# CARBON SEQUESTRATION RESULTING FROM BOTTOMLAND HARDWOOD AFFORESTATION IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY

**Bertrand F. Nero, Richard P. Maiers, Janet C. Dewey, and Andrew J. Londo**[1]

**Abstract**— Increasing abandonment of marginal agricultural lands in the Lower Mississippi Alluvial Valley (LMAV) and rising global atmospheric carbon dioxide ($CO_2$) levels create a need for better options of achieving rapid afforestation and enhancing both below and aboveground carbon sequestration. This study examines the responses of six mixtures of bottomland hardwood species to fertilizer and herbaceous release treatments as a means of enhancing afforestation and carbon sequestration in the LMAV. A completely randomized design with 6 x 2 x 2 factorial arrangement of treatments was employed on sites near Cleveland and Greenville, MS. Dormant unrooted cottonwood cuttings and bare-root (1-0) seedlings of all other species were planted in spring of 2006. First-year survival ranged from 50 to 80 percent for red mulberry, green ash/oak mix, NRCS species mix and an oak mix. Cottonwood monoculture and cottonwood/oak mix plantings showed survival below 40 percent. Very little differences in first-year growth were noted among the various planting types. Soil carbon prior to planting constituted more than 99 percent of the ecosystem carbon. We expect a shift and redistribution of carbon pools as the site transitions from herbaceous vegetation to forest.

## INTRODUCTION

Growing forests for carbon sequestration is a new concept for an old practice. The need for it is not only driven by the persistent rise in atmospheric carbon dioxide ($CO_2$) levels (IPCC 2007) but also the increasing extent of valuable forest loss coupled with resultant abandonment of marginal agricultural lands especially in the Lower Mississippi Alluvial Valley (LMAV) (Amacher and others 1998). To expedite the process of carbon sequestration under a forestry scenario, efficient afforestation mechanisms are required. Early afforestation efforts have favored fast-growing monoculture stands as an attempt to achieve rapid carbon sequestration (Nilsson and Schopfhauser 1995). In hardwood plantation silviculture, matching species to the site is essential in achieving successful regeneration and afforestation (Stanturf and others 1998). Stands of fast-growing species play a pivotal role in meeting the rising demand of woody biomass production (Schweitzer and Stanturf 1999), however, the impacts of slow/fast growing hardwood species on below- and above-ground carbon sequestration are not well defined in the Mississippi River alluvial bottomlands. In the LMAV, early reforestation activities primarily focused on pure stands of oaks and pecans for their wildlife value (Stanturf and others 1998), though currently mixed species plantings are being adopted (Schoenholtz and others 2001). While fast-growing monocultures provide a more rapid financial return to land owners and enhance public perception of reforestation efforts (Schweitzer and Stanturf 1999), carbon value, aesthetics and ecological integrity of such forests may be compromised. King and Keeland (1999) questioned the predominance of oaks in pre-settlement bottomland hardwood forests and suggested that the shortage of seedling availability may increase the diversity of future plantings. Establishing native bottomland hardwood species and types based on existing stands of similar soils and site characteristics offer better opportunities of restoring the historic LMAV bottomland hardwood forest and may assure multiple benefits including below- and aboveground carbon sequestration. Planting a variety of bottomland hardwood species may more closely approximate diversity of natural stands and may maximize below- and above-ground carbon sequestration because of the multifunctional characteristics of diverse forest ecosystems. If indeed these stands can thrive under this concept, these stands may prove more socially and ecologically valuable than traditional bottomland hardwood monoculture plantations. However, their ability to mimic succession and answer these questions are beyond the scope this study.

