

# GROWING COTTONWOODS FOR BIOMASS: RESULTS OF A TEN-YEAR IRRIGATION STUDY

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**Abstract**—Eastern cottonwood (*Populus deltoides* Bartr.) has potential as a short rotation alternate crop on marginal farmlands in the South to meet increasing biomass demands for pulp and bioenergy applications. Potlatch Corporation supported this study to investigate the effect of irrigation on the growth of cottonwood trees. The study was installed in the Delta region of AR in 1996. Survival, height, diameter, and biomass production of the various cottonwood clones were compared between the irrigated-bedded treatment and the unirrigated-subsoiled treatment. Several clones were replanted the second year due to poor initial survival. Data are presented for replanted and non-replanted clones. Survival for some clones dropped off greatly after five years. Irrigation with bedding increased volume growth over no irrigation with subsoiling. Growth differences were also apparent among clones within each of the two irrigation treatments. Lower survival sometimes resulted in greater volume growth of the remaining trees. Overall, irrigation increased height, diameter, and volume growth of all clones.

## INTRODUCTION

Eastern cottonwood (*Populus deltoides* Bartr.) is one of the fastest growing hardwood species in the United States. Many wood products are derived from cottonwood, including pulp for making high quality paper, furniture stock, crates and boxes, matches, and toothpicks (Dutrow and others 1970). Cottonwood trees grow best on well-drained sandy loam and silt loam soils near creek bottoms (McKnight 1970). The species has wide genetic diversity and can be easily propagated vegetatively by cuttings (Farmer and Wilcox 1964, Land and others 2001). These factors have made cottonwood a target of extensive research and selection for improved growth and disease resistance for more than 50 years (Land and others 1996). Selected and improved cottonwood clones are often grown as a short rotation woody crop to produce biomass for pulp. Interest has also increased in the South for converting the biomass to bioenergy. The performance of select clones usually varies by geographic origin and is influenced by other sources of genetic variation (Land and others 1996). Planting clones adapted to a given area, along with applying appropriate cultural treatments, can significantly improve biomass production.

This 10-year study was implemented by Potlatch Corporation and the University of Arkansas at Monticello School of Forest Resources. The purpose was to evaluate the response of selected cottonwood clones to irrigation. Irrigation could make growing cottonwood more viable on marginal lands.

## METHODS

### Site Location and Description

The study site is located at the University of Arkansas Pine Tree Branch Experiment Station in St. Francis County in east central AR. The study occupies about 15 acres near Second Creek. The soil is a Calloway silt loam. The site's previous use was a rotation of soybeans, wheat, and grain sorghum.

### Study Design and Layout

The design is a split-plot, where the whole-plot is irrigation treatment, and the split-plot is clone of cottonwood. Each

clone was replicated six times within each irrigation treatment in randomly assigned plots. Each plot contained 56 trees in a 7 by 8 tree layout. The interior 30 trees were measured, leaving an unmeasured buffer row around each measurement plot. The irrigated and unirrigated treatments were not randomized. Large buffers would have been required between the treatments, which were impractical for this study. Two treatment blocks were used, an unirrigated block and an irrigated block.

### Study Establishment

The site was sprayed prior to planting with Goal® and Roundup® herbicides to control weeds. Fertilizer was applied before planting at the rate of 100 pounds per acre of nitrogen. The unirrigated block was subsoiled prior to planting, and the liquid fertilizer was injected 20 inches below the soil surface. In the irrigated block, each planting row was sprayed with the fertilizer in a 2-foot-wide band, and then bedded (20-inch-high beds) to facilitate furrow irrigation.

Cottonwood cuttings were planted by hand at a 10 by 10 foot spacing in March 1996. Disking, herbicide spraying, and hand weeding continued for two years after the initial planting. Irrigation with well water was done each year whenever a 2-inch-rainfall deficit was reached. This occurred an average of five times per year, resulting in about 8 to 10 acre-inches of irrigation water per year.

Nine cottonwood clones were tested, two from Texas (S7C15 and S13C20), five from Stoneville (ST72, ST124, ST148, ST163, and Delta View, a mix of the four ST clones), and two hybrids from the northwestern U.S. (*Populus trichocarpa* Torr. (49-177) and Gray x *P. deltoides* Bartr. ex Marsh [1529]).

