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Populus Species and Hybrids for Use on Bottomland and Upland Sites in the Southern United States

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By

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Populus species and hybrids for use on bottomland and upland sites in the southern United States

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The objective of this research is to evaluate the performance of *Populus* species and hybrid poplars in short rotation biomass production systems. Eastern cottonwood and hybrid clones were evaluated at both an alluvial and upland test site in 2010 and 2011. Age-one and age-two measurements included tree survival, total height, and overall health. Age-two measurements also included breast height diameter and volume. Generally, eastern cottonwoods exhibited greater growth than hybrid clones on the alluvial site while the reverse was true for the upland site. Faster tree growth occurred on the alluvial site, but foliage diseases were more prevalent. Hybrids showed higher survival at both sites, however, disease susceptibility and lack of adaptability to flooding on the alluvial site confirms the need for further hybrid clone development. Clones exhibiting exceptional early growth and site adaptability are identified for possible biomass deployment and for inclusion into future breeding efforts.

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CHAPTER I

INTRODUCTION

Poplars have the potential to be a viable source of biomass for bioenergy and biofuels when grown as short-rotation woody crops (El Bassam 1998). *Populus* hybrids have in many cases been the taxa[1] of choice for the pulp and paper industry outside of the southern United States and the natural choice for the bioenergy and biofuels industry because of their fast juvenile growth, high photosynthetic capacity, and superior growth performance (Rae et al. 2004). This is especially true in the mid-West (MW) and Pacific Northwest (PNW) of the United States. Eastern cottonwood (*Populus deltoides* Bartram ex Marsh.) has been the *Populus* species of choice in the South, due to its rapid early growth and resistance to a variety of diseases. Although various *Populus* hybrids have been tested in the South, very few have survived for even short periods of time due to their susceptibility to a variety of diseases (Rousseau et al. 2008). These diseases include cottonwood leaf rust (*Melampsora medusae* Thum.), cottonwood leaf spot (*Marassonina brunnea* Magn.), and Septoria leaf spot and canker (*Septoria musiva* Peck.) Offsite plantings of *Populus* species and their resulting hybrids typically exhibit rapid early growth followed quickly by nearly stagnate growth (Daly 1964).

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[1] Any group or rank in a biological classification into which related organisms are classified.

Yield improvements of poplar plantations have been made by using carefully selected clones and applying intensive management culture (Ceulemans and Deraedt 1999). However, the process of identifying both adaptable and genetically superior growing clones across a range of sites is difficult due to a wide variety of diseases and the need for sites that possess deep fertile soils with good soil moisture availability and a lack of restrictive rooting zones (Orlovic et al. 1998). Thus, it is necessary to improve the understanding of adaptability among *Populus* taxa and clones within these variables.

Poplars have been employed primarily in rather short rotations with the goal being the production of fiber. The success of short rotation woody crops (SRWC) lies in the ability of the selected genotypes to exhibit rapid growth, ease of propagation, and economic viability. Exploitation of these traits can be accomplished through hybridization. Early hybridization studies by Stout and Schreiner (1933) started by testing approximately 13,000 open and controlled pollination seedlings obtained from a variety of poplar parent trees. These seedlings were examined for vigor, growth, and disease resistance. Based upon productivity results, they reduced the test population down to the best 600 seedlings. Preservation of hybrid vigor obtained in the first generation must be maintained through vegetative propagation of cuttings. The cuttings maintain their respective identity and lead to the formation of individual clones (i.e. genotypes) that possess the most vigorous genes. Over time, the test population identified the best 69 individual genotypes for further analysis of growth and vigor performance.

In 2011, fuel from biomass was responsible for 4% of the energy in the United States, with 45% of this coming from wood (DOE 2011). The United States consumed 134 billion gallons of gasoline in 2011. The Renewable Fuel Standard (RFS) mandated that 36 billion gallons of biofuels will be produced by 2022 to aid in the reduction of fossil fuel consumption in the United States. If the United States, and the South specifically, expect to meet the goals set for the development of renewable bioenergy and biofuels it will be necessary to develop a wide variety of woody biomass, including tree species, dedicated to the production of affordable biomass. *Populus* species, such as eastern cottonwood and hybrid poplars, have been shown to produce significant amounts of biomass (Riemenschneider 1997), but these production rates have been only maximized when grown on highly fertile alluvial sites (Randall and Mohn 1969). Highly fertile alluvial sites have no restrictive layers in the soil and excellent moisture all year. On these types of sites, eastern cottonwood and hybrid poplars are capable of producing trees with diameters of 12 inches and heights of 100 feet by age 10, resulting in approximately 16-18 green tons/acre/year (Rousseau 2011). An excellent site along with good management will produce above average yields. However, combining genetically superior genotypes with higher densities, and intense management will result in greater yields on a per acre basis. While high density plantings will result in smaller trees, the key is to maximize growth and thus yields over a short period of time (i.e. one to three years) that can be harvested for biofuels production and coppiced for the next rotation.

Currently, SRWC research is pushing forward so that it does not fall behind and has the capability of bringing high yielding biomass genotypes to the bioenergy and biofuels programs that are fast approaching. Increased breeding efforts for various species, including a variety of poplars for SWRC will provide superior genotypes for a wide variety of sites across the United States. With the knowledge of superior genotypes combined with the most efficient and economical manner to grow this biomass will in turn meet the strong demand for biomass.

CHAPTER II

OBJECTIVES

The main focus of this study was to develop an understanding of adaptability and growth for a variety of *Populus* species and hybrids as biomass candidates for the southeastern United States. The long-term goal of this overall project was to identify *Populus* clones for future use that are widely adapted and produce high biomass yields when grown on both alluvial and upland sites. In addition, these selections will be used in future breeding efforts.

While this thesis included two smaller studies, the main focus was on the early growth and adaptability of *Populus* Clonal Screening Trials established on two contrastingly different soils. The two smaller studies were based on the need to evaluate and develop European black poplar (*P. nigra* L.) genotypes adapted to the southern United States for hybridization and to design a specific long-term storage protocol for control pollinated *Populus* seed. To accomplish these goals we assessed:

1. Survival, growth, and foliar degradation among the eastern cottonwood and hybrid poplar clones on alluvial and upland sites.
2. Age-one survival, growth, and foliar degradation among a variety of *P. nigra* clones originating from six European countries on a Mississippi upland site.

3. Germination rates of eastern cottonwood seed when stored under three different protocols.

The rationale for this research was to identify new eastern cottonwood clones and various *Populus* hybrids from more recent selections that provide improved growth, disease resistance, and greater site adaptability. The study was primarily focused on growth, stress caused by foliar diseases, and the inherent environmental differences of two sites. Other environmental stress factors, including nutrient and water demands are understood to play a critical role in performance of the tested clones.

This work will increase our understanding of the adaptability of these selected *Populus* clones to differing physiographic sites, climates, soil characteristics, and various diseases. The screening of a variety of newly developed hybrid *Populus* taxa on both alluvial and upland sites should allow a fairly rapid identification of superior eastern cottonwood and hybrid clones. This study will document the early response of a variety of clones that will later be used in determining proper selection age (Coyle et al. 2006). The use of more current selections of eastern cottonwood bred with various *Populus* species may prove beneficial for alluvial and upland sites as a means of increasing biomass yields (Daly 1964). Findings from this research will aid in the development of improved techniques used to identify clones exhibiting: 1) superior growth, 2) increased levels of disease resistance, and 3) greater site adaptability. Do not forget that all chapters must end with a section break next page.

CHAPTER III

LITERATURE REVIEW

Today, the demand for wood on a global scale continues to grow as not only a source of heating and construction material but a myriad of other products. Combined with an emphasis on renewable energy, carbon sequestration, and other various ecosystem values wood will be in even greater demand. Thus, it is easy to see why some have stated that the value of wood to humanity is irreplaceable (Victor and Ausubel 2000). While the need for wood continues to grow the availability of forest land, and specifically working forest land is decreasing due to changes in societal needs and priorities. Population growth in the US has increased the demand for greater agricultural production, expansion of cities and suburbs, increased road systems, and increased demand for recreational land. The use of genetically superior genotypes along with increased management techniques has provided a means to offset this loss of land, with greater growth on less land. The same must be done with biomass production. Rather than using existing productive natural stands or agricultural land, it seems to be more feasible to establish cost-effective dedicated plantations. A potential solution to this problem is the development of tree plantations composed of fast-growing, elite genotypes (Boyle 1999).

Populus species are among the fastest growing trees in temperate forests (Rae et al. 2004). Due to their relatively fast growth and high photosynthetic capacity, *Populus* trees are a natural candidate for the biomass industry. In order for *Populus* plantations to succeed, they must produce not only higher yields over shorter rotation times than existing natural forests, but they must also compete with other energy biomass sources such as switchgrass (*Panicum virgatum* L.) and giant miscanthus (*Miscanthus x giganteus* J.M. Greef and Deuter ex Hodkinson and Renvoize) (South 1999).

The following section provides a short overview of the *Populus* species. Subsequent sections review the history of artificial regeneration and the selection of superior *Populus* clones over time based upon genetic characteristics. A summary of *Populus* diseases and pests is also included. A review of the techniques and methods used to store and prepare *Populus* cuttings and seed is also included as well as methods used to establish high yielding poplar plantations.

***Populus* Genus**

The genus *Populus* is represented by as many as 30 species. All of these species are found in the northern hemisphere, including North America, Europe, and Asia. However, no *Populus* species are found naturally in the southern hemisphere. The genus *Populus* is deciduous and dioecious, with leaves that are alternate, stipulate, petiolate, and simple. The leaves have glandular teeth along the margin and often have glands at the junction of the blade and petiole. Most poplars spread clonally by means of root-borne sucker shoots. Following bud break shoots continue to grow by initiating, expanding, and maturing leaves throughout the growing season (Eckenwalder 1996).

The *Populus* species evaluated in this study include eastern cottonwood (*P. deltoides*), European black poplar (*P. nigra*), and various hybrids created by crossing *P. deltoides* with *P. nigra*, black cottonwood (*P. trichocarpa* Torr. & Gray) and Japanese poplar (*P. maximowiczii* A. Henry). Eastern cottonwood is native to the southeast and central United States. It grows naturally near rivers and flooded areas. Black poplar is native to Europe and Asia and like eastern cottonwood performs well near water and low lying areas. When black poplar ages, it typically suffers greatly from disease. Black cottonwood is found primarily in the northwestern United States and western Canada. The Japanese poplar originates from eastern Asia. Evaluation and selection of hybrids containing superior genetic characteristics from each of these species has the potential to optimize the performance of genetic stock for biomass production.

***Populus* Diseases**

Several diseases can impact survival and growth of the various *Populus* species and their hybrids. While eastern cottonwood is susceptible to cottonwood leaf rust (CLR) (*Melampsora medusa)* it does not kill the tree but can reduce growth through reduction of photosynthetic area of the leaves and early defoliation. The disease can be recognized by a powdery orange-yellow discoloration (urediniospores) on the leaves, which has been termed rust. CLR causes defoliation during the latter portions of the growing season, making trees more susceptible to other environmental factors and diseases (Thielges and Adams 1975). The appearance of CLR also increases in areas of high moisture and humidity. The severity of this disease on an individual tree depends on the susceptibility of each genotype (Chastagner and Hudak 1999).

Depending on location, the appearance of CLR starts to be observed in early or late summer. Small white spots with a black border on the leaves are the first indicator of the disease. Then powdery orange-yellow uredinia begin to form and grow into a colony of urediniospores (Shain and Filer, 1989). At this stage, the disease is able to infect other plants by wind and insects. Later in the growing season, a thick infection of the uredinia will exist on a majority of the tree's leaves. Once the trees defoliate, the infected leaves remain in the ground litter during the fall and winter, allowing the disease to infect other trees the following spring (Thielges and Adams 1975).

Latitude has an influence on CLR prevalence, with disease virulence increasing as the disease moved south. Many races of CLR occur in its host's range (Prakash and Heather 1987). Numerous field observations during the growing season are the best way to evaluate genotype tolerance and level of resistance to these CLR races. Genetic improvement programs have used these types of measurements to identify the most resistant genotypes for a specific area. After testing and refinement, effective clonal selections can be made and used to propagate resistant genotypes for deployment (Land and Jeffreys 2006). For effective deployment of these clones, it is imperative to sustain a mixture of hosts by planting different clones in a plantation (Prakash and Heather 1989).

Another disease that causes problems for cottonwoods is *Marssonina*. Unlike *Melampsora*, *Marssonina* kills the leaf tissue and is recognized by brown-black spots on the leaves. These spots grow and become larger with a yellow-tan border. Once the disease infects a majority of the leaves, photosynthetic capacity is reduced, negatively impacting tree vigor. This disease causes premature defoliation, but the trees normally do not die unless they have been under other environmental stresses such as poor soil, drought, or a harsh winter. Young leaves are more susceptible than older leaves (Spiers and Hopcroft 1984). Inoculation occurs in the spring as spores from ground litter are carried by wind and rain to young leaves, new shoots, and petioles on the lower half of the tree's crown (Ostry 1987). The disease will overwinter in defoliated infected leaves and lesions in young, tender shoot growth.

The disease *Septoria musciva* can remain harbored within dead ground material or existing tree stem cankers. During the early growing season, *Septoria* produces spores that spread in the wind. The spores attack trees beginning in late spring, but to do so the spores must be in contact with the inner bark. This opening can be caused by existing *Septoria* stem cankers or other pests that bore through the bark. New infections normally occur during times of high precipitation and humidity (Ostry 1987).

Septoria can result in mortality to a number of *Populus* species and their hybrids. *Septoria* typically attacks young poplar trees. The disease causes a decrease in leaf photosynthetic capacity resulting in early defoliation (Newcombe and Ostry 2001). *Septoria* leaf spots are recognized as lesions on leaves that are brown and have a white-yellow center. Unlike the two other diseases previously described, *Septoria* can also manifest itself into a canker, on stems and branches. The stem canker will have a slight depression much like a gray-blue bruise and may ooze fluid. Infected stems and branches can be easily broken. While eastern cottonwood is resistant to *Septoria* cankers, hybrid poplars are very susceptible to both *Septoria* leaf spot and cankers. Although eastern cottonwood can be infected by *Septoria* leaf spot it rarely results in stem cankers (Weiland et al. 2003).

***Populus* Insects**

One of the most destructive insects of *Populus* is the cottonwood leaf beetle (CLB) (*Chrysomela scripta* F.). Damage resulting from CLB can range from minor defoliation to extensive defoliation and severe feeding on the tender portions of terminals. Both the adult and the larvae will skeletonize the leaves, eventually eating the entire leaf. When the CLB reaches epidemic population numbers and are not controlled the succulent portions of the stem are also fed upon, causing severe damage. Terminal damage takes considerable recovery time and can greatly affect growth. In addition, this type of damage can also cause crooked stems, disease entry points, and possibly death of the tree (Neel et al. 1976). Cottonwood leaf beetles damage is worst during the first three years of growth because of the high abundance of tender tissues (i.e. leaves and meristem) among the trees (Robison et al. 2006). This insect can be held in check with chemical insecticides such as Admire Pro (imidacloprid) and Sevin (carbaryl). In addition, some insects such as lady beetles prey on the eggs and pupae (Morris et al. 1975).

Adult CLBs will winter beneath bark and leaf litter of eastern cottonwood and other trees such as willows. At the onset of spring, they emerge from hibernation and begin to feed on young, tender leaves and buds. At this point, the female will begin to lay her eggs on the underside of the leaves. Once the eggs hatch after four to five days, the larvae will begin to feed on the bottom side of the leaves. The larval stage normally consists of ten days. Depending on the latitudinal location, there can be numerous generations each year (Neel et al. 1976). In Stoneville, Mississippi, Neel et al. (1976) reported that there can be as many as seven generations in a single growing season.

The cottonwood borer (*Plectrodera scalator* Fabricius) can also cause severe problems but is usually found in greater numbers in stool beds or cutting orchards. Adult cottonwood borers feed on tender bark and petioles of the tree when they emerge in the early summer months. Adults will also cause damage to the terminal shoots. The adults will bore just under the bark at the root collar to lay their eggs. Once the eggs hatch, the larvae will tunnel into the taproot, resulting in major damage in young saplings. This type of damage results in susceptibility to breakage during extreme weather conditions, such as high winds from thunderstorms. The affect to a stool bed can be extremely serious with poor survival of infected trees resulting from secondary diseases and loss of vigor to the trees. When this occurs the only recourse is to completely destroy the existing stool bed or cutting orchard, thus eliminating the insect and reconstruct a new cutting orchard. The cottonwood borer has very few natural enemies to aid in controlling a cutting orchard infestation (Solomon 1980).