Intensive early silvicultural treatments, including fertilization and herbicide use, can increase the survival and growth rates of planted hardwoods (Baker and Blackmon 1976, Ezell and Shankle 2004) and subsequently aboveground carbon sequestration in hardwoods. Because of past agricultural practices nitrogen (N) can be a limiting nutrient on LMAV soils protected by the levee system. Herbaceous competition is a major challenge to bottomland hardwood afforestation in the LMAV (Groninger and others 2003). Fertilization and herbaceous release practices in young afforested bottomland hardwood stands may boost success, but effects on below- and aboveground carbon sequestration are not well understood. Fertilization can affect other soil processes such as respiration, microbial activity, and soil pH (Lee and Jose 2004), thus potentially affecting net carbon sequestration on such afforested sites.

New and efficient silvicultural techniques will enhance afforestation establishment success, restore the ecological integrity of degraded lands, enhance carbon sequestration and meet the multiple objectives of landowners in the LMAV. Benefits of afforesting marginal lands in LMAV may include wildlife habitat restoration, connecting fragmented bottomland forest, sequestering carbon thereby providing carbon credits for land owners, as well as restoring many other valuable biogeochemical and hydrologic functions (Shoenholtz and others 2005). This study is designed to test the performance of a number of hardwood species mixtures under early herbaceous release and fertilizer application treatments on

[1]Graduate Research Assistant, Assistant Professor, Senior Research Associate, and Associate Professor, respectively, Department of Forestry, Mississippi State University, Starkville, MS.

*Citation for proceedings*: Stanturf, John A., ed. 2010. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 614 p.

two sites in the LMAV. Specific objectives are 1) to compare survival and growth performance of the different species mixtures after one growing season, 2) to examine the survival and growth response of different species mixtures to fertilizer application and herbaceous weed control and 3) to assess the trends of initial below-and above-ground carbon prior to afforestation.

## MATERIALS AND METHODS

### Study Sites

The study was conducted at two sites in the LMAV: 5 miles west of Greenville, MS (33°48'N, 90° 98'W) in Washington County and 5 miles north of Cleveland, MS (33°74'N, 90°73'W) in Bolivar County. The climate is typically warm and humid. The original vegetation cover was temperate deciduous bottomland hardwood forest. Mean annual temperature is 17 °C, with winter and summer averages of 6 °C and 28 °C, respectively. Mean annual rainfall is 1430 mm. Effects of small elevation changes on species survival and development have been reported (Hodges and Switzer 1979). The soils are alluvial in origin; dominant soil types are Commerce silt loam (Fine-silty, Mixed, Superactive, Nonacid, Thermic Fluvaquentic Endoaquepts) and Forestdale silty clay loam (Fine, Smectitic, Thermic Typic Endoaqualfs) on the Greenville and Cleveland sites, respectively (Morris 1961, Rogers 1958). Both sites have been in pasture for at least the past 25 years although the Greenville site supported row-crop agriculture prior to conversion to pasture.

### Treatments

A 6 x 2 x 2 factorial arrangement of treatments in a completely randomized design with 3 replicates was used on each site. Six types (levels) of bottomland hardwood (BLH) species mixtures (table 1), two levels of fertilizer (fertilizer and no fertilizer) and two levels of herbicide (herbicide and no herbicide) were used in the study. Nitrogen, Phosphorous and Potassium (NPK) fertilizer (15:10:5) planting tablets were applied to fertilizer treated plots, one tablet in a separate hole adjacent to each planted seedling. Goal®2XL was applied at a rate of 64 ounces per acre with Latron AG-98 at 0.25 percent vol. /vol. to control herbaceous weeds 2 and 5 months after planting. Goal®2XL was applied over the top of seedlings with a band width of about 0.5 m using an ATV mounted sprayer. Minor budbreak had occurred in seedlings at the first application in early April. At the time of the second application however, most seedlings had developed good foliage. The herbicide was intended to serve as herbaceous release for the woody crops and the fertilizer to provide immediate nutrient requirements soon after establishment of all planting stock. Bare-root (1-0) seedlings for all species, except cottonwood which were dormant un-rooted vegetative cuttings, were planted in January-February 2006 at a spacing of 3 by 3 m. The experimental unit was a quarter-acre plot with an average of 108 seedlings planted per plot. Initial heights and root collar diameters were measured prior to planting. Seedling survival, height and groundline diameter were measured every third month after planting. Subsequent growth data were based on a random sample of 25 percent of seedlings per plot. When plot survival decreased below 25 percent, whole plot monitoring was employed for the last set of data during the first growing season.