Poor survival caused the complete replanting of five cottonwood clones (S7C15, ST72, ST148, ST163, and Delta View) in Spring 1997. This resulted in two separate groups of clones: replanted clones, which grew nine years, and non-replanted clones, which grew for 10 years. Measurement data for the two groups were then analyzed separately.

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Field measurements collected were survival and total height (years 1, 2, 3, 5, 10), groundline diameter (years 1, 2 for non-replants; also year 3 for replants), and d.b.h. (years 3, 5, 10 for non-replants; years 5, 10 only for replants).

Biomass produced by each tree (dry tons of total aboveground biomass per tree) was calculated according to the formula shown below (Jenkins and others 2003). Metric units in the formula were converted to English units.

$$\text{Biomass} = \text{Exp}(\beta_0 + \beta_1 \ln \text{d.b.h.}) \quad (1)$$

where

biomass = total aboveground biomass (kg) for trees 2.5 cm d.b.h. and larger

$\text{Exp}$  = exponential function

$\beta_0 = -2.2094$  (for aspen/alder/cottonwood/willow species group)

$\beta_1 = 2.3867$  (for aspen/alder/cottonwood/willow species group)

$\ln$  = natural log base "e" (2.718282)

d.b.h. = diameter at breast height (cm)

## RESULTS AND DISCUSSION

### Irrigation Treatment

For the replanted clones, survival at year 10 across all clones was about the same for both irrigation treatments (table 1). However, growth and volume means were greater for the irrigated clones. For the non-replanted clones, survival was almost 20 percent higher for the irrigated clones (table 1). Irrigation also increased the other growth and volume means over the unirrigated clones. Irrigation of hybrid poplars, usually using drip systems, has been successful in increasing yields in the Northwestern United States. Irrigation in late summer may provide the most benefits (Land and others 1996).

### Clonal Differences (Replanted Clones)

Survival trends for each of the replanted clones are shown in figure 1. Some clones had relatively consistent survival over the nine-year growth period, but survival rates for two clones (irrigated S7C15 and unirrigated ST72) dropped off considerably after age 4.

For the replanted clones, growth and volume means within each irrigation level are shown in table 2. For each parameter, means were higher for irrigated trees. Within the unirrigated treatment, clone S7C15 trees performed best in terms of per acre biomass production, while ST163 performed the best in the irrigated treatment (not significant).

Figure 2 compares percent volume growth for the replanted clones over the nine-year growth cycle by two periods: the first four and the second five years. For all five replanted clones, volume growth was greater the second five years, in some cases double or triple. Growing these clones through the second five-year period was definitely worthwhile.

Dutrow and others (1970) reported average diameters for 9-year-old unirrigated cottonwoods ranging from 6.5 inches on poor sites to 9.0 inches on good sites. Diameters for the unirrigated replanted clones in this study are much smaller.

### Clonal Differences (Non-replanted Clones)

Survival trends for each of the non-replanted clones are shown in figure 3. Some clones had relatively consistent survival over the ten-year growth period, but survival rates for several clones dropped off considerably after age 5.

For the non-replanted clones, growth and volume means within each irrigation level are shown in table 3. For each parameter, means were higher for irrigated trees, except d.b.h. for clone 49-177. Within the unirrigated treatment level,

**Table 1—Means for replanted and non-replanted clones, compared by irrigation treatment at year 10**

| Variable                         | Replanted clones |           | Non-replanted clones |           |
|----------------------------------|------------------|-----------|----------------------|-----------|
|                                  | Unirrigated      | Irrigated | Unirrigated          | Irrigated |
| Survival, %                      | 61.2             | 59.2      | 38.6                 | 57.8      |
| Height, feet                     | 30.5             | 50.7      | 34.7                 | 52.7      |
| Diameter, inches                 | 4.53             | 6.66      | 6.08                 | 7.68      |
| Basal area, square feet per acre | 32.3             | 66.3      | 36.2                 | 78.5      |
| Biomass per tree, dry tons       | 0.045            | 0.115     | 0.089                | 0.155     |
| Biomass per acre, dry tons       | 12.4             | 29.3      | 15.4                 | 35.8      |