Japanese beetles (*Popillia japonica* Newman) can also be a severe pest consuming foliage of newly sprouting cottonwood clones and causing mortality. Like the CLB, the Japanese beetle will also skeletonize the foliage and the larvae will feed on roots. Since there are limited natural predators, the Japanese beetle can infest a cottonwood stand decreasing its growth rate as well as causing mortality. However, *Populus* is just a secondary host for this beetle.

The life cycle of the Japanese beetle begins with the emergence of the adult starting in May, with the males appearing a few days before the females. After the females have been bred, they lay their eggs in the soil around the base of trees or herbaceous material they are feeding on in the area. In 10 to 14 days, the eggs will hatch and feed on roots for the first two instars. The third instar typically over-winters in the soil until the next spring. When temperatures start to warm in the spring the larvae begin to feed on roots again until they emerge from the soil in May (Potter and Held 2002).

June beetles (*Phyllophaga spp.* Harris) are another cause of mortality for cottonwoods. In the southern U.S., June beetle larvae will feed primarily on the roots of young trees, while the adults will feed on the foliage sometimes completely defoliating trees in the infestation area. Both will cause a loss in vigor and growth (Luginbill and Painter 1953). This insect is a greater problem in areas which were previously in pasture as the insect population is typically higher under pasture management, thus causing severe . The life cycle of a June beetle normally takes 2 years to complete in the South (Rush and Hoffard 1989). Females will lay their eggs two to six inches below the soil surface. After two to three weeks the larvae will hatch and begin feeding on tender roots. The larvae will overwinter at deeper depths in the soil. When temperature increases in the spring, adult June beetles begin to emerge from the soil and begin feeding (Luginbill and Painter 1953). Fortunately, control of June beetles can be accomplished with insecticides such as imidacloprid (Williams and Hanks 1976).

Eastern Cottonwood Seed

In the natural environment, eastern cottonwood seed are able to survive for two to four weeks depending upon environmental conditions (Trappe 1964). When using seed for testing, especially control-pollinated seed, over a number of years, viable long-term storage is a necessity. Seed storage procedures have not been perfected and if the seed is not properly handled before storage viability can be greatly reduced (Stein et al. 1974). Catkins must be harvested from branches and brought into areas where the capsules can open. Once the capsules open, the cotton must be extracted. The most efficient technique to separate the seeds from the cotton is an air stream with different sizes of mesh screens (Roe and McCain 1962). In general, seeds are classified into five groups: 1) true orthodox

– can remain viable at ambient temperatures for years 2) sub-orthodox – can be stored for relatively short periods at subfreezing temperatures 3) temperate-recalcitrant – cannot be desiccated but can be stored at or slightly below freezing 4) tropical-recalcitrant – cannot be desiccated and also sensitive to low temperatures 5) intermediate – can be dried to moisture levels almost low enough to meet orthodox conditions (12-15%) but are sensitive to low temperatures (Schreiner 1974). Eastern cottonwood seed is classified as sub-orthodox seed.

Seed storage is important to a *Populus* improvement program because mature seed is generally dispersed in late May to early July and without proper moisture the chances of seedling survival is extremely low. Thus, there is a need to store seed over an eight to nine month period to allow for synchronous germination and a more uniform seedling test (Tauer 1979).

The seed storage environment is also critical, if cottonwood seed is to remain viable during the storage period. In any case, if the germination rates are poor going into storage, it certainly will not have good viability after coming out of storage (Holmes and Buszewicz 1958). The objective is to minimize seed metabolism without damaging the seeds. In order to obtain good seed germination and viability, seed moisture of eastern cottonwood must be between six and ten percent (Tauer 1979). The temperature limits of storage are basically determined by the moisture content of the seed. It is known that sub-orthodox seed can be stored for a couple of years at temperatures as low as -20°C (-4°F). Tauer (1979) found that seeds stored for 74 months at 5°C (41°F) had a germination rate of zero, whereas seeds stored at -20°C (-4°F) remained unaffected. Tauer (1979) also found seeds from different mother trees store differently at varying temperatures.

Regardless, when eastern cottonwood seeds are stored at -20°C (-4°F), seed viability is lengthened and there is no longer a maternal influence.

While vacuum storage aids in seed viability over time, it is rather excessive when proper moisture content and subfreezing temperatures are maintained (Schreiner 1974). Seed storage keeps the seeds in a dormant state. The time period in which the seed can stay at a dormant state without losing its capability to germinate varies, but cottonwood seeds will normally germinate across a range of temperatures when there is proper moisture, gas exchange, and light (Barton 1965). Faust (1936) found that tiny seeds do not have the same germination success rate as larger seeds regardless of the conditions.

Moisture must be present in order for a seed to germinate and begin growth. Seeds of eastern cottonwood immediately after harvest will germinate when saturated in water, but cottonwood seeds that have been stored show imbibition problems, which harms them even on filter paper that is relatively wet (Hosner 1957). Hatano and Asakawa (1964) found that seeds of some woody plants have a quicker germination response when temperatures vary such as below freezing at night and up to 26.6°C (80°F) during the day compared to constant temperatures. However, the International Seed Testing Association (ISTA) (1993) suggests while conducting germination tests on a majority of seeds from woody plants, but not all, in laboratory settings the optimal temperatures should be 20°C (68°F) at night and 30°C (86°F) during the day.

Gas exchange is imperative for seeds coming out of storage. If a seed is planted too deep in the soil or submerged in water, it will pose germination problems for seeds of many plant species because of the lack of oxygen. Eastern cottonwood typically will germinate when the seed is submerged in water, but only the beginning stages of germination (i.e. radicle emergence) can be completed when there is minimal oxygen (Hosner 1957). Many species depend on light to germinate, however germination in the natural environment usually is initiated without light. For some species, if light is to have an impact on germination, moisture and proper temperature must be present (Nyman 1963). Successful seed germination is critically important when developing control-pollinated progeny tests and it is important to thoroughly understand each step undertaken as we move from seed to seedlings.

During the early weeks of young cottonwood seedling development they are very vulnerable to damping off and desiccation. In most cases, *Populus* seed is grown in containers under a combination of greenhouse and outside irrigation conditions. Damping off can also result in significant mortality in greenhouse settings. Many attempts to control damping off such as seed treatments, soil additives, soil drenches, and steaming were tested but were unsuccessful. Soil drenches with formaldehyde constrained the disease, yet the seedlings were challenging to remove from the flats. After all of the trials, sphagnum moss was the most effective medium in a greenhouse (Shea and Kuntz 1956, Assibi et al. 2011).

Artificial Regeneration and Selection

The importance of artificial regeneration emerged as the United States population expanded and natural forests were harvested for agriculture and population growth. It was not until late in the 19th century that replanting techniques started to show signs of successfully regenerating harvested forests (Victor and Ausubel 2000). During the 1700's, eastern cottonwood was planted in Europe, with hybridization of eastern cottonwood and European black poplar following closely behind. The resulting hybrids were named Euramerican hybrids or *P. x Canadensis* and outperformed the native black poplar, resulting in hybrid poplar plantations established throughout Europe (Wright 1975). The refinement of *Populus* breeding began in 1912 when Henry (1914) crossed eastern cottonwood, European black poplar, and black cottonwood in England. Stout and Schreiner (1933) also researched crossability of different poplar species. The resultant poplar seedlings were typically selected in the nursery bed and cloned prior to testing (Demeritt 1981).

The U.S.D.A. Southern Hardwoods Laboratory, at Stoneville, Mississippi began poplar improvement work for the lower Mississippi River Alluvial Valley (LMAV) using eastern cottonwood during the 1960's and 1970's (Rousseau 1987). These studies were primarily based upon open-pollinated seedlings of selected phenotypes grown under a nursery setting and then selected for clonal propagation or juvenile material harvested from natural stands, which was then clonally propagated and tested. The resulting clonal population was thoroughly tested to identify the best performing clones, which formed a genetically superior deployment population. Many of the better performing clones have been tested throughout various locations around the world, where they have been evaluated and bred by many other individuals (Mohn et al. 1970). The clonal test population selections were primarily based on growth and disease resistance. As with most hardwoods, eastern cottonwood improvement programs are based on the collection and selection of species, provenances, and clones to be deployed on sites where performance was best (Pait 2004). A common constraint to tree improvement programs however, is the long time period required for trees to attain sexual maturity thus allowing testing of subsequent offspring (Pait 2004).

From the 1960's through the 1980's, industrial forest companies, such as Westvaco Corporation, established eastern cottonwood plantations using the clones developed by the U.S. Forest Service in Stoneville, Mississippi as well as local clones. The Stoneville, Mississippi clones were tested and showed adaptability to sites within the LMAV from Tennessee to southern Louisiana (Rousseau 1987). The soil does not drastically change along the Mississippi River, but with Wickliffe, Kentucky being 100-175 miles north of the Stoneville materials' origin there is potential for clone by site interactions (Randall and Cooper 1973). Clone tests established in 1966 by the Stoneville group near Wickliffe, KY showed that clones originating from near Stoneville, MS outperformed the more local Kentucky and Missouri clones (Robison et al. 2006). This test indicated that the assumption of "local is best", while the most logical option, may not always be the best (Lambeth et al. 2005). It is also difficult to make effective early-age selections in eastern cottonwood because of low juvenile-mature correlations (Cooper and Ferguson 1979). To ensure that the best clones for a certain geographic location are selected, it is mandatory to test for longer periods of time. Rousseau (1987) stated clonal selections are less efficient when selection ages of one and three are used when the final rotation age is nine years or greater, especially when disease is factored into the selection process.

Development of Genetic Stock

Yield and productivity improvements of poplar plantations have been made by using careful selections of both intra- and interspecific hybrids and applying short-rotation intensive management culture (Hansen 1991). Superior *Populus* clones should possess the following characteristics: 1) well adapted to the climatic conditions where it will be deployed , 2) faster-than-average overall growth characteristics, 3) good stem form, 4) good self-pruning ability, 5) above average rooting characteristics, and 6) resistant to insects and diseases (Maisenhelder 1961). Selection for these desirable characteristics within the eastern cottonwood population can be accomplished due to the great genetic diversity exhibited by the species. This diversity is due to the large natural distribution over a wide range of climate conditions. As a result, breeders and tree improvement workers have taken advantage of the opportunities for exceptional improvement through the ease of hybridization and vegetative propagation resulting in clones exhibiting rapid juvenile growth in multiple regions of the country (Jokela and Mohn 1976).

Controlled-pollinated seed is typically sown to containers and grown for a short-period of time (i.e. 8 to 14 weeks) in a greenhouse. The seedlings are then planted in either a nursery bed or a field site as a progeny test. There the resulting progeny are examined for both growth and foliar disease resistance. This period of evaluation is rather short ranging from one to three years. Selections are then vegetatively propagated to produce sufficient numbers of ramets per clone to be included into either a screening trial or a highly replicated clone test, which will examine rooting, growth, and disease resistance. In addition, other characteristics such as stem form and wood properties may also be measured. If the progeny selections were included into screening trials, this type of testing has the ability to include hundreds of clones since ramets numbers per clone are extremely low and if properly placed needs to be on only one site. A screening trial would provide the next stage following selection would be a highly replicated clone test. In general, a clone test will include a rather limited number of clones, usually between 30 to 50 clones, but will have from 10 to 12 replications per test site. At least two test sites are planted per year and duplicated the following year to insure that the clones are thoroughly tested prior to recommendations for deployment. In some cases, selections from clone tests will then be included into large clonal blocks as the final step, which focuses on determination of yields.

Rooting of eastern cottonwood plays a critical role in overall yield. Rooting ability will vary between seed sources, families, and clones. Eastern cottonwood is generally considered a poor rooter. Zsuffa (1976) reported that for clone trials established in Canada, the survival of dormant unrooted cuttings of eastern cottonwood was very poor, while survival of hybrid poplars was quite high. He also stated that the hybrid poplars tested rooted well, even under poor field conditions. The improved survival of the hybrids was a result of the greater inherent rooting characteristics of the species mated to eastern cottonwood (Friend et al. 1991). The greater rooting ability of the hybrids has been recognized as an important characteristic but unfortunately there has been no hybrid poplar, to date, that has been able to survive the inherent diseases found in the LMAV. However, greater rooting capacity can be selected for within eastern cottonwood resulting in increased survival of dormant unrooted cuttings. Examination of rooting under controlled conditions has been used to determine genotype rooting characteristics of unrooted cuttings (Zalesny et al. 2005).

Adaptability to climate conditions is important to the survival and growth performance of cottonwood clones. In 1964, the Illinois Agricultural Experiment Station collected open-pollinated seed throughout the cottonwood’s natural range. The material was distributed for testing to Stoneville, MS and other locations in the United States in

1966. The sources from Minnesota and Illinois showed high mortality at the Stoneville, MS test and were eliminated from the test. Therefore, cottonwood must be carefully examined prior to making planting recommendations. However, the use of southern material has proven to be an efficient method of increasing growth rates as well as disease resistance. For example, Rockwood (1968) showed that northern latitude sources stopped growing earlier in the season, while southern sources grew later into the growing season at the same location. The southern sources have a high mortality rate when grown in the north because of the longer growing period. Winter damage and dieback are common occurrences in southern sources grown at more northern latitudes (Jokela and Mohn 1976).

The achievement of superior genetic stock is not a short-term process and depending on pathways taken could take from 12 to 20 years. The first step is to study variation in natural stands. This can be done through either seedling progeny tests or clonal tests. These tests will allow an understanding of the inherent capabilities of desirable traits, the development of genetic parameters that will be needed in the determination of a selection index and genetic gain per unit of time.

Unfortunately, the selection of superior eastern cottonwood individuals from natural stands is difficult due to a very high environmental component. Yet, some organizations have tried to vegetatively propagate older trees but success was very limited due to lack of juvenility. In other cases selections from young (i.e. one to three years) were made and then vegetatively propagated for inclusion into stoolbeds and later clone tests proved to be extremely worthwhile. In addition, open-pollinated seed was collected from putatively superior phenotypes in natural stands and then included into nursery trials. Selections from these various processes will come under further scrutiny through a series of tests that look at adaptability as well as numerous other characteristics. Reciprocal recurrent selection is a very useful method of selection. Following thorough testing, selections are then mated in a specific design from which seedlings and later clones are developed. The resulting genetic stock is then once again put through the rigors of genetic testing to determine the amount of gain the progeny might exhibit over breeding parents. The overall objective is to clearly evaluate the genetic quality of the variety of genotypes that will allow sustained genetic gains through time (Randall 1973).

Using Genetically Superior Clones

Vegetative propagation allows the grower to take advantage of growing a specific clone thus capturing the total genetic variation of that specific genotype. Planting dormant unrooted *Populus* cuttings of a specific clone will result in a homogeneous stand. This allows the stand to be managed, harvested, and processed efficiently (Mohn et al. 1993).

Most *Populus* plantations are established using one-year-old dormant unrooted cuttings. The ability of a cutting to vigorously root along its entire length results in high survival and increased growth. Early flourishing of the unrooted cuttings' root system is vital for plantation establishment. Pre-soaking the unrooted cuttings in water for 24 – 48 hours prior to planting is a technique used to invigorate the root system. McKnight and Biesterfeldt (1968) reported that when *Populus* unrooted cuttings were stored in trenches filled with water, the cuttings exhibited good rooting and growth results after planting. Krinard and Randall (1977) showed that soaking treatments significantly increased cutting survival. The soaking of *Populus* cuttings also decreases early mortality rate (Petersen and Phipps 1976) and is a common practice when planting unrooted cuttings. For best results, cuttings should be planted between January and May.

The growth performance of dormant unrooted cuttings' roots and shoots depends on several planting factors. Dickmann et al. (1980) found that early establishment performance increases with larger cutting diameters. However, diameters above 0.6cm (.24inches) do not improve survival or growth (Robison and Raffa, 1996). Cutting diameters of 0.6cm – 1cm (.24 - .39inches) are recommended. A 90°cutting angle results in the best root and shoot growth because that cutting angle results in less damage to vigorous cells (Robison and Raffa, 1996). *Populus* unrooted cuttings are also affected by time of collection. Phipps and Netzer (1981) concluded that rooting and bud break is quicker for cuttings harvested late in the dormant season. Cutting storage temperature is also a factor in cutting growth performance. Cuttings stored at 2.8°C (37°F) generally develop more rapidly than those stored at temperatures below freezing.

