

Biomass productivity improvement for eastern cottonwood

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Abstract

Eastern cottonwood (*Populus deltoides* Marsh.) is grown in plantations by MeadWestvaco for use at its Wickliffe Kentucky Fine Papers Mill¹. Genetic and productivity research over the past two decades have led to significant increases in biomass yield while reducing production costs.

Initially, genetic research identified fast growing clones for sites along the Mississippi River alluvial floodplain near Wickliffe, Kentucky. Clone recommendations are refined continuously through testing, and we add new clones to the program to broaden the genetic base. Breeding and selection allow us to combine traits important to the paper making process in select clones. In 1996, a fiber farm was established, and additional genetic testing was needed to develop clones for this radically different production system. Biotechnological advances such as the use of genetic markers and transformation have proven their value for cottonwood, but regulatory approval is needed to commercialize this technology.

Over the past five years, our plantation productivity research has reduced fiber production costs by defining optimal management regimes for alluvial and fiber farm sites. As research identifies the best herbicides, rates, and application times, chemical weed control use is increasing and gradually substituted for mechanical cultivation. Studies on planting dates and cutting length showed that successful plantations can be established in July to avoid spring floods, and long cuttings grow faster than shorter ones. Water, nutrient, and spacing studies indicated that initial fiber farm management regimes could be improved substantially. In addition, research on cottonwood leaf beetle showed that damage was minimized during the critical plantation establishment phase using an insecticide that is new to forestry.

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1. Introduction

In the late 1960s, Westvaco's, now MeadWestvaco's, Wickliffe Kentucky Fine Papers Mill was established just south of the confluence of the Ohio and Mississippi Rivers to produce un-coated fine papers primarily for card stock and envelope production. An off-line coater was added in the mid-1980s, and the mill now produces mostly coated paper for magazines. Chips from sawmills and trees from woodlots owned by small, private landowners account for

most of the fiber supply. Oaks (*Quercus* sp.) are the primary species used because of their abundance and low cost in this region of the United States. Other species commonly used at the mill include hickory (*Carya* sp.), willow (*Salix* sp.), soft maple (*Acer saccharinum* L.), American sycamore (*Platanus occidentalis* L.), and eastern cottonwood.

Our company's philosophy has been to maintain a level of self-sufficiency, and plantations have been established on company-owned lands to provide fiber, particularly during critical periods when wood is difficult to obtain on the open market. Because pines are not native to the local area and a long-fiber species was needed at the Wickliffe Mill to add strength to the paper, loblolly pine became the first species developed under a plantation scenario. Plantations were established beginning in the early 1970s, and since then, pine tree improvement research has led to

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¹USDA Forest Service, Pacific Southwest Research Station, 3644 Avtech Parkway, Redding, CA 96002, USA. Since this paper was submitted, five paper mills and associated forestland, including the Wickliffe Mill, were sold forming NewPage (the mills) and Escanaba Timber LLC (the land).

the development of cold-hardy strains of loblolly pine. For over 35 years, the mill utilized a 70% hardwood (deciduous) species, 30% pine species mixture, which was obtained from both company land and private land. In 1997 that mixture shifted to 100% hardwood, and demand for this resource increased.

The company-owned forestland near the Wickliffe Mill covers 420 km² in four states. Of this, approximately 120 km² are in the bottomland hardwood type associated with the Mississippi and Ohio Rivers. Half of the bottomland area is covered with plantations, and half is in natural hardwood stands and open areas. Eastern cottonwood and American sycamore are the predominant hardwood plantation species.

Cottonwood has not been a preferred fiber source for the Wickliffe Mill because of its low wood density compared to oak species ($\sim 320 \text{ kg m}^{-3}$ vs. $\sim 550 \text{ kg m}^{-3}$) [1]. Because of pulping restrictions at the mill, mixing high and low-density fibers creates problems. A recent shift to heavier grades of paper has reduced this problem, and the mill is now able to increase the amount of cottonwood fiber used for papermaking.