**Table 2—Height, diameter, basal area, and biomass per acre (volume) means for replanted clones by irrigation level. Within each irrigation level, clonal means followed by different letters are significantly different at  $\alpha=0.05$**

| Clone      | Height, feet |       | DBH, inches |        | BA, square feet per acre |       | Biomass, tons per acre |       |
|------------|--------------|-------|-------------|--------|--------------------------|-------|------------------------|-------|
|            | unirr.       | irr.  | unirr.      | irr.   | unirr.                   | irr.  | unirr.                 | irr.  |
| S7C15      | 31.2ab       | 44.3a | 4.94a       | 5.56a  | 38.2a                    | 51.6a | 15.0a                  | 23.0a |
| ST163      | 33.0a        | 54.2a | 4.63ab      | 7.08ab | 36.9ab                   | 74.7a | 14.0ab                 | 33.5a |
| ST148      | 29.2ab       | 51.0a | 4.60ab      | 7.25 b | 33.8ab                   | 68.1a | 12.9ab                 | 30.6a |
| ST72       | 28.1 b       | 49.6a | 3.94 b      | 6.54ab | 20.2 b                   | 73.4a | 7.4 b                  | 32.2a |
| Delta View | 31.2ab       | 54.3a | 4.52ab      | 6.88ab | 32.2ab                   | 64.0a | 12.7ab                 | 28.2a |

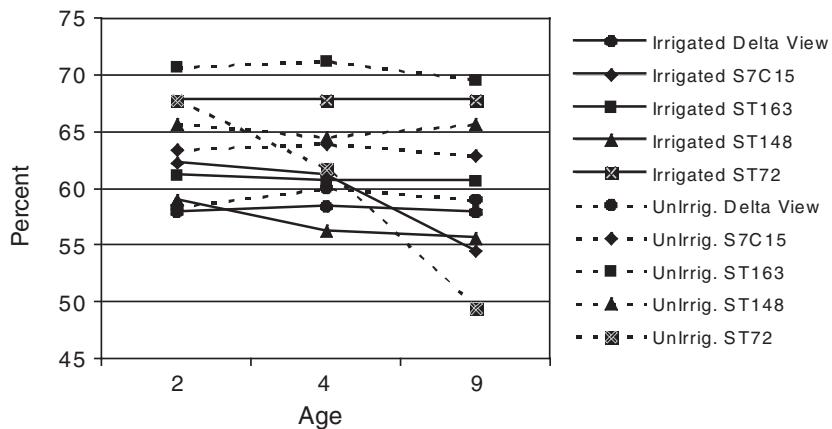


Figure 1—Percent survival by age and irrigation level for the replanted clones.

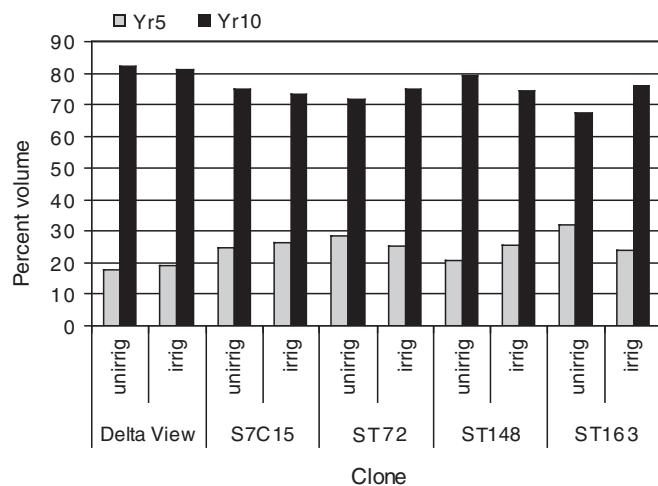


Figure 2—Percent volume growth for the replanted clones through ages 4 (year 5) and 9 (year 10).