Plantation Yields

Combining elite genotypes with effective silvicultural practices is important for realizing greater short-rotation production rates. Optimum yield and productivity levels are without a doubt linked to genotype, tree spacing, competition control, and the environment (Braatne et al. 1996). While the genotype plays a critical role in yield, there are a variety of other aspects that must be done properly if yields are to be maximized. These aspects include proper site preparation, including chemical controls and spacing, determination of optimal cuttings, proper storage, handling, and care of the cuttings, first year competition control and insect management, and finally possible second year competition and insect control.

Identification of superior *Populus* genotypes and the inclusion of intensive silvicultural practices resulted in significant yield improvements for companies like Crown Vantage and MeadWestvaco. The resulting combination of intensive management and superior genotypes supplied the fiber needs of these companies' paper mills in the 1980s and 1990s (Robison et al. 2006). New clone selections designed to increase yields were either made through clonal refinement or as a result of a designed breeding program (Coyle et al. 2006). While these plantations were grown on rich alluvial soils, the sites were designated marginal due to their location rather than the inherent soil quality. Many of these plantings were located on batture land (i.e. land between the levee and the Mississippi River), and subject to annual flooding. The high nutrient status of these soils along with new weed seed deposited annually from varying river levels created tremendous weed and vine competition, thus making competition control a necessity for plantation success (Robison et al. 2006). Research efforts showed that Goal™ (oxyfluorfen) and Pendulum™ (pendimethalin) were effective on the competition, except during the summer months when the weather was hot and dry (Robison et al. 2006). Ezell (2001) found a rate of 80 ounces per acre of Goal™ oxyfluorfen exhibited greater competition control resulting 80% clear ground and better than 80% survival after 120 days following planting of treatment plots for eastern cottonwood in January and February. Early chemical control of weeds delayed the need for mechanical competition control until later in the growing season. Due to harsh weather conditions after planting, it can be difficult to carry out mechanical operations, thus risking injury to the planted cuttings. With that risk in mind, chemical application can aid eastern cottonwood plantation establishment (Ezell 1994).

Advancements in understanding *Populus* clone adaptability to geographic location, climatic conditions, diseases and soil types will aid in genotype evaluation. To further develop *Populus* as a viable biomass candidate in the Southeastern United States, the breeding of more current eastern cottonwood selections with newer *Populus* species selections should help us in identifying intra- and interspecific hybrid clones adapted to alluvial and upland site environments. The resulting progeny will provide greater knowledge of *Populus* clone growth, disease resistance, and site adaptability. Clonal selection and testing will provide a refinement of superior clones or the determinations of types of clones that will hopefully lead to improved performance on alluvial and upland sites, thus making a significant contribution to renewable energy resource goals.

CHAPTER IV

MATERIALS AND METHODS

Sun Grant/Department of Energy *Populus* Feedstock Program

The Sun Grant/DOE Poplar Woody Crops Program is a collaborative effort among several industry groups and research institutions including the University of Minnesota, Mississippi State University, GreenWood Resources LLC and Arborgen, LLC. These four cooperators cover those geographic areas considered to have the greatest potential for *Populus* as a biomass crop. Mississippi State University's portion of the program, which includes my studies, covers the western portion of the South, including an alluvial site within the LMAV and an upland site in Mississippi. ArborGen covers the eastern portion of the southern United States, while GreenWood Resources covers the Pacific Northwest and the University of Minnesota covers the upper Mid-West region (Figure 1). Each of the cooperators agreed to donate 35 clones from their respective programs to be included in what was termed as a Consolidated Trial. This trial is identical to a short term screening study that is designed to evaluate the growth, disease resistance, and adaptability of the very best clones of each cooperator. Although, each cooperator is responsible for similar trials in 2010 and 2011, only the test sites installed by Mississippi State University will be covered in this study.

Figure 1 Location of four cooperators (stars) and Mississippi State's test sites (trees).

Consolidated *Populus* Trials

The consolidated trials featured a population of clones selected by each cooperator for superior performance in their respective geographic areas. In 2010, each cooperator donated 20 clones unique to their specific program. In 2011, each cooperator again donated 20 clones, but only 15 were unique while five clones had been included in the 2010 trials. Each cooperator was responsible for their respective test sites and since Mississippi State University was responsible for two test sites the decision was made to place these on distinctly different site types. One site was located in the central part of the United States on a fertile alluvial site along the Mississippi River in southeast Missouri near New Madrid, Missouri. The second site was located outside of the LMAV on a less fertile upland site in northeast Mississippi near Pontotoc, Mississippi. The two test sites were specifically selected to compare the performance of eastern cottonwood and hybrid poplars not only in terms of growth but disease resistance as well. While we were fully aware of the disease situation of the LMAV alluvial sites we were hoping that the most recently developed hybrid poplar could cope with these diseases. The performance of both the eastern cottonwood clones and the hybrid poplars when planted on upland soils was much less well defined for both growth and disease resistance. While both test sites were planted in 2010, only the upland site was planted in 2011 due to flooding of the alluvial site during the spring and summer of 2011.

The upland test site is located on the North Mississippi Research and Extension Center at the Pontotoc Ridge-Flatwoods Branch Experiment Station near Pontotoc, MS (34°8'N; 88°59'W). This area of Mississippi is characterized by long, hot summers, with relatively mild winters that have an average temperature of 16.4°C (61°F), and an average annual precipitation of 148.6 cm (58.5 inches). The soil is a severely eroded, well drained Atwood silt loam consisting of a silt loam at the surface, with a silty-clay loam and clay loam at deeper depths. Prior use of the study site consisted of agriculture and pasture land, which is still implemented near the site.

The alluvial site is located near New Madrid, MO (36°38'N; 89°19'W) in the Lower Mississippi River Alluvial Valley (LMAV). The climatic conditions of the Missouri site is characterized by hot summers and cold winters, with an average annual temperature of 14.4°C (58°F), and an average annual precipitation of 125.7 cm (49 inches). The soil is classified as Caruthersville series consisting of deep, moderately well drained, nearly level soils along the floodplain of the Mississippi River. This soil series consists of a very fine sandy loam both at the surface and at deeper depths. The study site had been most recently in row-crop agriculture, which is still presently taking place around the site.

Test Material

A total of 80 unique *Populus* clones were included in the 2010 Consolidated *Populus* Trial, while an additional 80, of which 60 were unique *Populus* clones, were included in the 2011 trial. Of the 80 clones included in the 2010 trial, 37 are eastern cottonwood clones while 43 are hybrid poplar clones (Tables 25 and 26). In the 2011 trial, the same number of eastern cottonwood clones and hybrid poplar clones as included in the 2010 trial, albeit mostly different clones. Information concerning clone identification, donating cooperator, and genetic background (i.e. taxa) are also listed in Tables 25 and 26. Dormant unrooted cuttings varied from 9 to 15 inches in length, with a bottom diameter of one inch and a desired top diameter of one half inch. Once the cuttings were received they were soaked in water for 24 hours, placed in plastic bags, and stored at 34°F until planting. Prior to planting, the cuttings were soaked in a solution of Admire ProTM, which was done to provide protection from cottonwood leaf beetle.

Site Preparation and Planting

The site was disked and slit at the spacing of 6 x 9 feet, then planted by hand. Goal 2XL was applied as a broadcast application at a rate of 64 oz. per acre for both the 2010 and 2011 trial. When the herbicide application wore out, weed and vine competition was controlled by mechanical means and hand cleaning. To reduce edge effect, a border row was planted with random cuttings around the entire test.

Study Design

The experimental design used for the 2010 and 2011 Consolidated *Populus* Trials is a nested design, also known as a compact family block design, consisting of three blocks, four sources, 20 clones per source, and two-tree row plots per source. The four sources are the group of 20 clones donated by each cooperator, which are randomly arranged in each of the three blocks. Within each of the four source plots, all 20 clones from the specific cooperator are randomly arranged, with each clone represented by two-tree row plots that were planted at a spacing of 6 x 9 feet. The trials were analyzed on a plot mean basis which is comprised of 20 unique clones nested within each of the four sources for a total of 80 clones included in each block for a total of 240 plots per trial.

Measurements

Individual tree measurements included survival, total height, and a crown rating at the end of the first year. Following the second year, tree measurements included survival, diameter at breast height (DBH), total height, and a crown rating. The crown rating for each tree was taken in the fall over three months (i.e. August, September, and October) on a scale from 1 – 5. This scale was designed to provide a means of describing crown foliage degradation due to various diseases such as *Septoria* leaf spot, *Marssonina,* and *Melampsora* rust. However, it is evident that other stress factors as a result of site conditions also affect crown foliage degradation. It is felt that these ratings provide a good estimate of source and clone within source adaptability for the two sites. A rating of 1 has a crown that shows no defoliation and is completely green. A rating of 2 has a crown that shows no defoliation, but the leaves are a mix of green and yellowish brown off-color. A rating of 3 has a crown that shows defoliation along the branches and stem, but less than 50%; leaves are a mix of green and yellowish brown off-color. A rating of 4 has a crown that shows defoliation along the branches and stem, but greater than 50%; leaves are a mix of green and yellowish brown off-color. A rating of 5 has complete defoliation. Total height and DBH was collected during the winter once trees were dormant. From those measurements, volume was calculated with the formula developed by Krinard (1988) for small diameter cottonwood where:

$$\textit{volume outside bark} = 0.09 + 0.002216D^2H \qquad \text{(Eq. 1)}$$

Statistical Analyses

The test was analyzed using the GLM approach to determine significant differences ($\alpha = 0.05$) among sources and clones at ages one and two height and age-two dbh and volume to determine the best performing sources and top ten percent performing clones at each site. The nonparametric Lifetest procedure was used to rank age-one and age two-source survival. The Kruskal Wallis test was used to determine significant differences ($\alpha = 0.05$) between the sources for age one and age two survival at both sites. The nonparametric NPAR1WAY procedure was used to rank age one and age two source and clone crown ratings using Wilcoxon mean scores. The Kruskal Wallis test was used to determine significant differences ($\alpha = 0.05$) between the crown rating rankings at both sites.

2011 *Populus nigra* Trial

The two sites chosen for the 2011 *Populus nigra* Trial are located on the same sites chosen for the 2010 and 2011 Consolidated *Populus* Trials. With the flooding along the Mississippi River preventing the planting of the alluvial site in Missouri, only the upland test site was planted during the spring of 2011.

Test Material

The genetic material selected for the Mississippi State University sites were based primarily on the most southerly material available. However, only a limited amount of material from Italy, Hungary, and Turkey was available. Therefore, ten clones from each of the six geographic sources represented by Austria, Croatia, Germany, Hungary, Italy, and Turkey were provided by the University of Minnesota as unrooted dormant cuttings in February 2011 (Table 28). The cuttings were 10 inches long, with a diameter range from ¾ inch at the base to ½ inch at the top. Upon arrival at Mississippi State University the cuttings were stored in plastic bags at 34°F until planting. Prior to planting, the cuttings were soaked in a solution of Admire Pro™ to protect from cottonwood leaf beetle.

Site Preparation and Planting

The site was disked and slit at the spacing of 6x9ft., then planted by hand. Goal 2XL was applied as a broadcast application at a rate of 64oz per acre. When the herbicide application wore out, weed and vine competition was controlled by mechanical means and hand cleaning. To reduce edge effect, a border row was planted with random cuttings around the entire test.

Study Design

The experimental design is a nested design, consisting of three blocks, with six geographic sources, ten clones per source, with each clone represented by a two-tree row plot. The cuttings were planted at 6 x 9 foot spacing. The test was surrounded by a single border of NM6.

Measurements

Survival and total height were measured following the first growing season. In addition, all of the trees were assessed for disease resistance through the crown rating system previously designed for the 2010 and 2011 Consolidated *Populus* Trials and explained in that section.

Statistical Analyses

The test was analyzed using the GLM approach to determine significant differences ($\alpha = 0.05$) among sources and clones at age one height to determine the best performing sources and top ten percent performing clones. The nonparametric Lifetest procedure was used to rank age one source survivals. The Kruskal Wallis test was used to determine significant differences ($\alpha = 0.05$) between the sources for age one survival. The nonparametric NPAR1WAY procedure was used to rank age one source and clone crown ratings using Wilcoxon mean scores. The Kruskal Wallis test was used to determine significant differences ($\alpha = 0.05$) between the crown rating rankings.

2010 and 2011 Eastern Cottonwood Seed Storage Study

Open-pollinated cottonwood seed were collected in 2010 and 2011 from four female clones in the 1995 MSU Cottonwood Clone Bank located on Mississippi Agricultural and Forestry Experiment Station near Stoneville, MS. During the month of June in 2010 and 2011, female catkins were harvested with a .22 caliber rifle. The catkins were placed in cardboard boxes with a mesh screen top to allow air flow while restricting any seed from escaping.

Once the cotton like fibers with seeds emerged from the capsules, the fibers were separated from the seed. The separation process was completed by forcing an air stream over the seed through a series of sieves design to catch cotton-type fiber while the seeds pass through the sieves. All of the seed were dried to a 10% moisture content, partitioned into 100 seed groups by clone, placed into ultra-centrifuge tubes, and stored by the designated storage treatment.

When the seeds were removed from storage, seeds from each of the clones and different storage methods were germinated on moist filter paper that was placed at the base of petri dishes and placed under grow lights. Germination percentage, which was designated as seed possessing both a radical and cotyledons, was calculated on the fourth day and recounted on the seventh. Three of the four clones (i.e. 1-8, 30-4, and S13C20) were common to both the 2010 and 2011 studies. Clone ST-148 included in the 2010 test was replaced with clone 1983-1 due to extremely low germination exhibited in the 2010 study.

In 2010, only two treatments were applied and these included, desiccant plus refrigeration at 35°F and a -112°F ultra-low were used and non-replicated 100 seed groups were randomly chosen for germination counts at week 1, 12, 28, and 40. In the 2011 study, one additional treatment, desiccant plus freezer -5ºF was added to the desiccant plus refrigerate and the ultra-low treatments that were used in the 2010 study. Germination rates were made at week 12, 24, and 40. All other conditions remained identical to that of the 2010 study. Germination data was transformed using arcsine transformation and differences were examined between treatments and among clones. In addition, time-moment correlations were calculated to examine germination over time.

CHAPTER V

RESULTS

2010 Consolidated *Populus* Trial

Survival

New Madrid Co., MO

Significant differences were noted among the four sources for both age one and two, with the UMN and GWR sources demonstrating higher survival rates than the MSU and AG sources. Age-one survival ranged from a low of 62% for the AG source to a high of 89% for the UMN source. The trend for age-two survival remained the same with the UMN and GWR sources showing the highest survival at 85% and 77%, respectively (but not significantly different from each other at the α=0.05 level) while the MSU and AG sources exhibited survival rates of 69% and 61%, respectively (also not significantly different from each other). The hybrid poplar clone survival of the UMN source was significantly different from the eastern cottonwood clones of the MSU and AG sources through the first two years of testing. However the GWR source survival was not significantly different from the MSU source. Mean survival was lower in year two relative to year one for all sources. The GWR source exhibited the highest mortality (10%) between ages one and two, as survival fell from a high of 87% at age one to 77% at age two.

Pontotoc Co., MS

Significant differences were shown among sources for survival at ages one and two. First-year survival ranged from a low of 71% for the AG source to a high of 99% for the UMN. Survival of the UMN source at 99% was statistically higher than the other three sources at both ages one and two. Mean age-two survival of all sources at the MS test site (85%) was higher than the mean survival at the MO test site (73%). Through age-two, all sources survived better at the MS test site than at the MO site. In fact, survival patterns of the four sources were similar over both sites, with the UMN source exhibiting the highest survival and the AG source exhibiting the lowest survival. Unlike the Missouri test site, second-year survival did not change from year one for all sources. In general, the UMN and GWR hybrid clones showed better survival through the first two years than the eastern cottonwood clones of the AG and MSU sources.

