X±se	Rank	AVGDIA BR (mm) X±se	Rank	AVGANGLE BR X±se	Rank
1-8	8±2	5	77.24±13.52	6	6.47±1.11	8	55±3	3
111232	2±1	3	68.82±6.19	7	6.55±0.44	7	57±3	1
ST-70	6±1	7	82.14±9.74	4	7.22±0.82	4	39±2	10
2433	3±1	10	96.31±5.49	2	9.79±0.57	2	41±2	9
117	8±1	4	66.23±5.12	8	7.20±0.51	5	56±3	2
9-8	9±1	2	55.91±6.43	10	5.45±0.46	10	44±1	7
S7C21	2±1	12	94.62±16.19	3	8.64±1.13	3	49±3	5
11-3	9±2	3	68.82±6.19	7	6.55±0.44	7	57±3	1
ST-240	6±1	8	78.90±9.92	5	7.12±0.74	6	42±3	8
64-217-1	14±3	1	61.13±10.74	9	6.02±1.05	9	48±8	6
22-4	6±2	9	31.14±11.47	12	2.84±0.86	12	34±10	12
82-18-2-1	8±2	6	54.27±9.64	11	4.17±0.49	11	49±2	4

APPENDIX B

RANKING OF CLONES WITH MEANS AND STANDARD ERRORS FOR ALL MEASURED TRAITS, POT STUDY

TABLE XXII

Ranking of Clones with Means and Standard Errors of the Mean for May 22 (HT1 and DIA1) and June 5 (HT2 and DIA2), Pot Study

Clone	HT1 (m) X±se	Rank	DIA1 (mm) X±se	Rank	HT2 (m) X±se	Rank	DIA2 (mm) X±se	Rank
1-8	0.47±0.03	4	7.54±0.35	2	0.66±0.05	2	8.68±0.38	2
111232	0.47±0.03	3	6.95±0.27	4	0.64±0.04	3	8.58±0.33	3
ST-70	0.42±0.04	7	6.09±0.45	8	0.56±0.04	6	7.33±0.52	9
2433	0.37±0.05	11	5.86±0.52	9	0.50±0.05	10	7.26±0.59	10
117	0.46±0.03	5	6.60±0.37	5	0.60±0.06	5	8.46±0.28	4
9-8	0.42±0.02	6	6.11±0.35	7	0.54±0.03	7	7.55±0.37	6
S7C21	0.59±0.04	1	8.17±0.55	1	0.80±0.05	1	10.17 ±0.72	1
11-3	0.49±0.04	2	7.19±0.56	3	0.64±0.05	4	7.93±0.55	5
ST-240	0.32±0.03	12	6.60±0.38	6	0.38±0.04	12	7.47±0.42	7
64-217-1	0.37±0.02	9	5.50±0.31	11	0.49±0.03	11	7.35±0.42	8
22-4	0.37±0.03	10	5.69±0.32	10	0.53±0.04	8	6.71±0.38	11
82-18-2-1	0.38±0.03	8	5.21±0.34	12	0.52±0.05	9	6.16±0.49	12

TABLE XXIII

Ranking of Clones with Means and Standard Errors of the Mean for June 19 (HT3 and DIA3) and July 3 (HT4 and DIA4), Pot Study

Clone	HT3 (m) X±se	Rank	DIA3 (mm) X±se	Rank	HT4 (m) X±se	Rank	DIA4 (mm) X±se	Rank
1-8	0.76±0.05	3	9.69±0.48	3	0.85±0.06	3	11.04±0.61	4
111232	0.81±0.05	2	9.62±0.39	4	0.92±0.06	2	11.16±0.52	3
ST-70	0.66±0.05	7	8.62±0.42	7	0.74±0.09	6	10.44±0.64	5
2433	0.58±0.04	10	7.76±0.58	8	0.62±0.04	8	7.75±1.35	12
117	0.72±0.09	5	9.92±0.32	2	0.77±0.10	5	11.24±0.50	2
9-8	0.62±0.03	8	8.73±0.38	6	0.65±0.03	9	9.49±0.45	7
S7C21	0.96±0.06	1	11.26±0.61	1	1.02±0.07	1	12.57±0.88	1
11-3	0.75±0.06	4	9.27±0.64	5	0.79±0.06	4	10.13±0.55	6
ST-240	0.41±0.03	12	7.63±0.53	11	0.45±0.05	12	8.18±0.63	11
64-217-1	0.53±0.03	11	7.69±0.39	10	0.55±0.04	11	8.26±0.35	10
22-4	0.67±0.05	6	7.71±0.36	9	0.73±0.05	8	8.89±0.38	8
82-18-2-1	0.59±0.09	9	7.59±0.71	12	0.61±0.08	10	8.54±0.70	9