Initial soil carbon and above-ground carbon were determined prior to planting. Soil samples to a depth of 100 cm were collected using Oakfield probes and 7.4 cm diameter by 3.7 cm height cylinder core samplers. Each 100 cm core sample had 3 replicates per plot, partitioned into four depths: 0–15 cm, 15–30 cm, 30–60 cm, 60–100 cm. Replicates for each depth were composited, dried to a constant weight at a temperature of 70 °C and ground and analyzed for soil total nitrogen (N) and total carbon (C) using a Fisons NA1500 elemental analyzer at the Mississippi State Forest and Wildlife Research Center (FWRC). Core-sampled soils were oven dried at 105 °C to a constant weight and the dry weight used to estimate the bulk density of the soil by depth for each plot. Bulk density data were used to estimate soil C on a per-hectare basis. Herbaceous data were collected using 0.5 by 0.5 m square quadrats with three replicates randomly located in each plot. All live biomass within a quadrat was removed and oven dried at 65–70 °C. Dry weights were determined and the amount of carbon estimated as half the dry weight per plot of herbaceous biomass (Vogt 1991). This constituted the initial above-ground carbon.

Mean change in height and diameter per plot relative to mean height and diameter at planting were estimated after the final measurements were made. Percent survival was also estimated relative to number of seedlings planted. Plot means of survival, height, and diameter were subjected to analysis of variance (ANOVA) using SAS and, where appropriate, significant means were ranked according to Fishers' Protected LSD test at P = 0.05. Herbaceous carbon changes over time and soil carbon changes with depth were compared using paired t-test at a significance level of alpha = 0.05.

## RESULTS

### Survival and Growth

Survival was analyzed to determine the effects of the different species combinations on the two test sites. First-year survival was approximately 56 percent on the Cleveland site and 45 percent on the Greenville site. On the Cleveland site, green ash/oak mixture and red mulberry monoculture stands had the highest survival at 75 percent and 72 percent, respectively. Survival of the oak mixtures and the NRCS species mixtures were slightly above 60 percent but not significantly different. Cottonwood monoculture and cottonwood/oak mix plots had the lowest survival of 17 percent and 48 percent respectively (table 2). Fertilizer and herbicide treatments at the Cleveland site had significant effects on survival (table 3). Survival of the only fertilizer treated plots were 15 percentage points lower than the control (no fertilizer, no herbicide treated plots). No significant differences were observed between the control, herbicide, and fertilizer+herbicide combined (interaction). Similar trends in survival were observed on the Greenville site with respect to species mixtures. Red mulberry monoculture had the highest percent survival rate (72 percent). No significant differences were observed between the green ash/oak mixture and the NRCS species mixtures (table 2). Oak mixed plots, cottonwood/oak mixture and cottonwood monoculture showed survival of less than 50. No significant differences were observed in survival on the Greenville site with respect to fertilizer and herbicide treatments (table 3).

**Table 1—Six types of bottomland hardwood species mixtures planted on marginal agricultural lands on Greenville and Cleveland test sites in MS**