Growth

New Madrid Co., MO

Significant source and clones within source differences were noted for all traits, which include age-one height and age-two height, diameter, and volume (Table 1). Among the four sources the MSU source was statistically taller than the other three sources at both ages one and two (Table 2). Age-one height ranged from 10.8 ft. for the UMN source to 13.8 ft. for the MSU source. Age-two height ranged from a low of 17.1 ft. for the UMN source to a high of 22.6 ft. for the MSU source. The difference in height between the MSU and the AG sources increased from 0.9 ft. at age-one to 1.2 ft. at age-two. While significant source differences were noted for age-two diameter, the MSU and AG sources were not statistically different from each other for age-two diameter exhibiting a mean of 3.0 and 2.9 inches, respectively. The largest age-two mean diameter and volume were also exhibited by the MSU and AG sources with values statistically different from GWR and UMN sources but not from each other. Age-two diameter ranged from a low of 1.8 in. for the UMN source to a high of 3.0 in. for the MSU source. Similarly, age-two volume ranged from a low of 0.23 ft^3 for the UMN source to a high of 0.58 ft^3 for the MSU source. The MSU and AG sources, which were predominately eastern cottonwood clones, were taller at the Missouri site than the hybrid poplar clones of the GWR and UMN source hybrid clones through the first two years. The predominately eastern cottonwood clones of the MSU and AG sources also demonstrated larger age-two diameter and volume than the hybrid clones of the GWR and UMN sources.

Table 1 Significance of the analysis for multiple growth variables of the 2010 Consolidated *Populus* Trial located at New Madrid Co., MO.

Source of Variation	df	Age-1 Height (ft)	---Age-2--- Height (ft)	DBH (in)	Volume (ft^3)
Block	2	*	*	NS	NS
Source	3	**[1]	**	**	**
Clone/Source	76	**	**	**	**
Block x Source	6	NS[3]	*[2]	NS	NS
Error	152				

[1-]** Highly Significant at the 0.01 alpha level
[2-]* Significant at the 0.05 alpha level
[3-]NS Not Significant at the 0.05 alpha level

Table 2 Age-two heights and their respective means for age-one height, growth between ages one and two, age-two diameter, and age-two volume of the four sources included in the 2010 Consolidated *Populus* Trial located near New Madrid Co., MS.

Source	Age-1 Height (ft)	---Age-2--- Height (ft)	Growth (ft)	DBH (in)	Volume (ft^3)
Mississippi State University	13.8a[1]	22.6a	8.8a	3.0a	0.58a
ArborGen	12.9b	21.4b	8.5a	2.9a	0.55a
Greenwood Resources	11.6c	18.6c	6.9b	2.2b	0.31b
University of Minnesota	10.8d	17.1d	6.4b	1.8c	0.23c

1- Means not sharing the same letter within a column indicate significant differences at $\alpha=0.05$.

For the top 10% of the test population (Table 3), seven of the top eight tallest clones were eastern cottonwood clones. During the first growing season, MSU clone 110804 demonstrated the best total height at 16.2 ft. After two growing seasons, the best performing clone was GWR8019 with a mean height of 26.0 ft. This clone (GWR8019) was the only hybrid, resulting from the *P. deltoides* x *P. maximowiczii* (DM) taxa, that was among the top 10% of the population at the Missouri site. However, age-two survival of this clone was only 66%. In addition, age-two diameter and volume of GWR8019 was less than that of the better eastern cottonwood clones. Eastern cottonwood clone 110412 from the MSU source ranked second for age-two height (25.9ft) and demonstrated 100% survival. Clone 3-1, another eastern cottonwood clone from the MSU source, was the only other clone among the top 10% of the population that exhibited 100% survival after two years. Five of the top eight fastest growing clones were clones included in the MSU source. Although mean age-two volume was greatest for the eastern cottonwood clone AG462, age-two survival was extremely poor at 33%. Volume production ranging from 0.88ft^3 to 0.73ft^3 and survival ranging from 83% to 100%

reveals a combination of fast growth and survival through age two. Age-one height, age-two height, dbh, and volume for all 80 clones appears in Appendix A. Additional clonal information for all of the trials can also be found in Appendix A.

Table 3 The top 10% of the test population of the 2010 Consolidated *Populus* Trial located at New Madrid Co., MO based on the tallest age-two clones and their respective Duncan's Multiple Range Test means for age-one height, growth between ages one and two, and age-two diameter, volume, and survival.

		Age-1	------------------------Age-2--------------------------				
Clone ID	Taxa[1]	Height (ft)	Survival (%)	Height (ft)	Growth (ft)	DBH (in)	Volume (ft^3)
8019	DM	14.7a[2]	67	25.7a	9.7a	2.8d	0.56g
110412	D	15.3a	100	25.9a	10.6a	3.3a	0.74a
AG462	D	14.8a	33	25.6a	10.9a	3.9a	0.95a
AG414	D	14.4a	83	25.1a	10.7a	3.7a	0.88a
111733	D	15.3a	83	24.7a	9.4a	3.1b	0.61c
110804	D	16.2a	83	24.3a	8.1a	3.5a	0.76a
ST66	D	15.1a	83	24.2a	9.1a	3.4a	0.73a
3-1	D	14.8a	100	24.2a	9.4a	3.4a	0.74a

1- Taxa include D=*Populus deltoides* and DM=*P. deltoides* x *P. maximowiczii*

2- Means not sharing the same letter within a column indicate significant differences at α=0.05.

Pontotoc Co., MS

Significant source and clones within source differences were noted for all traits, which include age-one height and age-two height, diameter, and volume (Table 4). The GWR (7.1ft.) and UMN (6.5ft.) sources were significantly taller than the MSU (5.5ft.) and AG (5.1ft.) sources at age one, but by age two only the GWR source (13.6ft.) was significantly taller than the other three sources (Table 5). First-year height ranged from a low of 5.1 ft. for the AG source to a high of 7.1 ft. for the GWR source. Age-two height ranged from a low of 10.5 ft. for the UMN and the AG sources to a high of 13.6 ft. for GWR source. Diameter ranged from a low of 0.8 in. for the UMN and AG sources to a high of 1.1 in. for the GWR source. Volume ranged from a low of 0.11ft^3 for the UMN source to a high of 0.14ft^3 for the GWR source. The UMN and GWR sources exhibited less height growth during the second year relative to the MSU and AG sources. Growth at the Mississippi test site was less than that obtained at the Missouri test site through the first two years.

Table 4 Significance among the sources of variation for age-one height, age-two height, age-two diameter, height growth between ages one and two, and age-two volume of the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS.

Source of Variation	df	Age-1 Height (ft)	------------Age-2 Height (ft)	DBH (in)	Volume (ft^3)------------
Block	2	**[1]	**	**	**
Source	3	**	**	**	**
Clone/Source	76	**	**	**	*
Block x Source	6	**	*[2]	*	*
Error	152				

1-** Highly Significant at the 0.01 alpha level
2-* Significant at the 0.05 alpha level
3-NS Not Significant at the 0.05 alpha level

Table 5 Age-two heights and their respective means for age-one height, growth between ages one and two, age-two diameter, and age-two volume of the four sources included in the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS.

Source	Age-1 Height (ft)	------------Age-2 Height (ft)	Growth (ft)	DBH (in)	Volume (ft^3)------------
Greenwood Resources	7.1a[1]	13.6a	6.6a	1.1a	0.14a
Mississippi State University	5.5b	11.4b	5.9ab	0.9b	0.13b
University of Minnesota	6.5a	10.5b	4.0c	0.8c	0.11c
ArborGen	5.1b	10.5b	5.4b	0.8c	0.12bc

1- Means not sharing the same letter within a column indicate significant differences at α=0.05.

When ranked by age-two height (Table 6), seven of the top eight clones were DM hybrids from GreenWood Resources, with only a single eastern cottonwood (D) clone from Mississippi State University found in the select population. Age-two survival among the selected eight clones showed that six clones exhibited 100% survival, including the only D clone. Two of the top eight clones (GWR7388 and GWR7416) exhibited survival rates of 83% and 67%, respectively. The tallest clone at age-one was GWR7388, with a mean height of 9.3 ft. However, clone GWR6329 was nearly as tall at 9.2 ft. At age two, GWR8019 was the tallest clone, with a mean height of 18.9 ft. Variation among the top clones for age-two diameter and volume was rather limited, with age-two diameters ranging from 1.3 to 1.6 inches and from 0.16ft^3 to 0.21 ft^3 for age-two volume. Examination of the selected populations of both test sites shows that only clone GWR8019 (DM) performed well at both sites. While the Missouri site is considered to be the more productive site, clone GWR8019 actually grew more between ages one and two at the Mississippi site (i.e. 9.7ft. vs 10.7ft.). While GWR 8019 was taller at the Missouri site (26.0ft.) versus the Mississippi site (18.9ft.) the overall height difference for GWR8019 between the two sites remained approximately the same.

Table 6 The top 10% of the test population of the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS based on the tallest age-two clones and their respective Duncan's Multiple Range Test means for age-one height, growth between ages one and two, age-two diameter, volume, and survival.

		Age-1	-----------------------	------------------	-Age-2-	------------------	-----------------------
		Height	Survival	Height	Growth	DBH	Volume
Clone ID	Taxa[1]	(ft)	(%)	(ft)	(ft)	(in)	(ft^3)
8019	DM	8.2a[2]	100	18.9a	10.7a	1.6a	0.21a
6323	DM	8.6a	100	17.6a	9.0a	1.5a	0.20a
7388	DM	9.3a	83	16.5a	7.2b	1.6a	0.20a
13788	DN	8.0a	100	16.4a	8.4a	1.3a	0.16a
6329	DM	9.2a	100	16.1a	6.9b	1.6a	0.18a
6320	DM	8.0a	100	15.9a	7.8b	1.4a	0.18a
7416	DM	7.9a	67	15.5a	7.7b	1.3a	0.16a
147-1	D	7.2aj	100	15.5a	8.2a	1.5a	0.19a

1- Taxa include D=*Populus deltoides*, DM=*P. deltoides* x *P. maximowiczii*, and DN=*P. deltoides* x *P. nigra*
2- Means not sharing the same letter within a column indicate significant differences at α=0.05

<u>Combined Analysis</u>

When both sites are analyzed together, the results indicate that the top 10% of the population is composed of five hybrids and three eastern cottonwood clones. While all of hybrids originated from GreenWood Resources, the taxa varied and included DM, DT, and DN taxa.

The MSU and GWR sources demonstrated significantly different age-one height as compared to the UNM and AG sources (Table 7). At age-two, significant source differences were noted for all traits. The combined analysis showed a range from a low of 8.6 ft. for AG and UMN sources to a high of 9.7 ft. for age-one height. Age-two height ranged from a low of 13.6 ft. for UMN source to a high of 16.9 ft. for the MSU source. The MSU source demonstrated statistical differences for all age-two traits. Mean diameter ranged from a low of 1.2 in. for the UMN source to a high of 2.0 in. for MSU.

Mean volume ranged from a low of 0.16 ft3 for the UMN source to a high of 0.35 ft3 for MSU source.

Table 7 Age-two height and their respective means for age-one height, growth between ages one and two, age-two diameter, and age-two volume of the four sources included in the 2010 Consolidated *Populus* Trial from the combined test sites located at Pontotoc Co., MS and New Madrid Co., MO.

Source	Age-1 Height (ft)	Age-2 Height (ft)	Age-2 Growth (ft)	Age-2 DBH (in)	Age-2 Volume (ft^3)
Mississippi State University	9.7a[1]	16.9a	7.3a	2.0a	0.35a
Greenwood Resources	9.3a	15.8b	6.7b	1.6c	0.22c
ArborGen	8.6b	15.3b	6.7b	1.7b	0.31b
University of Minnesota	8.6b	13.6c	5.1c	1.2d	0.16d

1- Means not sharing the same letter within a column indicate significant differences at α=0.01.

Table 8 Significance of the combined analysis for multiple growth variables of the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS and New Madrid Co., MO.

Source of Variation	df	Age-1 Height (ft)	Age-2 Height (ft)	Age-2 DBH (in)	Age-2 Volume (ft^3)
Location	1	**[1]	**	**	**
Blocks/Location	4	*[2]	**	**	*
Source	3	**	**	**	**
Clones/Source	76	**	**	**	**
Source x Location	3	**	**	**	**
Clone/Source x Location	76	*	**	**	**
Error	317				

1- ** Highly Significant at the 0.01 alpha level
2- * Significant at the 0.05 alpha level
3- NS Not Significant at the 0.05 alpha level

In the combined analysis, the results indicate that the top 10% of the population based on age-two height is composed of five hybrids and three eastern cottonwood clones. While all of hybrids originated from GreenWood Resources, they included three taxa (i.e. DM, DT, and DN). At age-one, the tallest combined site clone was GWR12805 (Table 9), with a mean height of 11.6 ft., but GWR8019 was only slightly shorter at 11.4 ft. Clone GWR12805 is a DT hybrid while GWR8019 is a DM hybrid. Based on age-two height, four of the eight clones in the selected population are hybrids, while four are eastern cottonwood (D) clones. The taxa of the four hybrids included three DM individuals (GWR8019, GWR6323, and GWR7388), and one DT individual (GWR12805). The tallest clone at age-two was GWR8019 at 21.7 ft. However, eastern cottonwood clone 25-2, a MSU clone, exhibited the largest age-two diameter at 2.9 in. Among the eight clones there was little variation for age-two total height and diameter, with a range of only 3 ft., and 1.1 in., respectively. Volume ranged from a low of 0.25ft.^{3} for GWR6323 to a high of 0.64 ft^3 for 25-2. Clone 110412 from the MSU source was the only clone of the age two selected population that exhibited 100% survival.

Table 9 The top 10% of the combined sites test population of the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS and New Madrid Co., MO based on the tallest age-two clones and their respective Duncan's Multiple Range Test means for age-one height, growth between ages one and two, age-two diameter, volume, and survival.

		Age-1	Age-2				
Clone ID	Taxa[1]	Height (ft)	Survival (%)	Height (ft)	Growth (ft)	DBH (in)	Volume (ft^3)
8019	DM	11.4b[2]	83	21.7a	10.3a	2.1b	0.35c
AG409	D	13.7a	17	20.8a	7.2c	2.5b	0.44b
110412	D	10.5b	100	20.1a	9.6a	2.4b	0.45b
25-2	D	10.6b	42	19.8a	9.2a	2.9a	0.64a
12805	DT	11.6b	75	19.1a	7.5c	2.1b	0.35c
111733	D	10.6b	92	19.0b	8.3b	2.1b	0.37c
6323	DM	10.3b	83	18.8b	8.4b	1.8e	0.25i
7388	DM	10.3b	75	18.7b	8.1b	2.0b	0.28f

1- Taxa include D=*Populus deltoides*, DM=*P. deltoides* x *P. maximowiczii*, and DT=*P. deltoides* x *P. trichocarpa*

2- Means not sharing the same letter within a column indicate significant differences at α=0.05

Crown Rating System

New Madrid Co., MO

The MSU and AG source demonstrated a statistically better age-two crown score at the Missouri test site than the UMN and GWR sources (Table 10). While the MSU source exhibited the best crown score at 2.8, the UMN source exhibited the worst crown score at 3.9. Thus the predominant eastern cottonwood clones included in the MSU and AG sources were superior in crown ratings to the hybrid poplar clones of the UMN and GWR sources.

Table 10 Wilcoxon mean scores for crown ratings after two growing seasons for the four sources included in the 2010 Consolidated *Populus* Trial located at New Madrid Co., MO.

Source	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
Mississippi State University	74.5a[1]	2.8
ArborGen	109.1a	2.9
Greenwood Resources	221.3b	3.7
University of Minnesota	270.4c	3.9

1- Means not sharing the same letter within a column indicate significant differences at $\alpha=0.05$.

When the best individual clones were selected based on crown scores and ranked using the Wilcoxon mean score, clones AG437 and AG461 exhibited the best average crown score of 2.3 (Table 11). A crown rating of 2.0 shows no defoliation, but the leaves are a mix of green and yellowish brown, caused by various foliar diseases. All eight clones exhibiting the best crown ratings were eastern cottonwood clones originating from either the MSU or AG sources.

Table 11 The top 10% of the test population of the 2010 Consolidated *Populus* Trial located at New Madrid Co., MO based on the best crown ratings and their respective Wilcoxon mean scores for crown ratings after two growing seasons.