From a management standpoint, eastern cottonwood provides key advantages over other tree species such as rapid growth rate in response to intensive cultural management. Traditional tree improvement and advances in plantation culture have worked synergistically to increase per hectare yields. Our goal to grow fiber more economically will be met by further increases in yield with concurrent reductions in establishment costs through genetic tree improvement, lower cost weed control, and optimal use of nutrient and water inputs. In addition, improved wood quality traits will make cottonwood a preferred fiber source for the Wickliffe Mill. Future yield and quality increases will result from continued gains from traditional research as well as through implementation of biotechnological advancements.

2. Tree improvement

Our company's first cottonwood plantations were planted in 1974 on alluvial sites using methods and clones developed by the US Forest Service Southern Hardwood Laboratory in Stoneville, MS. Growth rates of clones in these plantations exceeded those of local clones, but the potential for even greater gains prompted our company to invest in the genetic improvement of cottonwood. We decided early in the program to use pure eastern cottonwood as opposed to hybrid poplars because in our region many hybrids suffer from a stem canker caused by *Septoria musiva* Peck. [2]. Over the years, new selections were identified through collection and testing of seed and clones obtained from wild stands and other tree improvement programs. A breeding program was added later to combine the best traits of select clones.

Testing identifies clones for alluvial and fiber farm sites because these two plantation sites are very different.

MeadWestvaco fiber farms are intensively managed plantations that utilize drip irrigation to provide water and nutrients because the soils are sandy and infertile. Fiber farm sites were chosen to allow harvesting at any time of the year. Alluvial site plantations rely on rainfall and inherent soil fertility levels. The alluvial soils near the Wickliffe Mill are highly fertile because annual flooding of the Mississippi River deposits both soil and nutrients. While these sites allow rapid growth of cottonwood ($> 30 \text{ m}$ in 10 yr), flooding prevents tree harvesting during late winter and spring months. Data from clone tests replicated on both sites indicate significant genetic $\times$ environment interactions warranting development of clones for each site.

Tree improvement efforts began with a clone refinement program that resulted in substantial operational gains while at the same time adding new genotypes needed for a larger, diverse breeding population. At this point in time, it was still uncertain that Westvaco would enter into a more costly breeding program. In fact, in 1988 Westvaco suspended its cottonwood plantation-planting program, but fortunately a set of new clones had been selected and placed into a cutting orchard. While there was no cottonwood planting between 1989 and 1996, the research group was allowed to continue measuring established studies. This proved valuable when the program was reinstated in 1996. Test results provided the basis of a breeding population and indications of where additional gains could be made. Because of the limited number of genotypes in the breeding population and the need for short-term gains, we used a positive assortative mating scheme. At the same time, we continued to build the breeding population through collection of genotypes from other programs and new geographic areas.

A rigorous, three-step testing program ensures that the selected clones are well suited to local conditions through the elimination of poor performing genotypes at each step. Selections from progeny tests are placed in large, clone screening trials. Then, selections from the trials are planted in highly replicated clone tests on multiple sites. Short-term testing is employed throughout the program to increase genetic gain per unit of time, thus allowing newer clones to enter the deployment population in a shorter time frame. During clone testing, a number of traits are measured including growth, disease resistance (*Melampsora* leaf rust, *Marssonina* leaf spot), leaf retention, and the production of single stems. By selecting for a combination of traits, we have developed disease resistant, fast growing, and well-formed clones. We now include specific gravity as a selection criterion for cottonwood because high wood density ($\sim 400 \text{ kg m}^{-3}$) clones are a preferred fiber source for the mill. Certain cottonwood clones lend other valuable characteristics such as high brightness and high tensile energy absorption [3,4]. Whereas growth and disease resistance traits are easy and affordable to measure, wood quality measurements are both costly and time consuming. We are currently examining new techniques that will allow

rapid screening and effective culling of low-density clones [5].