| Treat-ment # | Planting Type | Stock type | Species Mixture/Combination |
|---|---|---|---|
| 1 | Monoculture | Unrooted Cuttings | Cottonwood (*Populus deltoides* Bartr. ex Marsh) |
| 2 | Monoculture | Bare-root seedlings | Red mulberry (*Morus rubra* L.) |
| 3 | Mixture | Bare-root seedlings | Oak mix: 33% Nuttall (*Quercus texana* Buckl.), 33% Willow (*Q. phellos* L.) and 33% Water oak (*Q. nigra* L.) |
| 4 | Mixture | Unrooted Cuttings & Bare-root seedlings | 50% Cottonwood and 50% Oak mix (Nuttall, Willow and Water) |
| 5 | Mixture | Bare-root seedlings | 50% Green ash (*Fraxinus pennsylvanica* Marsh.) and 50% Oak mix |
| 6 | Mixture | Bare-root seedlings | NRCS: [50% Nuttall, 20% Green Ash, 30% Sycamore (*Platanus occidentalis* L.), Persimmon (*Diospyros Virginiana* L.), Willow and Water oak] |

On the two sites, first-year survival of red mulberry monoculture and NRCS species mixtures were approximately the same. Of the remaining species combinations, survival was relatively better at the Cleveland site compared to the Greenville site. On the Cleveland site, the green ash/oak mixed plots exhibited the highest survival rate of 75 percent which was 25 percent better than on the Greenville site (table 2). Mean survival differed slightly for NRCS species mix, red mulberry and oak mixture, at the Cleveland site and for NRCS, red mulberry and Green ash/oak mix at the Greenville site. Mean survival of 15 percent and 37 percent were observed for the cottonwood monoculture and cottonwood/oak mix respectively (table 2). Mean survival for the oak mix, cottonwood/oak mix and cottonwood monoculture was respectively 58, 91, and 30 percent higher at the Cleveland site.

One-year growth in diameter and height were significantly different among species combinations on both sites. Growth in height and diameter in cottonwood monoculture stands were 72 cm and 5 mm, respectively. Little or no change in height and diameter was apparent for all other species mixture a year after establishment on both sites (table 4). Fertilizer-herbicide combined treatment yielded significantly greater growth especially in diameter in the Forestdale soils of Cleveland than the other three treatments (table 3). No significant difference in growth was observed on the Greenville site with respect to fertilizer and herbicide treatments (table 3).

**Below- and Aboveground Carbon**

Initial aboveground carbon estimated from the existing herbaceous vegetation prior to planting did not differ by site. However, seasonal differences were significant (fig. 1). The average aboveground carbon in May was approximately 3600 kg/ha, this decreased by about 700 kg/ha in the latter part of summer (August). Initial below ground data revealed that soil nitrogen (fig. 2a) and soil carbon (fig.2b) concentrations tended to decrease with depth on both sites. Soil nitrogen and carbon differed significantly by site in the upper 15 cm layer but tended to be similar in the deeper layers at P = 0.05. Nitrogen and carbon values within the top 15 cm soil layer were about 1 mg-N/g soil and 17 mg-C/g soil greater than values within the 15–30 cm subsurface layer on the fine textured Cleveland soils. On the coarse textured soils of Greenville, mixed differences were observed in soil N concentrations, where the highest N concentration was in the 15–30 cm layer (fig.2a). Below the 15 cm layer, soil C did not differ significantly with depth on the Greenville Commerce silt loam soils; soil C was however, 5 mg-C/g soil greater in the surface 15 cm layer. Soil bulk density ranged from 1.1 to 1.2 g/cm$^3$ for all soil depths except for surface soil-densities of Cleveland which had soil-density as low as 0.7 g/cm$^3$. At the ecosystem level, above-ground biomass represented

**Table 2—Mean survival of bottomland hardwood species mixtures following one growing season on Cleveland and Greenville sites. Values followed by the same letter in the same column are not significantly different at P = 0.05**

| | Mean Survival (%) | |
|---|---|---|
| Species | Greenville (GV) | Cleveland (CL) |
| Cottonwood (CW) | 12.70 e | 16.50 d |
| Red mulberry | 71.90 a | 71.70ab |
| Oak mix | 40.10 c | 63.30 b |
| CW/Oak mix | 25.20 d | 48.20 c |
| Green ash/oak mix | 58.40 b | 75.30 a |
| NRCS spp. mixes | 61.90ab | 62.20 b |

less than one percent of the total ecosystem carbon on both Cleveland and Greenville sites (table 5). Below ground C indicated that 54 percent of Cleveland soil C accrued in the upper 30 cm layer at the Cleveland site while 44 percent C occurred in the same layer of the Greenville site (table 5). Total ecosystem C was more than 1 kt/ ha greater at the Cleveland site compared to the Greenville site.