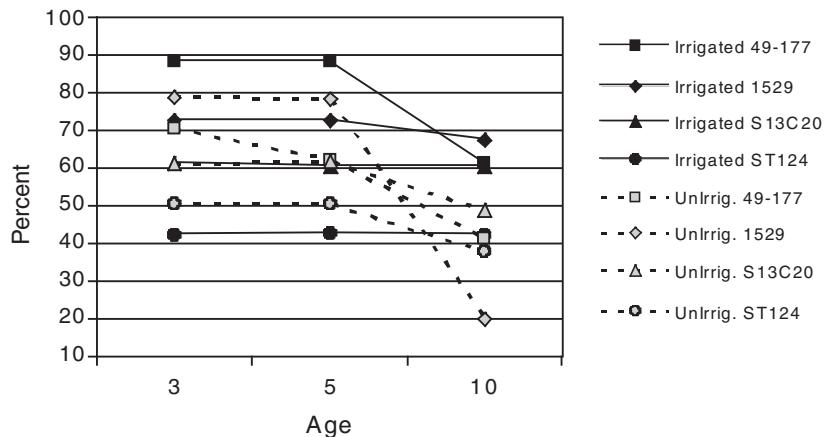


Figure 3—Percent survival by age and irrigation level for the non-replanted clones.

**Table 3—Height, diameter, basal area, and biomass per acre (volume) means for non-replanted clones by irrigation level. Within each irrigation level, clonal means followed by different letters are significantly different at  $\alpha=0.05$**

| Clone  | Height, feet |        | DBH, inches |        | BA, square feet per acre |        | Biomass, tons per acre |        |
|--------|--------------|--------|-------------|--------|--------------------------|--------|------------------------|--------|
|        | unirr.       | irrig. | unirr.      | irrig. | unirr.                   | irrig. | unirr.                 | irrig. |
| 49-177 | 37.9a        | 46.3a  | 6.92a       | 6.71a  | 48.1a                    | 65.6a  | 21.2a                  | 28.4a  |
| 1529   | 32.4a        | 44.7a  | 5.98ab      | 6.75a  | 20.7 b                   | 73.6a  | 8.6b                   | 32.0a  |
| S13C20 | 34.9a        | 56.8 b | 5.50 b      | 7.95 b | 36.2ab                   | 92.5a  | 14.6ab                 | 42.9a  |
| ST124  | 33.1a        | 62.9 c | 5.90ab      | 9.33 c | 37.3ab                   | 82.6a  | 16.1ab                 | 40.1a  |

clone 49-177 trees performed best in terms of per acre biomass production, while S13C20 performed the best in the irrigated treatment. However, per acre production differences were not significant in the irrigated treatment.

Figure 4 compares percent volume growth at ages 3, 5, and 10 years for the non-replanted clones. The age 3 volume calculation is possible because d.b.h. could be measured on the non-replanted clones. For some clones (1529, 49-177) volume growth was less the second five years than the first five years. A rotation shorter than 10 years might be better for these clones. Later volume growth for clone 1529

was negative due to very poor survival. Clone ST124 had consistent low survival (fig. 3), allowing more growing space for the remaining trees, which produced more volume per tree.

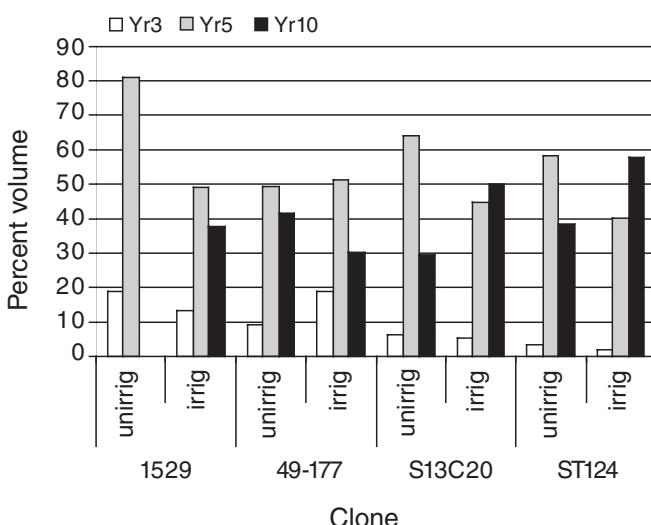
#### The Best Clones?

An annual growth calculation (dry tons per acre per year) can be made to compare the replanted clones with the non-replanted clones (table 4). Each group has good performers, but some clones show big treatment differences.

Table 5 lists the four best clones in each irrigation level in terms of biomass production in dry tons per acre per year. Production does not seem to be closely related to survival rate. However, the clone or clones to select for growing will likely depend on whether or not the site will be irrigated.