TABLE XXIV

Ranking of Clones with Means and Standard Errors of the Mean for July 17 (HT5 and DIA5) and August 7 (HT6 and DIA6), Pot Study

Clone	HT5 (m) X±se	Rank	DIA5 (mm) X±se	Rank	HT6 (m) X±se	Rank	DIA6 (mm) X±se	Rank
1-8	0.94±0.12	3	12.01±0.81	3	1.14±0.06	5	18.97±0.94	1
111232	0.96±0.06	2	11.99±0.53	4	1.28±0.08	3	17.64±0.81	4
ST-70	0.74±0.10	6	11.34±1.05	5	1.22±0.12	4	15.97±1.52	5
2433	0.61±0.05	9	9.03±0.79	10	0.74±0.08	11	12.07±0.92	11
117	0.73±0.10	7	12.26±0.81	2	0.97±0.09	7	18.18±1.70	2
9-8	0.63±0.03	8	9.82±0.41	7	1.51±0.85	1	13.03 ±0.72	9
S7C21	1.08±0.06	1	14.44±0.79	1	1.37±0.07	2	17.77±1.67	3
11-3	0.79±0.06	4	10.47±0.46	6	0.97±0.05	6	15.44±0.72	6
ST-240	0.42±0.03	12	8.07±0.41	12	0.67±0.06	12	11.23±1.34	12
64-217-1	0.53±0.04	11	8.91±0.42	11	0.75±0.06	10	12.87±0.62	10
22-4	0.75±0.04	5	9.71±0.45	8	0.89±0.04	9	14.34±0.70	8
82-18-2-1	0.57±0.07	10	9.49±0.86	9	0.93±0.08	8	14.94±0.61	7

TABLE XXV

Ranking of Clones with Means and Standard Errors of the Mean for August 21 (HT7 and DIA7) and September 4 (HT8 and DIA8), Pot Study

Clone	HT7 (m) X±se	Rank	DIA7 (mm) X±se	Rank	HT8 (m) X±se	Rank	DIA8 (mm) X±se	Rank
1-8	1.34±0.05	3	21.53±0.97	3	1.50±0.05	3	24.79±0.76	3
111232	1.43±0.10	2	20.28±0.60	4	1.61±0.08	2	23.25±1.17	4
ST-70	1.10±0.09	10	15.16±1.39	9	1.33±0.10	4	20.93±1.92	6
2433	0.91±0.07	7	14.11±0.63	10	1.08±0.11	10	16.58±1.56	10
117	1.14±0.13	4	21.73±2.35	2	1.28±0.09	5	25.10±1.99	2
9-8	0.71±0.08	12	13.27±1.12	12	0.87±0.09	11	16.41±1.31	12
S7C21	1.54±0.05	1	23.57±1.03	1	1.71±0.06	1	27.06±1.11	1
11-3	1.13±0.09	5	17.20±1.14	5	1.28±0.11	6	20.71±1.31	7
ST-240	1.09±0.21	6	13.48±1.92	11	0.89±0.11	12	16.54±2.59	11
64-217-1	1.05±0.10	9	16.34±1.77	7	1.15±0.06	8	18.96±0.65	9
22-4	0.89±0.07	11	15.69±1.46	8	1.11±0.08	9	21.44±1.27	5
82-18-2-1	1.08±0.08	8	17.11±1.25	6	1.23±0.09	7	20.44±1.94	8

TABLE XXVI

Ranking of Clones with Means and Standard Errors of the Mean for September 18 (HT9 and DIA9) and October 2 (HT10 and DIA10), Pot Study