Biotechnology is another tool employed to develop desirable cottonwood clones. DNA markers are used to verify clonal identity during the propagation process to ensure that nursery blocks of improved clones are not contaminated with other clones. In addition, select cottonwood clones have been transformed with a gene for herbicide resistance that makes mechanical cultivation unnecessary after initial site preparation. Additional traits to improve wood quality and growth are being studied by ArborGen, a joint venture between MeadWestvaco, Rubicon and International Paper supporting research in sustainable forestry through biotechnology. This technology could provide a significant reduction in plantation establishment costs and add value to the final product, but the economics of the approval and regulation process and the unwillingness of the forest industry to drive these efforts in the United States limit the commercial deployment of transgenic *Populus* clones. Although we consider the quality of the science to be exceptional, the commercialization of a transgenic tree would be a bold step in the United States because of the difficult challenge of public acceptance.

3. Plantation productivity

The genetic improvement program ensures that the best clones are selected for planting, but many other biotic and abiotic factors influence productivity. For example, eastern cottonwood annual growth can approach 10 m in height and 10 cm in ground-level diameter from coppice at the Biosphere 2 Center [6]. While these growth rates were achieved indoors under optimal growing conditions, they indicate the potential growth of this species. Our plantation productivity research program is designed to identify and alleviate the barriers that restrict growth rates. Study areas include weed competition control, nutrition, water relations, planting dates, planting stock types, and pest problems.

Weed competition slows tree growth rates, and weed control is one of the several major costs associated with plantation management. Because alluvial sites are very productive, weed species grow extremely fast. With unrestricted weed growth, eastern cottonwood grows poorly and can succumb to a combination of herbaceous weed and vine competition during the first growing season. Mechanical cultivation is used extensively to remove competing vegetation, but many weed species sprout prolifically or maintain large seed banks in the soil and grow back rather quickly after cultivation.

Chemical weed control is a more desirable alternative to efficiently manage competition, but few chemicals are specifically labeled for cottonwood forest plantations. Our company believes in strict adherence to pesticide labels, and chemicals can be used only when the specific site type and species are listed on the label. The limited production

area of cottonwood provides little incentive for chemical companies to pursue expensive registration. To alleviate this problem, we have been evaluating herbicides such as imazapic, imazapyr, and clopyralid for use in cottonwood plantation systems to add *Populus* to their labels and to adjust rates to make them cost effective. Oxyfluorfen and pendimethalin are two useful pre-emergent herbicides, but the effectiveness of these two chemicals is limited during hot dry periods of the summer months when first-year cottonwood is growing rapidly. Information obtained from studies on weed control effectiveness and tree tolerance is shared with chemical companies and state regulatory agencies. In some instances, we have been able to obtain special use registration for specific counties within a state, which is a significantly less costly alternative to full, federal registration (e.g., diclosulam). Other weed control studies provide information on application rates and timing. If labeled application rates can be lowered without compromising weed control, we can reduce our costs while also reducing the amount of chemical released to the environment. Past studies showed that timely herbicide application can result in clean, fast-growing plantations at a lower cost than mechanical cultivation.

As mentioned previously, MeadWestvaco's alluvial sites are inherently high in fertility because of soil deposition and nutrient replenishment from annual flooding. Frequently, flooding is a problem because it prevents plantation accessibility or decreases plantation survival. High floodwaters destroy the foliage on submerged portions of established trees, and growth rates can be reduced depending on the length of flooding. Newly planted trees are often killed when floods occur soon after growth initiation. In an effort to manage the influence of the river, we are studying how to modify our planting practices to avoid losses.

Cottonwood is normally planted from January through April using dormant, un-rooted cuttings. Spring flooding usually occurs in April and May when the cuttings first start to grow. To avoid the impact of flooding, we wanted to determine how late in the year we could successfully establish plantations. We were also interested in the growth differences between our standard 46 cm cuttings and longer, 92 cm cuttings with the expectation that longer cuttings would survive better if their tops grew quickly above flood levels. All cuttings in the study were planted at a depth of 40 cm. As expected, early planted cuttings grew the most because they had a longer growing season (Fig. 1). Longer cuttings grew significantly taller than the standard cuttings ($P < 0.001$), and the difference was greatest for the latest planting date. This information resulted in a change to longer cuttings to take advantage of the faster growth regardless of planting date. Even when planted in July, the longer cuttings grew tall enough to avoid damage from the next season's flooding.