#### Economic Analysis

Growing cottonwoods for biomass must be economically attractive in order for farmers and landowners to be willing to invest in a plantation. A production rate of about 5 to 10 dry tons of biomass per acre per year is necessary (Land and others 2001). Net present values (NPV) were calculated for three of the best clones in terms of high production rates for either the unirrigated, irrigated, or both treatments. Assumptions are: (1) that existing farmland is converted and no site preparation is needed; (2) initial planting costs are \$131 per acre, based on 436 cuttings planted per acre at \$0.30 each; (3) irrigation costs are about \$40 per year; (4) annual property taxes are \$4 per acre; (5) the biomass price per dry ton is \$7.50; and (6) the rate of return is 3 percent. The results are shown in table 6 below.



**Figure 4—Percent volume growth for the non-replanted clones through ages 3, 5, and 10.**

Growing cottonwoods for biomass could become more attractive once demand and prices increase and planting

**Table 4—Mean annual biomass production, or volume growth, (dry tons/acre/year) for all clones**

| Clone    | Replanted clones |        | Non-replanted clones |        |      |
|----------|------------------|--------|----------------------|--------|------|
|          | unirrig.         | irrig. | unirrig.             | irrig. |      |
| S7C15    | 1.67             | 2.56   | 49-177               | 2.12   | 2.84 |
| ST163    | 1.56             | 3.72   | 1529                 | 0.86   | 3.20 |
| ST148    | 1.43             | 3.40   | S13C20               | 1.46   | 4.29 |
| ST72     | 0.82             | 3.58   | ST124                | 1.61   | 4.00 |
| Delta V. | 1.41             | 3.13   |                      |        |      |

**Table 5—The four best clones in terms of mean annual biomass production (volume growth), with corresponding percent survival, by irrigation level after 10 years**

| Unirrigated |                |            | Irrigated |                |            |
|-------------|----------------|------------|-----------|----------------|------------|
| Clone       | Tons/acre/year | Survival % | Clone     | Tons/acre/year | Survival % |
| 49-177      | 2.12           | 62         | S13C20    | 4.29           | 61         |
| S7C15       | 1.67           | 64         | ST124     | 4.00           | 43         |
| ST124       | 1.61           | 51         | ST163     | 3.72           | 61         |
| ST163       | 1.56           | 71         | ST72      | 3.58           | 68         |

**Table 6—Income, expenses, and net present value (NPV) over 10 years for three of the best performing clones. Expenses were discounted to calculate net present value. The per ton price needed to break even is also shown**

| Parameter           | Clone and irrigation level |       |        |        |
|---------------------|----------------------------|-------|--------|--------|
|                     | ST124                      |       | S13C20 | 49-177 |
|                     | unirr.                     | irr.  | irr.   | unirr. |
| Yr10 Income, \$     | 121                        | 301   | 322    | 159    |
| 10 yr. Expenses, \$ | 166                        | 525   | 525    | 166    |
| NPV, \$             | (75)                       | (290) | (274)  | (47)   |
| Break even, \$      | 14                         | 17    | 16     | 11     |

costs are decreased. Irrigation costs must be reduced, or clones selected that perform well in particular regions without irrigation. After the first rotation, planting costs will be negligible if coppicing is used. Indications are that the Conservation Reserve Program (CRP) will cost-share short rotation woody plantations. However, weed control and fertilization costs must be considered. Some of the clones produced more biomass during their first 4 to 5 years of growth than the last five years during the 10 year rotation. For example, clone 1529 had the highest production of all clones after five years with a positive NPV requiring a breakeven price of just \$6.50 per dry ton.

## CONCLUSIONS

Irrigation did not affect overall survival for the replanted clones, but survival was higher for the irrigated non-replanted clones. Clonal survival varied widely within irrigation treatments, but better survival did not necessarily result in greater volume growth. Irrigation with bedding increased volume growth over the unirrigated treatment with subsoiling. Some clones exhibited greater volume production rates than others, however, volume growth overall was less than expected. Production rates of 5 to 10 dry tons per year would be required for a viable operation. The economics of growing these cottonwood clones in AR should improve with reduced growing costs (through better cultural treatments) and increased prices. Cost-share payments will also help.

Most farmers and landowners will probably want to use unirrigated lands for growing short rotation woody energy crops. Additional research to refine cultural treatments such

as spacing, rotation length, weed control, and fertilizer, along with further testing of these and other cottonwood clones, will be needed. Much of this work has been done in other regions of the United States, but little information exists for AR.

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