Clone	HT9 (m) X±se	Rank	DIA9 (mm) X±se	Rank	HT10 (m) X±se	Rank	DIA10 (mm) X±se	Rank
1-8	1.59±0.05	3	28.61±1.19	3	1.55±0.05	4	29.47±1.14	3
111232	1.78±0.08	2	26.23±0.93	4	1.82±0.08	2	26.92±1.91	5
ST-70	1.51±0.09	4	24.74±1.86	6	1.57±0.11	3	26.09±2.12	6
2433	1.19±0.14	10	22.61±2.31	10	1.27±0.14	10	22.61±2.26	10
117	1.40±0.08	5	28.64±1.57	2	1.43±0.08	5	29.60±1.72	2
9-8	1.00±0.10	12	19.65±1.38	12	1.08±0.10	12	18.94±1.65	12
S7C21	1.81±0.08	1	29.81±1.59	1	1.88±0.08	1	31.90±1.69	1
11-3	1.30±0.15	6	23.94±1.45	7	1.40±0.12	6	25.76±1.85	7
ST-240	1.06±0.13	11	20.63±2.98	11	1.23±0.15	11	21.02±3.11	11
64-217-1	1.24±0.06	8	23.23±1.40	9	1.29±0.05	9	24.54±1.62	9
22-4	1.22±0.09	9	25.96±1.13	5	1.33±0.08	7	27.71 ±1.89	4
82-18-2-1	1.28±0.12	7	23.89±1.99	8	1.31±0.10	8	24.73±1.84	8

TABLE XXVII

Ranking of Clones with Means and Standard Errors of the Mean for Maximum Photosynthetic Activity (A_{max}), *u*mol CO_2 m^{-2} s^{-1}, Pot Study

Clone	July26/28 X±se	Rank	Aug 31/Sep 1 X±se	Rank	Sep 12/14 X±se	Rank	Sep 26/28 X±se	Rank
1-8	21.30±1.88	5	16.71±1.23	10	15.27±0.71	9	10.60±1.66	9
111232	21.64±1.70	3	17.70±1.19	7	15.51±0.51	8	15.04±1.14	5
ST-70	18.99±1.88	11	18.41±1.35	3	16.52±0.62	5	11.42±1.00	7
2433	18.77±2.02	12	18.21±1.30	4	17.00±1.50	4	12.92±1.17	4
117	20.84±2.02	7	17.74±1.99	6	16.26±2.19	6	13.81±1.82	3
9-8	19.73±1.60	9	16.87±1.44	9	16.21±1.12	7	9.94±1.10	10
S7C21	22.70±1.33	2	16.33±1.25	11	4.09±1.32	11	8.89±1.56	11
11-3	19.72±2.26	10	17.90±0.99	5	18.45±0.83	2	15.04±1.14	1
ST-240	21.59±2.28	4	17.58±2.24	8	13.42±2.16	12	10.97±1.25	8
64-217-1	20.82±1.36	8	15.82±1.22	12	15.18±1.92	10	8.51±1.99	12
22-4	21.29±1.97	6	20.22±1.44	1	19.15±1.46	1	12.64±1.78	6
82-18-2-1	22.86±1.64	1	19.62±1.31	2	18.18±2.20	3	14.73±1.53	2

TABLE XXVIII

Ranking of Clones with Means and Standard Errors of the Mean for Water Use Efficiency (WUE), *u*mol CO_2 mmol H_2O , Pot Study

Clone	July26/28 X±se	Rank	Aug 31/Sep 1 X±se	Rank	Sep 12/14 X±se	Rank	Sep 26/28 X±se	Rank
1-8	0.98±0.14	7	1.16±0.20	11	1.73±0.26	8	1.69±0.26	10
111232	0.99±0.11	6	1.18±0.15	9	1.72±0.26	10	2.19±0.31	5
ST-70	0.87±0.15	11	1.27±0.19	7	1.94±0.23	6	2.03±0.27	7
2433	0.84±0.13	12	1.45±0.25	2	1.84±0.15	7	2.19±0.30	4
117	1.04±0.17	2	1.35±0.23	4	1.95±0.28	5	2.27±0.28	3
9-8	0.90±0.10	10	1.18±0.22	10	2.06±0.33	4	1.84±0.29	9
S7C21	1.01±0.12	4	1.24±0.19	8	1.73±0.29	9	1.93±0.36	8
11-3	0.93±0.13	9	1.34±0.23	5	2.14±0.26	2	2.70±0.35	1
ST-240	0.98±0.17	8	1.31±0.17	6	1.48±0.24	12	1.68±0.12	11
64-217-1	1.00±0.10	5	1.11±0.22	12	1.64±0.23	11	1.43±0.22	12
22-4	1.02±0.13	3	1.43±0.16	3	2.15±0.12	1	2.04±0.26	6
82-18-2-1	1.11±0.15	1	1.53±0.27	1	2.12±0.33	3	2.51±0.36	2

TABLE XXIX

Ranking of Clones with Means and Standard Errors of the Mean for Leaf Characteristics, Leaf Density in Upper Meter of Stem (LFDENS), Leaf Density in Branches in Upper Meter of Stem (BRLFDENS), Leaf Angle (LFANGLE), and Leaf Internode Length (NODELGTH), Pot Study