Clone	Source[1]	Taxa[2]	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
AG437	AG	D	8.5	2.3
AG461	AG	D	20.8	2.3
AG462	AG	D	20.8	2.4
141A-5	MSU	D	24.8	2.4
158A-4	MSU	D	26.1	2.4
105-1	MSU	D	33.0	2.5
27-5	MSU	D	35.4	2.5
AG427	AG	D	37.8	2.5

1- Sources include ArborGen=AG and Mississippi State University=MSU
2- Taxa include D=*Populus deltoides*

Pontotoc Co., MS

The AG, MSU, and GWR sources demonstrated better age-two crown ratings at the MS test site than the UMN source (Table 12). Average crown scores ranged from 3.8 for the UMN source (worst) to 3.3 for the MSU (best).

Table 12 Wilcoxon mean scores for crown ratings after two growing seasons for the four sources included in the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS.

Source	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
ArborGen	135.4a[1]	3.3
Mississippi State University	154.2ab	3.4
Greenwood Resources	173.3b	3.4
University of Minnesota	317.0c	3.8

1- Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05.

The top 10% individual clone crown ratings were ranked by the Wilcoxon mean score (Table 13). GWR 6198 and 6320 demonstrated the best average crown score of 3.0.

A crown rating of 3.0 shows some defoliation along the branches and stem, but less than 50%; leaves are a mix of green and yellowish-brown. Six of the eight lowest crown rating clones on the MS sites were hybrids. Five of these six clones originated from the GWR source and represented several taxa including, DT, DM, and DN. The final hybrid is a TD clone originating from the AG source. GWR 6320 and 6329 were among the top 10% of the test population for both growth and disease resistance at the MS test site.

Table 13 The top 10% of the test population of the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS based on the best crown ratings and their respective Wilcoxon mean scores for crown ratings after two growing seasons.

Clone	Source[1]	Taxa[2]	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
6198	GWR	DT	38.4	3.0
6320	GWR	DM	58.1	3.0
AG187	AG	TD	62.8	3.1
4491	GWR	DT	62.8	3.1
24-128	AG	D	73.0	3.1
13780	GWR	DN	77.8	3.1
ST244	MSU	D	81.0	3.1
6329	GWR	DM	83.2	3.1

1- Sources include ArborGen=AG, Greenwood Resources=GWR, and Mississippi State University=MSU

2- Taxa include D=*Populus deltoides*, DM=*P. deltoides x P. maximowiczii*, DN=*P. deltoides x P. nigra*, DT=*P. deltoides x P. trichocarpa*, and TD=*P. trichocarpa x P. deltoides*

Combined Analysis

When the two 2010 test sites are evaluated under a combined analysis for crown ratings, the MSU and AG sources show the best two-year crown ratings (Table 14). Combined site crown scores ranged from 3.9 for the UMN source (worst) to 3.1 for the MSU and AG sources (best).

Table 14 Wilcoxon mean scores for crown ratings after two growing seasons for the four sources included in the 2010 Consolidated *Populus* Trial from the combined test sites located at Pontotoc Co., MS and New Madrid Co., MO.

Source	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
Mississippi State University	197.7a[1]	3.1
ArborGen	245.6b	3.1
Greenwood Resources	416.4c	3.5
University of Minnesota	583.7d	3.9

1- Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05

Eastern cottonwood clones from MSU and AG demonstrated the best overall combined crown scores (Table 15). Four of the top clones were also in the top 10% of the test population at the MO test site. However, none of the highest ranked clones from the MS test site were included in the combined analysis and selection of the top 10%. At age two none of the top performing clones for volumetric traits were included among the top crown rating clones.

Table 15 The top 10% of the combined test population of the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS and New Madrid Co., MO based on the best crown ratings and their respective Wilcoxon mean scores for crown ratings after two growing seasons.

Clone	Source[1]	Taxa[2]	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
158A-4	MSU	D	93.8	2.8
AG412	AG	D	127.2	2.8
27-5	MSU	D	131.0	2.8
141A-5	MSU	D	147.0	2.8
AG409	AG	D	147.0	2.9
ST244	MSU	D	153.8	3.0
113-324	AG	D	156.7	3.0
AG437	AG	D	160.0	3.0

1-Sources include ArborGen=AG and Mississippi State University=MSU
2-Taxa include D=*Populus deltoides*

2011 Consolidated *Populus* Trial - Upland Test Site - Pontotoc, MS

Survival

Mean age-one test survival was 93%, with the UMN source exhibiting the highest survival at 98% and being statistically higher than both the MSU and AG sources. However, the UMN source was not statistically different from the GWR source (Table 16). First-year survival ranged from a low of 86% for the MSU source to a high of 98% for the UMN source. The first year survival rates of the MSU and AG sources are higher than the first-year survival in the 2010 Consolidated *Populus* Trial.

Growth

The GWR source was statistically taller than the other three sources (Table 16). This source is comprised solely of various hybrid poplar taxa and was nearly a foot taller than the UMN source, which is primarily composed of DN hybrid poplar taxa. First-year height ranged from a low of 5.2ft for the MSU source to a high of 6.7ft for the GWR.

Table 16 Age-one heights and their respective means for age-one height for the four sources included in the 2011 Consolidated *Populus* Trial located at Pontotoc Co., MS.

	---------Age-1---------	
Source	Survival (%)	Height (ft)
Greenwood Resources	97ab[1]	6.7a
University of Minnesota	98a	5.8b
ArborGen	93bc	5.4bc
Mississippi State University	86c	5.2c

[1-]Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05.

Examining the top 10% of the tallest clones in the 2011 test population, the GWR hybrid 6318 (DM) exhibited the tallest mean height of 7.6ft. GWR hybrids 13309 (DN) and 6588 (TD) were also among the tallest clones at age one. However, of the eight tallest clones at age one four were GWR hybrids that included three different taxa (i.e. DM, DN, and TD), The remaining four clones were eastern cottonwood (D) either from AG or MSU.

Table 17 The top 10% of the test population of the 2011 Consolidated *Populus* Trial located at Pontotoc Co., MS based on the tallest age-one clones and their respective Duncan Multiple Range Test means for age-one height.

		----------Age-1------------	
Clone	Taxa[1]	Survival (%)	Height (ft)
6318	DM	100	7.6a-c[2]
6588	TD	100	7.4a-e
6294	DM	100	7.3a-e
110804	D	100	7.3a-e
AG185	D	100	7.2a-f
AG434	D	83	7.2a-f
AG439	D	83	7.1a-g
13309	DN	100	7.1a-h

1-Taxa include D=*Populus deltoides*, DM=*P. deltoides* x *P. maximowiczii*, DN=*P. deltoides* x *P. nigra*, and TD=*P. trichocarpa* x *P. deltoides*
2-Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05.

Crown Rating System

The GWR and AG sources demonstrated better first-year crown ratings at the MS test site than either the MSU or UMN sources (Table 18). But there was little variation among the four sources, with a range of the average crown scores of only 0.4 from best to worst. Average crown scores ranged from the best at 2.8 for GWR and AG sources to the worst for the UMN source at 3.2. A rating of 3 has a crown that shows defoliation along the branches and stem, but less than 50%; leaves are a mix of green and yellowish brown off-color.

Table 18 Wilcoxon mean scores for crown ratings after one growing season for the four sources included in the 2011 Consolidated *Populus* Trial located at Pontotoc Co., MS.

Source	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
Greenwood Resources	188.6a[1]	2.8
ArborGen	192.5a	2.8
Mississippi State University	226.4b	2.9
University of Minnesota	289.5c	3.2

[1-]Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05.

When evaluating crown ratings on an individual clonal mean bases the best performing clones are ranked by the Wilcoxon mean score and shown in (Table 19). Clones with the best crown score were the MSU eastern cottonwood 93-7 and GWR hybrids 6329 (DM) and 6294 (DM), all of which exhibited an average crown score of 2.3. Six of the eight top clones were hybrids, with all six coming from the GWR source. Four of the six clones (i.e. 6294, 6318, 6320, and 6329), were DM hybrids, while clones 4700 is a DT hybrid and 13309 is a DN hybrid. GWR hybrids 6318, 6294, and 13309 were in the top 10% for both growth and disease resistance at the Mississippi test site during the 2011 trial.

Table 19 The top 10% of the test population of the 2011 Consolidated *Populus* Trial located at Pontotoc Co., MS based on the best crown ratings and their respective Wilcoxon mean scores for crown ratings after one growing season.

Clone	Source[1]	Taxa[2]	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
93-7	MSU	D	43.0	2.3
6329	GWR	DM	43.0	2.3
6294	GWR	DM	52.7	2.3
4700	GWR	DT	59.5	2.4
13309	GWR	DN	59.5	2.4
6320	GWR	DM	76.0	2.4
AG441	AG	D	76.0	2.4
6318	GWR	DM	76.0	2.4

[1-]Sources include ArborGen=AG, Greenwood Resources=GWR, and Mississippi State University=MSU
[2-]Taxa include D=*Populus deltoides*, DM=*P. deltoides x P. maximowiczii*, DN=*P. deltoides x P. nigra*, DT=*P. deltoides x P. trichocarpa*

2011 *Populus Nigra* Trial - Upland Site - Pontotoc, MS

Survival

Age-one test survival was excellent at 98%. All six *Populus nigra* sources showed excellent first-year survival ranging from 92 to 100% (Table 20). Only the German source, exhibiting 92% survival was statistically different from the Italian, Croatian, and Hungarian sources, all of which exhibited 100% survival at age one.

Growth

Significant source differences were noted among the six *P. nigra* sources for age-one height. The Italian and Turkey sources were not statistically different from each other for age-one height. However, the Italian source was statistically taller at age one than the Austrian, Croatian, German, and Hungarian sources. Mean age-one heights ranged from a high of 5.7 feet for the Italian source to a low of 4.0 feet for the German source (Table 20).

Table 20 Age-one height and their respective means for age-one height for the four sources included in the 2011 *Populus nigra* Trial located at Pontotoc Co., MS.

	--------------Age-1----------	
Source	Survival (%)	Height (ft)
Italy	100a[1]	5.7a
Turkey	97ab	5.2ab
Austria	98ab	5.0bc
Croatia	100a	4.9bc
Hungary	100a	4.6c
Germany	92b	4.0d

[1-]Means not sharing the same letter within a column for a given age indicate significant differences at α=.05.

When clonal variation was examined, there was very little variation at this time with the top 10% of the test population showing little more than a half of a foot of difference in total height. The tallest age-one clone was TO191MS2, which originated from the Turkey source, exhibited a mean height of 6.8 feet (Table 21). At age-one, half of the top 10% of the *P. nigra* population originated from the Italian source.

Table 21 The top 10% of the test population of the 2011 *Populus nigra* Trial located at Pontotoc Co., MS based on the tallest age-one clones and their respective Duncan's Multiple Range Test means for age-one height.

		Age-1		
Clone	Source[1]	Height (ft)	Wilcoxon (Rank Sums) Mean Scores	Average Crown Score
TOM14MS2	TUR	6.8a[2]	92.3	1.5
IO4MS2	ITA	6.6ab	177.8	1.7
A548MS1	AUS	6.6abc	207.3	1.8
IO3MS5	ITA	6.3a-d	144.6	1.6
IO3MS4	ITA	6.2a-e	201.3	1.8
CMS3	CRO	6.2a-f	299.8	2.4

[1-]Sources include Austria=AUS, Croatia=CRO, Germany=GER, Hungary=HUN, Italy=ITA, and Turkey=TUR
[2-] Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05

Crown Rating System

The Turkey source demonstrated the best age-one crown rating than the other five sources (Table 22). The average crown scores among the sources ranged from poorest being 2.1 for the German source to best, which was 1.5 for the Turkey source. A 1.5 rating indicates that the majority of the crown is green with some off color but no defoliation. Whereas the 2.1 crown rating of the German source indicates that the appearance of the crown is more of a mottled green-brown coloration.

When evaluating the clones that have the best crown scores three originate from Turkey, with one each from Italy, Croatia, and Hungary (Table 23). Ranking the six of clones that make up the top 10 % of the test population based on crown scores also exhibits very little difference among these six clones (Table 23).

Table 22 Wilcoxon mean scores for crown ratings after one growing season for the four sources included in the 2011 *Populus nigra* Trial located at Pontotoc Co., MS.

Source	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
Turkey	95.7a[1]	1.5
Hungary	136.3b	1.6
Croatia	147.0bc	1.7
Italy	166.2c	1.7
Austria	256.1d	2.1
Germany	261.8d	2.1

[1-]Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05.

Table 23 The top 10% of the test population of the 2011 Consolidated *Populus* Trial located at Pontotoc Co., MS based on the best crown ratings and their respective Wilcoxon mean scores for crown ratings after one growing season.

Clone	Source[1]	Wilcoxon (Rank Sums) Mean Score	Average Crown Score
IO3MS1	ITA	52.5	1.3
T191MS3	TUR	52.2	1.3
TO14MS3	TUR	70.9	1.3
CMS1	CRO	70.9	1.4
H22MS4	HUN	70.9	1.4
TO14MS1	TUR	70.9	1.4

[1-] Sources include Croatia=CRO, Hungary=HUN, Italy=ITA, and Turkey=TUR

2010 Seed Storage

In the 2010 study, the two treatments (i.e. over desiccant at 38°F and ultra-low at -112°F) that were examined to determine long-term storage of eastern cottonwood seed showed no significant treatment or clonal differences over the four measurement times (i.e. 1, 12, 28, and 40 weeks). However, two of the clones showed lower initial germination rates which dropped to a specific level approximately 30% and then leveled off regardless of the treatment or length of storage. The germination rates of the seed placed in the ultra-low were fairly consistent over the 40 weeks of testing. Clone S13C20 showed an initial (fresh) germination rate of 87% and by the end of 40 weeks in ultra-low storage the germination rate was 76%. Correlations were rather high within a treatment across clones and time. In fact, the correlations between week 1 and week 40 for both storage treatments were greater than 90%.

2011 Seed Storage

In the 2011study, of the four clones used, two clones (i.e. 1-8 and S13C20) were also used in the 2010 Seed Storage Study. The seed from all four clones was recollected for the 2011 Seed Storage Study. Results of this study showed no significant treatment differences among the four clones. Once again clone 1-8 showed a drop in germination rates from week 12 to week 40 for the desiccant plus 38°F and the desiccant plus -5°F storage treatments. However, clone 1-8 remained constant from week 12 to week 40 stored in the ultra-low treatment. The germination rates of the other three clones remained fairly constant for all treatments and length of storage. The correlations between week 12 and week 40 were extremely high for all treatments except the desiccant plus refrigerate, which was only 29%.

CHAPTER VI

DISCUSSION

One of the objectives of this study is to identify possible superior clones that demonstrate a number of desired characteristics, such as excellent rooting, rapid early growth, and resistance to various stress factors affecting photosynthetic rates. The importance of each characteristic is critical to the ability of being able to identify those clones that exhibit these desired characteristics at an early age. When these desired traits can be effectively predicted at an early age this allows for a shorter generation interval and increases genetic gain per unit of time. While preliminary identification of clones is an objective of this study it is no different for any tree improvement program. In combination, the favorable performance of these traits will increase production regardless of the rotation length. This study was focused on short-term results that may vary from one to five years for dedicated biomass production to ten years for a more traditional pulpwood product. The data reported here will not determine the final verdict of the genetic material tested for fast growth genotypes, but it will provide insight into future directions. This is especially true of the hybrid poplars tested, since the taxa included in this group have been shown in the past to be susceptible to diseases present in the LMAV area of mid-South as well as various sites throughout the South (Rousseau et al. 2008). However, the hybrid poplars clones included in these tests have not been previously tested in the southern United States. In addition, the eastern cottonwood parentage of the hybrid poplar clones that originated from GreenWood Resources used selections developed by James River and later Crown Vantage for use on sites near Vicksburg, MS. In essence, the 2010 and 2011 Consolidated *Populus* Trial established in this study are used to determine those clones that exhibit adaptability as related to growth, disease resistance, and rooting which will be added to more intensive testing and possibly included into a breeding program. This aspect of testing is a portion of a *Populus* program known as clonal refinement. In this scenario, superior clones from a variety of programs are brought together to determine their respective performance on specified sites.

The three characteristics previously noted factor into the selection process. When using dormant unrooted cuttings, survival is based on the ability of the cutting to produce an effective root system, which will support initial shoot formation as well as rapid growth. This early growth phase is critical in determining yield, especially when yields are to be optimized between ages one and five. The ability of the clone to resist various stress factors including diseases and pests affecting the crown foliage is also critical in the overall health of the tree and the optimization of growth.