On fiber farms, the sandy soil that helps us from a management standpoint is also our biggest problem. The soils that cover our fiber farms were formed from sandy

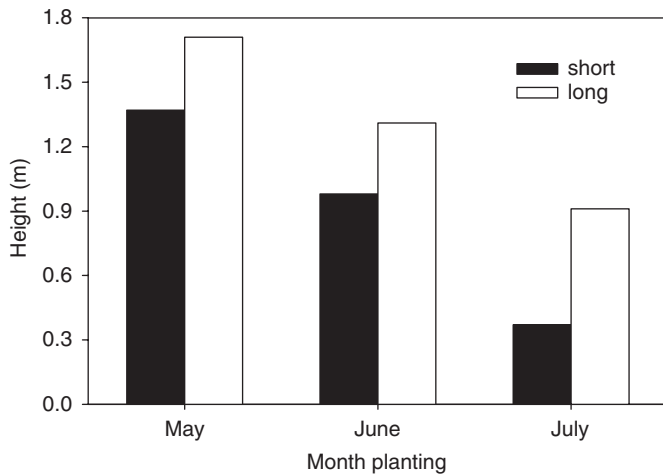


Fig. 1. Eastern cottonwood height growth from short (46 cm) and long (92 cm) dormant, un-rooted cuttings planted during May, June, or July. Longer cuttings were significantly taller ($P > 0.001$) at all planting dates.