Clone	LFDENS X±se	Rank	LFDENS BR X±se	Rank	LFANGLE X±se	Rank	NODELGTH (cm) X±se	Rank
1-8	29±3	8	188±62	4	56±6	2	0.04±0.01	1*
111232	32±2	6	32±20	12	49±3	8	0.03±0.00	2
ST-70	28±1	9	46±29	11	51±2	5	0.03±0.01	2
2433	25±2	12	84±25	10	49±4	7	0.04±0.00	2
117	32±2	4	152±47	7	48±1	10	0.03±0.00	1
9-8	27±2	10	207±62	3	42±1	12	0.04±0.00	1
S7C21	33±3	3	101±53	9	50±2	6	0.03±0.00	2
11-3	32±2	5	159±49	6	55±3	3	0.03±0.00	2
ST-240	30±3	7	114±33	8	49±6	9	0.04±0.00	1
64-217-1	39±3	1	176±38	5	47±2	11	0.03±0.00	2
22-4	26±2	11	347±64	1	54±3	4	0.04±0.01	1
82-18-2-1	34±3	2	266±81	2	56±3	1	0.03±0.00	2

*Rank of Internode length results in only 1-2 due to same lengths in several clones.

TABLE XXX

Ranking of Clones with Means and Standard Errors of the Mean for Leaf Characteristics, Main Stem Leaf Area(MSAREA), Branch Leaf Area (BRAREA), and Total Leaf Area(TOTALAREA),Pot Study

Clone	MSAREA (cm^2) X±se	Rank	BRAREA (cm^2) X±se	Rank	TOTALAREA (cm^2) X±se	Rank
1-8	2031.77±424.29	9	13832.54 ±4568.13	3	15864.32±4214.99	3
111232	4357.51±397.63	1	3879.83±1829.12	11	8237.47±1715.52	10
ST-70	2843.72±421.48	3	3370.50±2129.35	12	6214.22±1979.10	12
2433	2499.65±477.12	6	8314.16±2479.40	8	10813.80 ±2214.25	8
117	1478.25±314.86	10	9674.80 ±3011.76	6	11153.11±2965.72	7
9-8	2225.83±407.86	7	11365.20 ±3590.55	4	13591.03±3422.31	4
S7C21	2605.50±430.99	5	6972.45±3417.43	9	9577.95±3096.61	9
11-3	2937.80±456.86	2	9305.55±2560.80	7	12243.35±2364.08	5
ST-240	2730.17±755.80	4	4881.95±1739.99	10	7612.13±1259.94	11
64-217-1	2157.07±269.81	8	14345.91±3129.97	2	16502.98±2977.59	2
22-4	957.37±271.65	12	16336.76±2998.48	1	10813.80±2214.25	1
82-18-2-1	1335.29±272.26	11	10284.13 ±4302.05	5	11619.42±4071.40	6

TABLE XXXI

Ranking of Clones with Means and Standard Errors of the Mean for Length of Season Between Bud Flush and Bud Set (LENGTHSEASON) and Leaf Fall, Days between bud flush and Leaf Fall (LEAFALL), Pot Study

Clone	LENGTHSEASON (days) X±se	Rank	LEAFALL (days) X±se	Rank
1-8	183±0	2	239±1	5
111232	181±0	8	230±1	10
ST-70	180±1	12	238±3	6
2433	180±1	11	228±1	12
117	182±0	5	235±2	8
9-8	186±2	1	246±4	2
S7C21	182±1	6	250±4	1
11-3	181±1	9	233±4	9
ST-240	183±1	3	242±3	4
64-217-1	182±1	7	236±2	7
22-4	183±1	4	242±2	3
82-18-2-1	180±0	10	229±2	11

TABLE XXXII

Ranking of Clones with Means and Standard Errors of the Mean for Branch Characteristics, Number of Branches in Upper Meter of Stem (BRNUMUM), Average Length of Branches in Upper Meter (AVGLENBR), Average Diameter of Branches in Upper Meter (AVGDIABR), and Average Branch Angle from Main Stem (AVGANGLEBR), Pot Study