Survival

As previously noted, survival is one of the keys to greater productivity. Since dormant unrooted cuttings are typically used as the regeneration stock for *Populus*, the ability of the cutting to effectively root quickly and establish a sufficient root system for rapid growth is a critical selection trait. Although eastern cottonwood is known as a prolific rooter in comparison to many southern hardwood species, it ranks far below the majority of other Populus species used to create hybrids. Early survival is primarily related to the inherent rooting characteristics of the individual clone as well as proper handling and storage. For the two years studied, hybrid clones survived better than eastern cottonwoods at both sites. This result is in accordance with their ability to establish roots more efficiently (Zsuffa 1976).

Age-two mean survival of all sources in the 2010 Consolidated *Populus* Trial was observed to be better at the Mississippi site (85%) than the Missouri site (73%). The trend was that for both sites was that survival of the hybrid poplars, regardless of the taxa, survived better than the eastern cottonwood. This was certainly not surprising as it is widely known that eastern cottonwood is not as a prolific rooter as hybrid poplars (Zsuffa 1976). Both sites were well maintained, especially during the first growing season and survival problems were primarily a result of the inherent rooting characteristics of the individual genotype. However, there is considerable variation for survival among the eastern cottonwood clones, with clones like 110412, 111234, and 27-5 showing 100% survival and clone 105-4 showing 0% survival. This variation allows the ability to make effective selections for rooting within eastern cottonwood resulting in increased survival and subsequent yields on a per acre basis. The 2010 trial is composed of 37 eastern cottonwood clones, all of which originated from either ArborGen or Mississippi State University and 63 hybrid poplars that are made up of five different taxa. The different hybrid taxa include 24 DN clones, 11 TD clones, 6 DM clones, 1 TN clone, and 1 NM clone. When age-two survival is examined by taxa, eastern cottonwood (D) was 67.8%, with the hybrid poplar taxa showing 93.2% for DN, 84.1% for TD, and 80.5% for DM. It is interesting to note that mortality between ages one and two was less for eastern cottonwood (0.8%) than the hybrid poplars, regardless of taxa. The three most abundant hybrid poplar taxa exhibited a loss of 1.3, 2.8, and 3.1%, for the DN, DM, and TD taxa, respectively. The mortality observed between ages one and two may be indicative of a lack of adaptability to either specific site conditions or pest resistance. This lack of adaptability was expected because of the distance that the UNM source was moved southward. This was also observed in the bud set data where the UNM sources set bud much earlier than the southern eastern cottonwood. The higher survival rates of the hybrid poplars from UMN and GWR sources were observed at both sites indicating superior rooting capacity. Soil quality and composition as well as weather may have influenced survival as the Mississippi site received less rain than average during the first growing season. For the Missouri site environmental factors affecting mortality included a rather high infestation of cottonwood borers, during the first growing season and long-term flooding during the second growing season.

Unfortunately, we were only able to plant the upland site in Mississippi in 2011 as the alluvial site in Missouri remained flooded during the majority of the growing season. In the 2011, trial a total of 60 unique clones were established with 20 clones common to the 2010 and 2011 Consolidated *Populus* Trial. First-year survival of the 2011 Consolidated *Populus* Trial was better than the first year survival of the 2010 Consolidated *Populus* Trial. This could have been due to better site preparation, better handling and processing of the planting material, different planting dates, and possibly better clones from each of the sources. There was also no shortage of rain during 2011 compared to 2010. The 2011 *Populus nigra* Trial demonstrated excellent survival for all clones and had significantly better results than the other two trials. These results suggest that *Populus nigra* clones may have better root establishment during the first year of growth at an upland site than eastern cottonwood or other hybrid taxa clones.

The 2010 and 2011 Trials were designed to determine the best clones across a variety of types throughout the South. If selecting for biomass production for rotations of from one to five years, it is reasonable to assume that clone selections could be made by age one or two. However, there is a need to be cognizant of disease problems that could greatly impact growth as these clones as they continue to be planted in the same area or coppiced for a number of rotations. There could be a movement or buildup of the disease into areas of either little presence of the disease or unacceptable hosts. Rousseau et al. 2008, showed that while NM-6 and other hybrid poplar clones seemed to be only slightly impacted by disease at age one, the impact was severe at age nine with only two clones showing some tolerance to *Septoria musiva* and *Marssonina brunnea*, with the remaining clones tested either showing either mortality or severe dieback. So when examining the top 10% of the test population the incidence of disease must be looked at first. At this point there is a lack of understanding of the extent of the primary disease problems potentially associated with the upland site in Mississippi. However, the Missouri alluvial site is known for a high level of the three most important diseases (i.e. *Septoria musiva*, *Marssonina brunnea*, and *Melampsora medusa*) (Prakash and Thielges, 1989). Even if the disease does not result in mortality, the growth loss each year from the reduction of leaf area and early defoliation will result in poor growth performance as the genotype ages (Rousseau et al. 2008).

Only two clones within the top 10% of the test population for growth at the alluvial site exhibited poor survival causing a concern for possible future use. One of these two clones was an eastern cottonwood clone originating from ArborGen (AG462), which could possibly indicate inherent poor rooting. However, since this clone also exhibited excellent height and diameter performance it should be examined again in a test where the ramet numbers are greatly increased, thus providing a better clarity to the possible survival problem. The second clone was a DM hybrid poplar from GreenWood Resources (GWR8019). In this case we assume that the survival problems are more than likely linked to flood tolerance rather than disease or poor inherent rooting since this clone showed 100% survival on the upland site. It was noted from more recent observations that disease problems on the upland has begun to build-up similar to that what was observed during the previous year measurements of the alluvial site. The survival trend shown for all of the trials remained the same for the 20 common clones included in both the 2010 and 2011 trials for the upland sites, where the hybrid poplar clones survived better than the eastern cottonwood clones. However, it is also interesting to note that survival of the eastern cottonwood clones from MSU showed little variation in survival between 2010 and 2011, while two eastern cottonwood clones from ArborGen showed much higher survival in 2011. This change in survival may possibly be tied to conditions of the material at harvest or handling. The excellent survival (93%) exhibited by the five MSU eastern cottonwood clones chosen as the common clones indicates that good inherent rooting characteristics can be selected for in eastern cottonwood.

Growth

It was expected that the alluvial site in Missouri would exhibited growth superior to that of the upland site located in Mississippi. Indeed this was the case as mean heights were 40-50% greater at the Missouri test site than the Mississippi site. Similarly, mean volumes were also 50-70% greater at the Missouri site. Site differences can also be seen in the mean differences between the alluvial and upland trial sites in 2010 for age-one total height, age-two total height, dbh, and volume were 6.0ft., 8.6ft., 1.6in., and 0.30ft3, respectively. Growth differences exhibited between the alluvial and upland sites were certainly not unexpected, as eastern cottonwood is a riparian species found naturally on sites that possess nutrient rich soils that are alkaline with good moisture availability and a lack of inherent pans (Foster 1986 and Coyle et al. 2006). In general, eastern cottonwood clones exhibited the best growth at the alluvial site while the hybrid poplars grew better at the upland site. One of the primary reasons for the early superior performance of the hybrid poplars on the upland site may be in part due to the ability of these taxa to establish roots more efficiently than eastern cottonwood clones as indicated by Zsuffa 1976.

All sources planted at the Missouri alluvial site demonstrated their best growth during the first year. The somewhat reduced growth during the second year may have been the result of the extended flooding experienced along the LMAV during 2011 as well as the lack of adaptability for the hybrid poplars. Prior to testing, there was a concern expressed that the clones developed by the University of Minnesota would probably not perform well in the South since they were selected for performance in a totally different environment. In general, moving northern genetic material too far south has often resulted in poor growth due to differences in photoperiod and a more conservative growth phenology. The reverse is also true where moving southern material too far north often results in winter injury and mortality. In addition, testing by organizations, such as MeadWestvaco, has shown that hybrid poplars in general have resulted in poor growth and subsequent mortality when grown on annually flooded alluvial sites in the LMAV (Rousseau et al. 2008). However, it is unusual for eastern cottonwood to exhibit slower annual growth during the second year. Since eastern cottonwood rooting develops slower than hybrids, the expectation would be that the continual rooting of cottonwood clones would be expressed during the second and third years, where the developing individual takes advantage of the favorable environmental conditions (Rousseau 1987). Eastern cottonwood clones exhibited the best age-one height and age-two height, diameter, and volume on the 2010 Missouri site. Although the DM clones on the alluvial site were nearly as tall as the eastern cottonwood clones, the average diameter was nearly an inch smaller. The smaller diameter greatly affected volume production, which will affect total biomass yields. However, only six DM hybrid clones were tested and the results suggest that a larger population of this particular type of hybrid should be examined if they remain resistant through five years. Most sources planted at the Mississippi upland site demonstrated second-year height growth that was similar to or greater than first year. The DM taxa performed the best on the upland site, for all traits. The eastern cottonwood taxa performed the worst for all traits except age-two diameter and volume.

Eastern cottonwood clones MSU 110412 and AG414 had excellent growth rates at the Missouri site and warrant further monitoring as prime selections for recommendations for deployment in the LMAV. Although AG462 had the best growth of all clones, survival (rootability) appears to be a major problem as it exhibited 33% survival at the Missouri site and 67% survival at the Mississippi site. While this definitely raises some concerns about AG462, the excellent early growth and its disease resistance warrants further testing. Eleven of the 37 eastern cottonwood clones exhibited age-two survival, height, diameter, and volume greater than the test mean for eastern cottonwood. These 11 clones are excellent candidates for further testing. The DM hybrid GWR8019 performed well on both the alluvial and the upland site and is included in the top 10% of the test population based on survival and growth and should also be examined further. However, if this clone proves to be susceptible to diseases in the future it should be eliminated from further consideration from those sites where it was tested. Thus, the continued monitoring of GWR8019 will be needed to determine disease susceptibility of this clone. Clone GWR8019 and GWR6323 performed well at the Mississippi site and should continue to be evaluated for upland adaptability. In fact, five of the six DM clones exhibited superior survival and growth on the upland site. If diseases do not become an overwhelming problem, increased testing of this taxon will be warranted. It should be noted that a limited number of clones from this taxon has been tested on upland sites in western Kentucky with not a single clone surviving after nine years (Rousseau et al. 2008).

Year-one height of the 2011 Consolidated *Populus* Trial and the 2011 *Populus nigra* Trial on the Mississippi site and was slightly shorter than the heights obtained in the first year of the 2010 Consolidated *Populus* Trial on the same site. The trend noted between eastern cottonwood and hybrid poplars in the 2010 Consolidated *Populus* Trial where the hybrid poplar taxa exhibited higher survival and better age-one height compared to the eastern cottonwood material was also noted in the 2011 Consolidated *Populus Trial*. However, this is only age-one data and more information is needed prior to any final decisions are made on performance. Examination of the performance of the

20 clones represented in both years on the upland site provides some interesting aspects in terms of growth. In comparing total height of the seven eastern cottonwood clones between the 2010 and 2011 trials only the MSU clone 110412 in the 2011 trial did not exceed its height exhibited in the 2010 trial. However, this was not the case for the various hybrid poplar taxa where the hybrid taxa in the 2010 trial were on the average taller in comparison to the 2011 trial. Still, the DM hybrid taxon proved to be the tallest, at 8.2ft., in the 2011 trial. The other three taxa (i.e. D, TD, and DN) showed very little difference in age-one height, with an average height close to six feet. This type of variation can be expected at age one as this is greatly affected by stoolbed quality, handling, storage, cutting quality, early competition control and environmental effects. But the stable performance of the DM hybrids for survival and age one height in both the 2010 and 2011 trials indicates that unless disease becomes a critical factor, this taxon must be highly considered for testing and deployment on upland sites.

Crown Rating System

Eastern cottonwood clones demonstrated better mean crown ratings on the alluvial site in Missouri, with the MSU and AG sources demonstrating statistically greater foliage retention and less loss of photosynthetic leaf area. On the upland site in Mississippi, the MSU and AG eastern cottonwood crown ratings were also generally better than the GWR and UMN hybrids. These results are most likely due to the fact that eastern cottonwood is resistant to *Septoria musiva* and *marssonina brunnea* while currently, all of the hybrids tested in the LMAV are susceptible (Rousseau 2008). It was also shown by Rousseau et al. 2008 that the hybrids taxa tested took a few years for *Septoria musiva* to manifest itself into stem cankers and result in tree mortality.

Several AG and MSU eastern cottonwood clones showed good crown ratings at the Missouri test site and warrant further monitoring as potentially good LMAV disease resistant performers. These clones will be monitored for survival, growth, and crown rating performance as well as changes in possible stem cankers. Although eastern cottonwood clones also demonstrated better overall mean crown ratings at the Mississippi test site, individual hybrid clones from GreenWood Resources were the best performers. Hybrid clones such as GWR6320 and GWR6329 were in the top 10% for both growth and crown rating at the Mississippi test site suggesting good adaptability to upland locations. In addition, GWR6320 was in the top 10% crown rating at the Mississippi test site for both the 2010 and 2011 Consolidated *Populus* Trials. Survival, growth, and crown rating of these two clones should continue to be watched.

Crown ratings of the various *Populus nigra* sources at age one on the Mississippi test site were better than the Consolidated *Populus* Trial sources crown ratings. These results show that *Populus nigra* clones demonstrate better disease resistance during the first year of growth at an upland site than the *P. deltoides*, *P. deltoides* x *P. maximowiczii*, *P.trichocarpa* x *P. deltoides*, and *P. deltoides* x *P. nigra* hybrid clones evaluated in the Consolidated *Populus* Trials. However, early-age crown ratings can be misleading and crown ratings of the *Populus nigra* clones should continue to determine the actual longer term disease resistance and site adaptability. If some clones do prove to be disease resistant and adapted to the specific site conditions they will be used in the development of new hybrid clones between *P. deltoides* and *P. nigra*.

Seed Storage

During the development of a breeding program, it is important to be able to effectively store control-pollinated seed for both the short and long-term. Since eastern cottonwood is a riparian species there is considerable variation in seed maturation, which could extend from the late spring through most of June, July, and the early portion of August (Hosner 1957). This variation makes it difficult to synchronize seedling development and the ability to detect differences among families and individuals. Past studies have indicated that storage is possible for up to a single year (Tauer 1979).

My studies in 2010 and 2011 indicated that either seed placed in vials over desiccant in a desiccator and stored at 38°F or placed in vials and stored in an ultra-low freezer survived well through 40 weeks. However, because of the time situation the studies did not extend past 40 weeks. The lack of significant differences between the two treatments shows that at least through 40 weeks, both treatments were effective methods of storing cottonwood seed. This indicates that either storage type would be suitable, if the seed were used within this time frame. The importance of these findings will lay the ground work for additional studies that would investigate extended periods of germination. One of the most encouraging aspects from this study was that the ultra-low storage, while not significantly different from the desiccant storage, showed a higher germination rate over time and across clones than the desiccant storage. If these germination rates remain consistent over greater periods the ultra-low storage treatment may become a standard for storing seed for many years.

Storage of eastern cottonwood seed has always been a problem forcing researchers to develop specific guidelines for testing cottonwood progeny or bypassing progeny tests and moving directly to clonal (Schreiner 1974). In many cases the steps to clonal propagation are dictated by the environment and the biology of the species. In the southern United States the typical process from seed maturation to testing is complicated by the ability to have the seed available early enough to germinate the seed, complete the growing of the seedlings for outplanting in sufficient time in the field for successful establishment. If seed could be successfully stored for at least one-year, seed germination could be synchronized and seedlings developed during a more favorable environment. Therefore, the information gained based on progeny tests would greatly aid the selection process. In addition, the ability for indefinite long-term storage would have a profound impact on developing new mating designs.