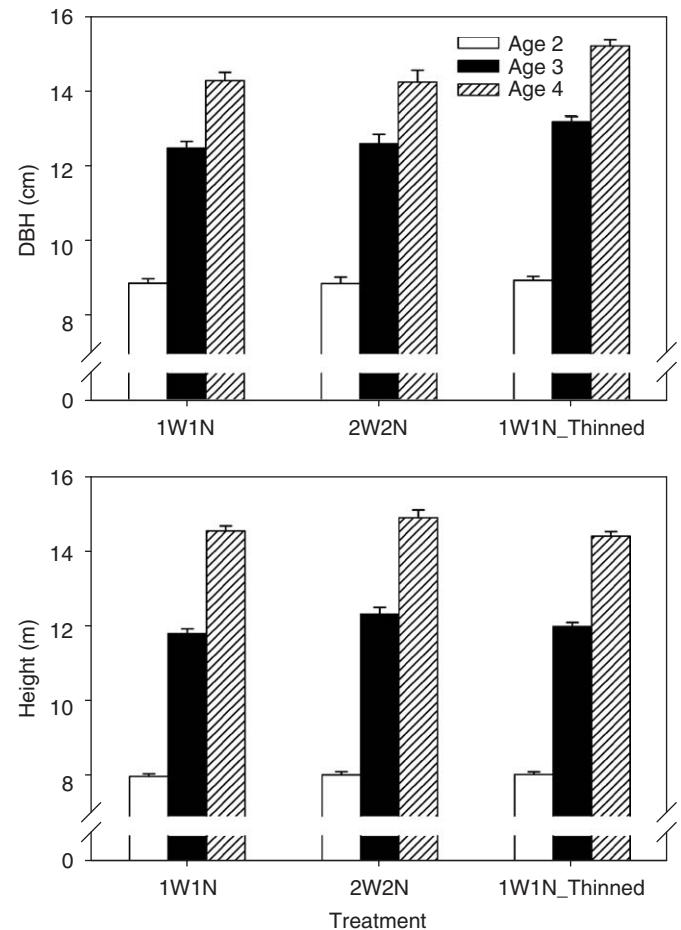


Fig. 2. Eastern cottonwood diameter at breast height (DBH) and height growth for thinned (33% of trees removed) and un-thinned trees with single (1N1W = $168 \text{ kg ha}^{-1} \text{ yr}^{-1}$ nitrogen and 0.5 cm d^{-1} water) and double (2N2W) nutrient and water levels. Statistical differences were detectable at age 3 ($P > 0.02$) and age 4 ($P > 0.01$) for DBH. No differences were detected for height. For DBH at age's three and four, Duncan's multiple-range test indicated a significant difference between the thinned treatment (1N1W-thinned) and the other two un-thinned treatments (1N1W and 2N2W) treatments, which were not different from each other.

alluvial sediments on broad, old natural levees. Because of the high sand content, trees can be harvested any day of the year, even after heavy rains. This provides a fiber source when alluvial plantations are inaccessible because of wet soils or flooding. As expected, fiber farm sites are much lower in nutrient levels and water holding capacity than alluvial sites; therefore, nutrition and water supply studies were established to maximize growth rates without providing excess nutrients or water. For example, data from one study helped to determine how increasing water, nutrient, and light levels affected tree growth. Fiber farm spacing, originally designed at $2.4 \times 3.4 \text{ m}$, was much closer than the $3.6 \times 3.6 \text{ m}$ spacing used on alluvial soils. Irrigation and nitrogen fertilization rates are 0.5 cm d^{-1} and $168 \text{ kg ha}^{-1} \text{ yr}^{-1}$, respectively. After three years, we found that doubling the water or nitrogen available to the trees had no significant effect on height or diameter growth (Fig. 2). However, thinning a stand by 33% while maintaining the base nutrient level significantly increased tree diameter at age 3 ($P > 0.02$) and age 4 ($P > 0.01$) over the single or double irrigation and nitrogen treatments. Apparently, tree diameter growth was restricted more by growing space than by water or nutrient levels in this study. As a result, we now plant fewer trees per hectare.

In both alluvial and fiber farm stands, cottonwood leaf beetle (*Chrysomela scripta* F.) is a major defoliator of cottonwood. Adults and larvae feed on young leaves, and when cottonwood leaf beetle (CLB) population numbers are high, they can completely consume young leaves and shoot tips. Eastern cottonwood trees grow rapidly during the first three growing seasons when they are particularly susceptible to CLB infestations because of the high percentage of succulent leaf and stem tissue [7,8]. Studies show that growth rate and biomass production can be reduced by 33% over the first two years when defoliation levels reach 75% [9]. Control measures using contact

insecticides are effective [10], but timing is critical, and observations indicate that insecticide applications are often made after CLB has damaged the trees. Residual, systemic insecticides are desirable because insect control is continuous. Our recent studies show that imidacloprid reduces CLB feeding, and severe feeding that causes terminal damage to the trees was almost completely eliminated. Moreover, significant increases in height from 10 to 30% were found for trees treated with imidacloprid. Based on this information, new federal labeling is now under consideration allowing use of this chemical on *Populus* species.

4. Summary

MeadWestvaco's eastern cottonwood research program is focused on producing the highest yields at the lowest

growing costs on alluvial and fiber farm sites. While our tree improvement program is successful, we find that our goals cannot be met unless we combine our best clones with improved management techniques. We must understand what influences the growth of our clones so that we can target these traits or processes to further increase yields.

Our cottonwood genetic improvement program uses breeding and testing to continuously produce new, high quality clones. Through time we have refined our selection process to combine growth, disease resistance, leaf retention, form, rooting, and wood quality traits. While the development of genetically modified, herbicide resistant material has been accomplished, and while the potential gains from this technology are high, the commercialization of this material is still an uncertainty.

Findings from planting date and stock type studies have been put into operational use. Our ongoing work in chemical control of weeds and insects is critical to further reductions of growing costs. Modest use of pesticides has allowed us to protect our newly planted cottonwood cuttings from various pests while increasing growth. The refinement of rates and timing of chemical applications will further reduce growing costs.

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