Clone	BRNUMUM X±se	Rank	AVGLENBR (cm) X±se	Rank	AVGDIABR (mm) X±se	Rank	AVGANGLEBR X±se	Rank
1-8	8±2	4	65.43±5.06	5	8.30±0.54	6	57±2	4
111232	2±1	12	75.54±6.64	4	9.20±0.51	4	43±1	12
ST-70	2±1	11	82.72±8.71	1	10.79±1.29	1	46±1	11
2433	4±1	9	76.30±12.94	3	9.91±1.43	2	48±3	10
117	7±2	7	49.93±5.01	11	7.61±0.68	8	56±1	5
9-8	9±2	2	48.20±5.99	12	7.00±0.56	12	51±2	9
S7C21	4±2	10	80.02±7.92	2	9.28±0.84	3	52±2	7
11-3	7±2	6	52.48±4.67	10	7.03±0.51	11	58±2	3
ST-240	6±2	8	63.31±11.55	7	8.53±1.18	5	52±2	8
64-217-1	7±1	5	54.73±4.26	9	8.11±0.50	7	60±2	2
22-4	13±2	1	59.47±5.27	8	7.15±0.34	10	61±5	1
82-18-2-1	9±2	3	65.39±7.89	6	7.60±0.55	9	54±3	6

TABLE XXXIII

Ranking of Clones with Means and Standard Errors of the Mean for Above-Ground Biomass including branches and main Stem (ABOVEBIO), Below-Ground Biomass or Root Biomass (BELOWBIO), Specific Gravity (SG), and Number of Roots (ROOTS), Pot Study

Clone	ABOVEBIO (g) X±se	Rank	BELOWBIO (g) X±se	Rank	SG (g/cm^2) X±se	Rank	ROOTS (number) X±se	Rank
1-8	318.85±24.28	2	115.40 ±13.51	8	0.39±0.01	4*	35±1	4
111232	269.14±14.87	4	130.25±6.98	5	0.36±0.01	9	22±6	11
ST-70	226.34±32.51	7	166.64±37.67	1	0.35 ±0.01	10	19±3	12
2433	153.99±40.67	12	91.51±21.77	11	0.37 ±0.01	8	28±3	10
117	248.16±25.89	5	129.40 ±18.29	6	0.38±0.01	6*	40±6	2
9-8	160.26±29.36	11	92.56 ±15.67	10	0.32±0.01	12	35±4	5
S7C21	413.40±53.95	1	159.81±27.76	2	0.41±0.01	2	46±5	1
11-3	220.51±39.33	9	157.79±25.64	3	0.41±0.02	3	34±5	6
ST-240	161.94±48.82	10	50.30±16.88	12	0.33±0.02	11	33±3	8
64-217-1	298.47±53.81	3	118.97±15.74	7	0.39±0.01	4	33±3	7
22-4	223.25±27.87	8	113.43±15.91	9	0.38±0.01	6	30±5	9
82-18-2-1	235.84±35.94	6	141.24 ±21.73	4	0.42±0.01	1	37±4	3

*two of the same weights

TABLE XXXIV

Ranking of Clones with Means and Standard Errors of the Mean for *Melampsora* Leaf Rust, (% leaf surface covered with urediospores) , Field Study and Pot Study

Clone	Field Study X±se	Rank	Pot Study X±se	Rank
1-8	26±4	4	29±4	2
111232	9±4	3	46±7	10
ST-70	0±0	1*	0±0	1
2433	0±0	1	37±5	5
117	49±7	7	40±4	7
9-8	31±4	5	38±8	6
S7C21	57±5	8	43±5	9
11-3	60±0	9	35±6	3
ST-240	37±5	6	36±10	4
64-217-1	67±3	11	40±8	8
22-4	63±7	10	69±4	12
82-18-2-1	77±3	12	57±7	11

*=two with same rank

VITA

Leslie Marie Hite

Candidate for the Degree of

Master of Science

Thesis: MULT-TRAIT CHARACTERIZATION OF SELECT EASTERN COTTONWOOD CLONES

Major Field: Forest Resources

Biographical:

Personal Data: Born in West Monroe, Louisiana, December 28, 1974, the daughter of Mr. and Mrs. Cecil David Strickland

Education: Graduated from West Monroe High School, West Monroe, Louisiana, in May 1992; received certificate in Practical Nursing from Delta-Ouachita Vocational Institute, West Monroe, Louisiana November 1994; received Bachelor of Science degree in Forest Resources from Louisiana Tech University, College of Natural Resources, Ruston, Louisiana, in May, 2000; completed requirements for Master of Science degree at Oklahoma State University in December, 2002.

Professional Experience: Licensed Practical Nurse at Glenwood Regional Medical Center, West Monroe, Louisiana, March, 1995-May, 2000; Student Assistant in Forestry Department at Louisiana Tech University, Ruston, Louisiana, January, 2000-May, 2000; Graduate Research Assistant for Department of Forestry at Oklahoma State University, June, 2000-September, 2002.