Summary

Populus has great potential for use in the production of biomass for bioenergy and biofuels. The variability that exist within *Populus* will allow for even greater gains to be made through both clonal refinement as well as breeding. The taxa tested within this project provided insights into both positive and negative aspects of the current germplasm. It is obvious that eastern cottonwood is well suited for fertile alluvial soils but gains are needed in determining those clones that exhibit both excellent rooting and increased growth. It is also obvious that when eastern cottonwood is moved offsite the current clones suffer from lower nutrient and moisture availability. On these sites, the hybrid poplars have performed well exhibiting excellent rooting and good early growth rates. However, disease becomes the greatest hurdle for both short-term as well as long-term productivity, especially when coppiced is viewed as needed tool for regeneration. Thus selection of genotypes that exhibit a combination of high biomass productivity with disease resistance will be critical to success of intensively managed plantations. Matching productive clones to specific sites takes considerable data, evaluation, and time. Clones with high growth rates the first few years may be appropriate for use in biomass plantings. However, a balance between growth, survival, and disease susceptibility must be achieved. This study demonstrated that while hybrid poplars generally exhibited greater survival, pure eastern cottonwood clones commonly experienced better growth. Based on these data, individual clones have been identified for their good survival, growth, and disease resistance performance. Further LMAV testing is warranted for eastern cottonwood clones 110412 and AG414. In addition, GWR hybrid 8019 should also continue to be watched for its LMAV growth performance. Further upland testing is recommended for GWR hybrids 8019, 6323, 6320 and 6329. Each experienced superior growth at the upland site during the two years studied. However, GWR 6320 and 6329 were in the top 10% for both growth and disease resistance and should be closely monitored for their performance. GWR hybrid 8019 was in the top 10% for growth at both the upland and LMAV site. Its performance should be closely watched at both test sites. Overall, the *Populus nigra* clones experienced superior disease resistance at the upland site relative to eastern cottonwood and other hybrid clones that were evaluated. In conclusion, it is evident that the results reported here are extremely preliminary and care must be taken to fully test those genotypes that exhibit early superiority to get a better understanding of their long-term performance.

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APPENDIX A

LEAST SQUARE MEANS TABLES

Table 24 Least Square means for age-one height and age-two height, DBH, and volume by clone, source, and taxa of the eighty clones included in the combined 2010 Consolidated *Populus* Trial located at New Madrid Co., MO and Pontotoc Co., MS.

			-----Age-1-----		--------------Age-2--------------			
Clone	Source[1]	Taxa[2]	Survival (%)	Height (ft)	Survival (%)	Height (ft)	DBH (in)	Vol (ft^3)
AG187	AG	TD	100	8.3	100	14.7	1.5	0.19
AG188	AG	TD	75	8.0	75	13.9	1.3	0.16
AG229	AG	TD	92	9.1	92	14.3	1.4	0.17
AG409	AG	D	17	ne	17	ne	ne	ne
AG410	AG	D	17	8.7	17	15.1	2.1	0.38
AG412	AG	D	83	9.0	83	17.2	2.1	0.39
AG413	AG	D	75	8.5	75	15.5	2.1	0.42
AG414	AG	D	92	9.8	92	18.6	2.4	0.50
AG427	AG	D	58	8.2	58	14.7	1.8	0.38
AG435	AG	D	50	9.3	50	15.9	2.0	0.44
AG437	AG	D	42	7.5	42	13.9	1.5	0.29
AG443	AG	D	67	9.2	67	17.4	2.3	0.47
AG461	AG	D	67	9.3	67	17.0	1.9	0.34
AG462	AG	D	50	10.4	50	18.9	2.3	0.53
S7-C1	MSU	D	100	9.2	100	15.6	1.8	0.33
ST244	MSU	D	67	9.8	67	17.7	2.1	0.40
ST66	MSU	D	83	10.0	83	17.2	2.1	0.42
ST81	AG	D	83	10.6	83	17.4	2.0	0.36
113-324	AG	D	92	7.6	92	14.1	1.7	0.28
24-128	AG	D	92	9.5	83	17.0	1.7	0.22
011-32S	AG	D	42	7.4	42	12.8	2.0	0.45
NM-6	UMN	NM	100	9.1	92	10.3	0.8	0.11
DN-5	UMN	DN	100	8.2	100	13.5	1.4	0.19
3-1	MSU	D	92	10.2	92	18.1	2.3	0.44
27-5	MSU	D	100	9.2	100	16.3	1.6	0.27
25-2	MSU	D	42	8.8	42	16.9	2.2	0.47
30-4	MSU	D	42	9.2	33	15.6	1.6	0.23
61-4	MSU	D	92	10.0	83	17.1	1.9	0.29
80-5	MSU	D	58	10.2	58	16.6	2.0	0.30
90-7	MSU	D	83	9.7	83	16.6	1.9	0.35
94-3	MSU	D	25	9.7	25	16.2	1.9	0.32
105-4	MSU	D	0	0.0	0	0.0	0.0	0.00
105-1	MSU	D	92	9.7	92	17.4	2.2	0.38
139A-3	MSU	D	58	8.3	58	13.3	1.6	0.25
141A-5	MSU	D	50	8.8	50	16.4	1.8	0.33
147-1	MSU	D	83	10.2	83	18.1	2.3	0.36
158A-4	MSU	D	67	6.6	67	12.2	1.6	0.26

Table 24 (Continued)

1428	GWR	TD	92	8.0	92	11.9	1.2	0.14
4491	GWR	DT	100	7.8	100	12.4	1.3	0.15
6018	GWR	TD	58	9.6	58	16.5	1.7	0.26
6198	GWR	DT	92	8.8	83	14.2	1.7	0.24
6320	GWR	DM	92	10.5	92	16.8	1.8	0.24
6323	GWR	DM	83	10.6	83	18.9	1.9	0.26
6329	GWR	DM	92	11.1	83	18.2	2.0	0.27
7388	GWR	DM	83	10.4	75	18.7	2.0	0.28
7416	GWR	DM	67	10.1	67	17.4	1.8	0.23
8019	GWR	DM	100	11.4	83	22.3	2.2	0.38
9732-40	UMN	DN	83	8.7	83	11.7	1.2	0.16
9732-36	UMN	DN	92	8.0	92	13.4	1.3	0.16
9732-31	UMN	DN	100	9.3	100	15.0	1.5	0.20
9732-24	UMN	DN	100	9.1	100	14.9	1.5	0.20
9732-18	UMN	DN	75	6.7	67	11.0	0.8	0.11
10269	GWR	TD	92	7.7	83	12.0	1.1	0.14
10270	GWR	TD	100	8.6	92	15.2	1.5	0.18
12804	GWR	TD	83	7.0	75	12.4	1.1	0.14
12805	GWR	DT	75	11.6	75	19.1	2.1	0.35
12824	GWR	DN	100	8.5	100	14.9	1.4	0.19
13317	GWR	TN	100	8.8	67	12.3	1.0	0.12
13775	GWR	DN	100	9.0	100	17.4	1.9	0.28
13780	GWR	DN	100	8.3	100	16.6	1.5	0.20
13781	GWR	DN	83	9.4	83	14.9	1.4	0.17
13788	GWR	DN	100	10.3	100	18.7	2.0	0.30
110412	MSU	D	100	10.5	100	20.1	2.4	0.45
110804	MSU	D	92	10.9	92	17.8	2.1	0.43
111014	AG	D	92	10.0	92	17.0	1.9	0.34
111234	AG	D	100	9.4	100	16.3	1.9	0.37
111733	MSU	D	92	10.6	92	19.0	2.1	0.37
22021009	UMN	DN	100	9.4	100	15.4	1.5	0.20
22021048	UMN	DN	100	9.5	92	13.2	1.1	0.14
22033013	UMN	DN	100	9.3	100	14.5	1.4	0.19
22057011	UMN	DN	100	8.7	100	13.4	1.1	0.15
99001111	UMN	DN	92	8.2	92	11.1	0.9	0.11
99007071	UMN	DN	92	8.0	92	14.3	1.3	0.16
99007108	UMN	DN	92	7.9	92	13.0	1.2	0.14
99007115	UMN	DN	100	7.9	100	12.8	1.3	0.17
99007116	UMN	DN	92	9.6	92	14.7	1.4	0.17
99008002	UMN	DN	92	7.9	83	14.0	1.2	0.14
99008098	UMN	DN	100	8.6	92	15.8	1.5	0.19
99037051	UMN	DN	83	10.0	83	16.6	1.7	0.22
99105008	UMN	DN	92	8.4	92	14.0	1.2	0.15

[1] = Sources include ArborGen=AG, Greenwood Resources=GWR, Mississippi State University=MSU, and University of Minnesota=UMN.
[2] = Taxa D=*Populus deltoides*, DM=*P. deltoides x P. maximowiczii*, DN=*P. deltoides x P. nigra*, DT=*P. deltoides x P. trichocarpa*, NM=*P. nigra x P. maximowiczii*, TD=*P. trichocarpa x P. deltoides*, and TN=*P. trichocarpa x P. nigra*.

Table 25 Least Square means for age-one height and age-two height, DBH, and volume by clone, source, and taxa of the eighty clones included in the combined 2010 Consolidated *Populus* Trial located at New Madrid Co.

Clone	Source[1]	Taxa[2]	-----Age-1----- Survival (%)	Height (ft)	--------------Age-2-------------- Survival (%)	Height (ft)	DBH (in)	Vol (ft^3)
AG187	AG	TD	100	10.6	100	16.6	1.9	0.23
AG188	AG	TD	67	10.0	67	16.3	1.7	0.21
AG229	AG	TD	83	11.8	83	17.5	1.9	0.23
AG409	AG	D	33	13.3	33	20.3	2.5	0.43
AG410	AG	D	17	13.2	17	21.5	3.5	0.67
AG412	AG	D	83	12.9	83	22.7	3.3	0.66
AG413	AG	D	50	12.9	50	22.2	3.7	0.75
AG414	AG	D	83	14.4	83	25.1	3.7	0.88
AG427	AG	D	67	12.7	67	22.2	3.3	0.66
AG435	AG	D	33	14.7	33	24.0	3.7	0.80
AG437	AG	D	33	11.8	33	21.3	2.7	0.49
AG443	AG	D	50	13.2	50	22.5	3.7	0.81
AG461	AG	D	33	13.5	33	23.4	3.0	0.56
AG462	AG	D	33	15.3	33	26.2	3.9	0.96
S7-C1	MSU	D	100	13.8	100	22.6	3.0	0.55
ST244	MSU	D	50	14.3	50	24.0	3.4	0.69
ST66	MSU	D	83	15.1	83	24.2	3.4	0.73
ST81	AG	D	67	15.3	67	23.4	3.1	0.60
113-324	AG	D	83	11.3	83	20.3	2.8	0.46
24-128	AG	D	83	11.6	67	19.2	2.2	0.29
011-32S	AG	D	33	13.0	33	21.6	4.0	0.83
NM-6	UMN	NM	100	11.3	83	12.0	1.1	0.13
DN-5	UMN	DN	100	10.4	100	17.5	2.1	0.28
3-1	MSU	D	100	14.8	100	24.2	3.4	0.74
27-5	MSU	D	100	13.3	100	21.7	2.6	0.44
25-2	MSU	D	67	12.9	67	23.6	3.7	0.82
30-4	MSU	D	50	14.0	33	21.1	2.3	0.35
61-4	MSU	D	100	13.6	83	21.7	2.8	0.46
80-5	MSU	D	67	14.1	67	20.8	2.7	0.43
90-7	MSU	D	67	14.6	67	23.4	3.1	0.60
94-3	MSU	D	17	14.4	17	21.9	3.0	0.52
105-4	MSU	D	0	0.0	0	0.0	0.0	0.00

Table 25 (Continued)

105-1	MSU	D	83	13.1	83	22.6	3.1	0.61
139A-3	MSU	D	67	11.8	67	18.1	2.7	0.41
141A-5	MSU	D	50	12.8	50	22.2	3.1	0.55
147-1	MSU	D	67	13.1	67	20.8	3.0	0.53
158A-4	MSU	D	83	10.5	83	19.3	2.8	0.44
1428	GWR	TD	83	10.2	83	13.7	1.7	0.18
4491	GWR	DT	100	9.6	100	15.2	1.7	0.19
6018	GWR	TD	50	13.5	50	20.9	2.4	0.38
6198	GWR	DT	83	11.7	67	16.3	2.6	0.34
6320	GWR	DM	83	12.9	83	17.8	2.2	0.30
6323	GWR	DM	67	12.6	67	20.2	2.3	0.33
6329	GWR	DM	83	13.0	67	20.2	2.4	0.35
7388	GWR	DM	83	11.6	67	21.0	2.4	0.37
7416	GWR	DM	67	12.4	67	19.3	2.2	0.30
8019	GWR	DM	100	14.7	67	25.7	2.8	0.55
9732-40	UMN	DN	83	11.5	83	15.2	1.8	0.22
9732-36	UMN	DN	83	9.9	83	17.0	1.8	0.22
9732-31	UMN	DN	100	11.8	100	19.1	2.2	0.29
9732-24	UMN	DN	100	11.4	100	18.0	2.0	0.28
9732-18	UMN	DN	50	8.1	33	11.7	1.1	0.13
10269	GWR	TD	83	10.2	67	15.1	1.5	0.17
10270	GWR	TD	100	10.6	83	17.1	2.0	0.24
12804	GWR	TD	100	9.2	83	15.0	1.6	0.18
12805	GWR	DT	67	14.9	67	22.9	3.0	0.55
12824	GWR	DN	100	11.0	100	18.2	2.0	0.26
13317	GWR	TN	100	10.1	33	12.1	1.1	0.12
13775	GWR	DN	100	11.4	100	20.8	2.7	0.43
13780	GWR	DN	100	10.9	100	18.9	2.1	0.28
13781	GWR	DN	83	10.6	83	17.9	1.8	0.23
13788	GWR	DN	100	12.6	100	21.0	2.7	0.43
110412	MSU	D	100	15.3	100	25.9	3.3	0.74
110804	MSU	D	83	16.2	83	24.3	3.5	0.76
111014	AG	D	100	13.7	100	23.2	3.1	0.58
111234	AG	D	100	14.5	100	23.7	3.2	0.65
111733	MSU	D	83	15.3	83	24.7	3.1	0.61
22021009	UMN	DN	100	11.6	100	19.2	2.1	0.28
22021048	UMN	DN	100	11.2	83	16.1	1.5	0.17
22033013	UMN	DN	100	12.3	100	19.4	2.1	0.28
22057011	UMN	DN	100	10.5	100	17.8	1.6	0.21
99001111	UMN	DN	83	10.2	83	12.3	1.0	0.12
99007071	UMN	DN	83	10.0	83	16.8	1.7	0.20
99007108	UMN	DN	83	9.0	83	15.8	1.5	0.18
99007115	UMN	DN	100	10.9	100	17.2	2.0	0.24

Table 25 (Continued)

99007116	UMN	DN	83	11.1	83	17.5	1.9	0.22
99008002	UMN	DN	83	9.7	67	16.1	1.4	0.17
99008098	UMN	DN	100	10.9	83	18.9	2.0	0.27
99037051	UMN	DN	67	12.3	67	20.1	2.2	0.31
99105008	UMN	DN	83	10.1	83	17.1	1.5	0.19

[1] = Sources include ArborGen=AG, Greenwood Resources=GWR, Mississippi State University=MSU, and University of Minnesota=UMN.
[2] = Taxa D=*Populus deltoides*, DM=*P. deltoides x P. maximowiczii*, DN=*P. deltoides x P. nigra*, DT=*P. deltoides x P. trichocarpa*, NM=*P. nigra x P. maximowiczii*, TD=*P. trichocarpa x P. deltoides*, and TN=*P. trichocarpa x P. nigra*.

Table 26 Least Square means for age-one height and age-two height, DBH, and volume by clone, source, and taxa of the eighty clones included in the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS.

			-----Age-1-----		--------------Age-2--------------			
Clone	Source[1]	Taxa[2]	Survival (%)	Height (ft)	Survival (%)	Height (ft)	DBH (in)	Vol (ft^3)
AG187	AG	TD	100	6.1	100	12.9	1.1	0.15
AG188	AG	TD	83	6.0	83	11.4	0.9	0.11
AG229	AG	TD	100	6.4	100	11.0	0.9	0.11
AG409	AG	D	0	0.0	0	0.0	0.0	0.00
AG410	AG	D	17	4.3	17	8.7	0.7	0.09
AG412	AG	D	83	5.1	83	11.6	0.9	0.12
AG413	AG	D	100	4.2	100	8.8	0.5	0.09
AG414	AG	D	100	5.3	100	12.2	1.0	0.13
AG427	AG	D	50	3.6	50	7.2	0.3	0.09
AG435	AG	D	67	3.9	67	7.2	0.4	0.09
AG437	AG	D	50	3.2	50	6.5	0.4	0.10
AG443	AG	D	83	5.2	83	12.3	0.9	0.13
AG461	AG	D	100	5.2	100	10.6	0.8	0.11
AG462	AG	D	67	5.4	67	11.6	0.8	0.11
S7-C1	MSU	D	100	4.6	100	8.6	0.6	0.10
ST244	MSU	D	83	5.3	83	11.3	0.9	0.11
ST66	MSU	D	83	4.9	83	10.3	0.8	0.11
ST81	AG	D	100	5.9	100	11.3	0.9	0.12
113-324	AG	D	100	4.0	100	7.9	0.6	0.10
24-128	AG	D	100	7.3	100	14.8	1.3	0.16
011-32S	AG	D	50	1.8	50	4.0	0.1	0.08
NM-6	UMN	NM	100	7.0	100	8.6	0.6	0.10
DN-5	UMN	DN	100	5.9	100	9.5	0.7	0.10
3-1	MSU	D	83	5.6	83	12.1	1.1	0.14
27-5	MSU	D	100	5.1	100	10.9	0.7	0.11

Table 26 (Continued)

25-2	MSU	D	17	4.8	17	10.3	0.7	0.11
30-4	MSU	D	33	4.4	33	10.2	0.8	0.11
61-4	MSU	D	83	6.5	83	12.5	1.0	0.13
80-5	MSU	D	50	6.3	50	12.5	1.2	0.17
90-7	MSU	D	100	4.9	100	9.7	0.6	0.10
94-3	MSU	D	33	5.0	33	10.4	0.9	0.12
105-4	MSU	D	0	0.0	0	0.0	0.0	0.00
105-1	MSU	D	100	6.3	100	12.2	1.3	0.15
139A-3	MSU	D	50	4.8	50	8.6	0.5	0.09
141A-5	MSU	D	50	4.7	50	10.5	0.6	0.10
147-1	MSU	D	100	7.2	100	15.5	1.5	0.19
158A-4	MSU	D	50	2.7	50	5.0	0.5	0.08
1428	GWR	TD	100	5.9	100	10.1	0.7	0.10
4491	GWR	DT	100	6.0	100	9.7	0.9	0.11
6018	GWR	TD	67	5.7	67	12.1	1.1	0.13
6198	GWR	DT	100	5.9	100	12.1	1.1	0.15
6320	GWR	DM	100	8.0	100	15.9	1.4	0.18
6323	GWR	DM	100	8.6	100	17.6	1.5	0.20
6329	GWR	DM	100	9.2	100	16.1	1.6	0.18
7388	GWR	DM	83	9.3	83	16.5	1.6	0.20
7416	GWR	DM	67	7.9	67	15.5	1.3	0.16
8019	GWR	DM	100	8.2	100	18.9	1.6	0.21
9732-40	UMN	DN	83	6.0	83	8.3	0.5	0.10
9732-36	UMN	DN	100	6.2	100	9.9	0.7	0.10
9732-31	UMN	DN	100	6.8	100	10.8	0.9	0.11
9732-24	UMN	DN	100	6.8	100	11.8	1.0	0.12
9732-18	UMN	DN	100	5.3	100	10.2	0.6	0.10
10269	GWR	TD	100	5.2	100	9.0	0.7	0.10
10270	GWR	TD	100	6.6	100	13.3	1.0	0.13
12804	GWR	TD	67	4.7	67	9.8	0.7	0.11
12805	GWR	DT	83	8.4	83	15.4	1.3	0.15
12824	GWR	DN	100	6.0	100	11.5	0.9	0.12
13317	GWR	TN	100	7.5	100	12.4	0.9	0.11
13775	GWR	DN	100	6.6	100	14.0	1.0	0.13
13780	GWR	DN	100	5.7	100	14.2	1.0	0.13
13781	GWR	DN	83	8.1	83	12.0	0.9	0.11
13788	GWR	DN	100	8.0	100	16.4	1.3	0.16
110412	MSU	D	100	6.6	100	14.6	1.3	0.15
110804	MSU	D	100	5.6	100	11.2	0.8	0.11
111014	AG	D	83	5.5	83	10.4	0.8	0.12
111234	AG	D	100	4.4	100	8.8	0.5	0.10
111733	MSU	D	100	6.0	100	13.2	1.1	0.13
22021009	UMN	DN	100	7.3	100	11.7	0.8	0.12

Table 26 (Continued)

22021048	UMN	DN	100	7.8	100	10.3	0.7	0.10
22033013	UMN	DN	100	6.4	100	9.7	0.7	0.10
22057011	UMN	DN	100	6.9	100	9.1	0.6	0.10
99001111	UMN	DN	100	6.3	100	9.9	0.8	0.11
99007071	UMN	DN	100	6.1	100	11.9	0.9	0.11
99007108	UMN	DN	100	6.8	100	10.3	0.8	0.11
99007115	UMN	DN	100	5.0	100	8.4	0.5	0.10
99007116	UMN	DN	100	8.0	100	11.9	1.0	0.12
99008002	UMN	DN	100	6.1	100	11.9	0.9	0.12
99008098	UMN	DN	100	6.3	100	12.8	1.0	0.12
99037051	UMN	DN	100	7.7	100	13.0	1.1	0.13
99105008	UMN	DN	100	6.7	100	10.9	0.8	0.11

[1] = Sources include ArborGen=AG, Greenwood Resources=GWR, Mississippi State University=MSU, and University of Minnesota=UMN.
[2] = Taxa D=*Populus deltoides*, DM=*P. deltoides x P. maximowiczii*, DN=*P. deltoides x P. nigra*, DT=*P. deltoides x P. trichocarpa*, NM=*P. nigra x P. maximowiczii*, TD=*P. trichocarpa x P. deltoides*, and TN=*P. trichocarpa x P. nigra*.

Table 27 Least Square means for age-one height by clone, source, and taxa of the eighty clones included in the 2011 Consolidated *Populus* Trial located at Pontotoc Co., MS.

Clone	Source[1]	Taxa[2]	---------Age-1-------- Survival (%)	Height (ft)
AG185	AG	D	100	7.2
AG187	AG	TD	83	5.6
AG188	AG	TD	100	5.4
AG229	AG	TD	100	6.1
AG411	AG	D	100	4.5
AG414	AG	D	100	5.9
AG431	AG	D	100	6.3
AG432	AG	D	83	4.6
AG433	AG	D	100	3.5
AG434	AG	D	83	7.2
AG435	AG	D	83	5.8
AG436	AG	D	100	5.1
AG437	AG	D	100	5.9
AG438	AG	D	100	5.4
AG439	AG	D	83	7.1
AG440	AG	D	83	2.7
AG441	AG	D	100	5.3
AG442	AG	D	100	5.3

Table 27 (Continued)

AG444	AG	D	100	4.5
S7-C1	MSU	D	100	5.2
S7-C8	MSU	D	83	5.7
ST244	MSU	D	100	6.1
ST66	MSU	D	83	6.0
NM-6	UMN	NM	100	5.7
DN-5	UMN	DN	100	6.3
26-2	MSU	D	83	6.6
27D-1	MSU	D	67	2.9
31-3	MSU	D	100	4.8
36-2	MSU	D	83	4.2
41B-5	MSU	D	67	4.2
80-7	MSU	D	83	4.4
79-4	MSU	D	83	5.0
93-7	MSU	D	17	3.4
96-7	MSU	D	100	4.5
111-1	MSU	D	100	5.6
113B-3	MSU	D	100	5.5
115-1	MSU	D	100	4.8
120-4	MSU	D	100	5.9
1428	GWR	TD	100	6.9
4512	GWR	DT	100	6.6
4700	GWR	DT	100	5.6
5077	GWR	TD	100	7.0
5081	GWR	TD	83	6.4
6018	GWR	TD	100	6.3
6198	GWR	DT	83	4.9
6294	GWR	DM	100	7.3
6300	UMN	DN	83	3.8
6318	GWR	DM	100	7.6
6320	GWR	DM	100	8.2
6329	GWR	DM	100	8.1
6588	GWR	TD	100	7.4
6600	GWR	TD	100	6.4
6612	GWR	TD	100	6.8
7174	GWR	DT	100	6.8
7300	GWR	TD	100	7.0
7306	GWR	TD	100	6.6
9732-31	UMN	DN	100	5.8
12804	GWR	TD	67	2.8
13309	GWR	DN	100	7.1
21400	UMN	DN	100	6.0
21700	UMN	DN	100	5.1

Table 27 (Continued)

31500	UMN	DN	100	8.8
41700	UMN	DN	100	5.9
110412	MSU	D	83	4.8
110804	MSU	D	100	7.3
111234	MSU	D	83	5.5
111733	AG	D	100	4.6
22021008	UMN	DN	100	6.8
22021048	UMN	DN	100	6.9
22053007	UMN	DM	83	6.0
22057002	UMN	DN	100	3.5
22057006	UMN	DN	100	6.2
22057059	UMN	DN	100	5.3
22156023	UMN	DM	100	5.0
99007115	UMN	DN	100	3.2
99008081	UMN	DN	100	5.7
99038013	UMN	DN	100	6.9
99038036	UMN	DN	100	5.7
99059043	UMN	DN	100	5.9

[1] = Sources include ArborGen=AG, Greenwood Resources=GWR, Mississippi State University=MSU, and University of Minnesota=UMN.
[2] = Taxa D=*Populus deltoides*, DM=*P. deltoides x P. maximowiczii*, DN=*P. deltoides x P. nigra*, DT=*P. deltoides x P. trichocarpa*, NM=*P. nigra x P. maximowiczii*, and TD=*P. trichocarpa x P. deltoides*.

Table 28 Least Square means for age-one height by clone, source, and taxa of the eighty clones included in the 2011 *Populus nigra* Trial located at Pontotoc Co., MS.

			---------Age-1---------	
Clone	Source[1]	Taxa[2]	Survival (%)	Height (ft)
A548MS1	AUS	N	100	6.6
A548MS2	AUS	N	100	4.9
A548MS3	AUS	N	83	4.6
A548MS4	AUS	N	100	4.8
A548MS5	AUS	N	100	4.2
A550MS1	AUS	N	100	4.1
A550MS2	AUS	N	100	5.4
A550MS3	AUS	N	100	5.9
A550MS4	AUS	N	100	4.8
A550MS5	AUS	N	100	4.8
CMS1	CRO	N	100	4.5
CMS2	CRO	N	100	4.8

Table 28 (Continued)

CMS3	CRO	N	100	6.2
CMS4	CRO	N	100	5.3
CMS5	CRO	N	100	4.4
CMS6	CRO	N	100	4.5
CMS7	CRO	N	100	4.5
CMS8	CRO	N	100	5.1
CMS9	CRO	N	100	4.1
CMS10	CRO	N	100	5.3
G13MS1	GER	N	100	3.4
G13MS2	GER	N	83	4.2
G13MS3	GER	N	100	4.0
G13MS4	GER	N	100	3.6
G13MS5	GER	N	83	4.4
GO1MS1	GER	N	83	4.6
GO1MS2	GER	N	100	4.2
GO1MS3	GER	N	83	4.0
GO1MS4	GER	N	83	3.4
GO1MS5	GER	N	100	4.9
H16MS1	HUN	N	100	5.1
H16MS2	HUN	N	100	5.1
H16MS3	HUN	N	100	6.2
H16MS4	HUN	N	100	5.2
H16MS5	HUN	N	100	4.3
H22MS1	HUN	N	100	4.5
H22MS2	HUN	N	100	3.3
H22MS3	HUN	N	100	4.4
H22MS4	HUN	N	100	3.2
H22MS5	HUN	N	100	4.5
IO3MS1	ITA	N	100	5.2
IO3MS2	ITA	N	100	5.7
IO3MS3	ITA	N	100	5.4
IO3MS4	ITA	N	100	6.2
IO3MS5	ITA	N	100	6.3
IO4MS1	ITA	N	100	5.2
IO4MS2	ITA	N	100	6.6
IO4MS3	ITA	N	100	5.4
IO4MS4	ITA	N	100	5.0
IO4MS5	ITA	N	100	5.9
T191MS1	TUR	N	100	5.0
T191MS2	TUR	N	100	4.5
T191MS3	TUR	N	100	5.7
T191MS4	TUR	N	100	6.2
T191MS5	TUR	N	100	6.0

Table 28 (Continued)

TO14MS1	TUR	N	100	4.6
TO14MS2	TUR	N	83	6.8
TO14MS3	TUR	N	100	3.9
TO14MS4	TUR	N	100	5.5
TO14MS5	TUR	N	83	4.4

[1] = Sources include Austria=AUS, Croatia=CRO, Germany=GER, Hungary=HUN, Italy=ITA, and Turkey=TUR.
[2] = Taxa N=*Populus nigra*.

Table 29 Comparison of the 10% of the test population based on age-two volume and corresponding age-two crown rating system with the top 10% of the test population based on age-two crown rating system and corresponding age-two volume for the 2010 Consolidated *Populus* Trial located at New Madrid Co., MO.

Top 10% for Volume					Top 10% for CRS				
Clone	Source[1]	Taxa[2]	Vol (ft^3)	CRS	Clone	Source[1]	Taxa[2]	Vol (ft^3)	CRS
AG414	AG	D	0.88	51.5	158A-4	MSU	D	0.44	26.1
25-2	MSU	D	0.82	98.5	105-1	MSU	D	0.61	33.0
110804	MSU	D	0.76	103.2	27-5	MSU	D	0.44	35.4
3-1	MSU	D	0.74	91.5	ST-66	MSU	D	0.73	38.8
110412	MSU	D	0.74	91.5	90-7	MSU	D	0.60	42.8
ST-66	MSU	D	0.73	38.8	AG412	AG	D	0.66	46.6
AG412	AG	D	0.66	46.6	113-324	AG	D	0.46	48.6
111234	AG	D	0.65	67.9	AG414	AG	D	0.88	51.5

[1] = Sources include ArborGen=AG and Mississippi State University=MSU.
[2] = Taxa D=*Populus deltoides.*

Table 30 Comparison of the 10% of the test population based on age-two volume and corresponding age-two crown rating system with the top 10% of the test population based on age-two crown rating system and corresponding age-two volume for the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS.

Top 10% for Volume					Top 10% for CRS				
Clone	Source[1]	Taxa[2]	Vol (ft^3)	CRS	Clone	Source[1]	Taxa[2]	Vol (ft^3)	CRS
8019	GWR	DM	0.21	235.0	6198	GWR	DT	0.15	38.4
7388	GWR	DM	0.20	205.8	6320	GWR	DM	0.18	58.1
6323	GWR	DM	0.20	100.3	AG187	AG	TD	0.15	62.8
147-1	MSU	D	0.19	96.5	4491	GWR	DT	0.12	62.8
6329	GWR	DM	0.18	83.2	24-128	AG	D	0.16	73.0
6320	GWR	DM	0.18	58.1	13780	GWR	DN	0.13	77.8
80-5	MSU	D	0.17	197.5	ST-244	MSU	D	0.11	81.0
7416	GWR	DM	0.16	122.5	6329	GWR	DM	0.18	83.2

[1] = Sources include ArborGen=AG, Greenwood Resources=GWR, and Mississippi State University=MSU.

[2] = Taxa D=*Populus deltoides*, DM=*P. deltoides x P. maximowiczii*, DN=*P. deltoides x P. nigra,* DT=*P. deltoides x P. trichocarpa*, and TD=*P. trichocarpa x P. deltoides*.

Table 31 Comparison of the 10% of the test population based on age-two volume and corresponding age-two crown rating system with the top 10% of the combined test population based on age-two crown rating system and corresponding age-two volume for the 2010 Consolidated *Populus* Trial located at Pontotoc Co., MS and New Madrid Co., MO.

Top 10% for Volume					Top 10% for CRS				
Clone	Source[1]	Taxa[2]	Vol (ft^3)	CRS	Clone	Source[1]	Taxa[2]	Vol (ft^3)	CRS
AG414	AG	D	0.50	166.9	AG412	AG	D	0.39	127.2
110412	MSU	D	0.45	197.2	27-5	MSU	D	0.27	131.0
3-1	MSU	D	0.45	198.7	ST-244	MSU	D	0.34	153.8
110804	MSU	D	0.43	229.5	113-324	AG	D	0.28	156.7
ST-66	MSU	D	0.42	181.6	AG414	AG	D	0.50	166.9
AG443	AG	D	0.40	198.6	147-1	MSU	D	0.36	179.5
AG412	AG	D	0.39	127.2	ST-66	MSU	D	0.42	181.6
105-1	MSU	D	0.38	221.2	111234	AG	D	0.37	194.2

[1] = Sources include ArborGen=AG and Mississippi State University=MSU.

[2] = Taxa D=*Populus deltoides.*