**Table 3—Chemical treatment effects on first year mean survival, change in height and diameter on two sites in the LMAV. Values in the same column followed by the same letter are not significantly different at P = 0.05 for each site**

| Treatment | Height (cm) | Diameter (mm) | Survival (%) |
|---|---|---|---|
| Cleveland | | | |
| Control | 8.30ab | 0.96b | 63.40a |
| Fertilizer | 8.73ab | 1.28b | 48.50b |
| Herbicide | 4.26b | 0.73b | 57.40ab |
| Fertilizer+ Herbicide | 16.81a | 2.67a | 55.50ab |
| Greenville | | | |
| Control | 6.35a | 0.60a | 45.40a |
| Fertilizer | 7.68a | 0.82a | 45.80a |
| Herbicide | 11.24a | 1.14a | 50.00a |
| Fertilizer+ Herbicide | 3.90a | 1.02a | 39.00a |

## DISCUSSION

### Survival and Growth

Survival and growth of bottomland hardwood species are influenced by several factors ranging from seedling quality/ handling to environmental factors (Stanturf and others 1998). Success of bottomland hardwood afforestation has varied with site preparation (Lockhart and others 2003), species type (Stanturf and others 2000), soil type, planting stock/method (Stanturf and others 1998), and competition control (Ezell and Catchot 1998). In general, a survival of 247–494 seedlings/ha or 50–80 percent at age three is considered successful among restorationists in the LMAV (King and Keeland 1999). While (Allen 1990) reported successful hardwood afforestation at 266 stems per acre (665 stems/ha), the Natural Resources Conservation Service (NRCS) standard for successful afforestation is a minimum of 247 stems/ha of acceptable species after 3 years of establishment (Stanturf and others 2001). Although, the 50–80 percent survival rate shown by most of the species mixtures (red mulberry, NRCS, green ash/oak mix and the oak mix) in this study (table 2) should have been higher, they are within reported limits for successful afforestation. The wide variations in survival on both sites may be among other variables an indication of species preference for site. Red mulberry and NRCS species mixtures appear to be better adapted to both site conditions but the inconsistencies in survival of the other species combinations may be due to factors such as drought, herbivory, noxious and persistent herbaceous species competition, planting stock quality, handling, planting conditions as well as edaphic site factors.

Rapid early growth in height for bottomland hardwood species is essential to overcoming difficult site conditions (Stanturf and others 2000). Common site conditions impacting hardwood survival and growth include; flooding, restrictive pans, competing vegetation, drought, herbivory, soil pH levels and presence of vines (Stanturf and others 2000, Stanturf and others2004). Correctly matching species to soil/site conditions may ensure high survival and continued growth. However, rapid early growth of species such as cottonwood or slow early growth of oaks may not necessarily indicate long-term adaptability of a particular species to site. Soil-site characteristics tied to species needs for long-term growth is key to successful establishment. Survival and growth trends observed in this study may be attributed to a number of these site factors. First-year growth in height changed only slightly for all of the species mixtures. The two monoculture treatments showed opposite growth patterns. Cottonwood monoculture had a 71–74 cm increase in height with 6 mm increase in diameter while red mulberry monoculture stands decreased by 25 cm in height relative to the initial height at planting. The survival of cottonwood in this study is similar to the findings of (Randall and Krinard 1977) who noted first year survival of unrooted cuttings to be 36 percent. First-year growth of cottonwood in this study was however far below the 8-9 feet height and 3.1 inches diameter growth by Randall and Krinard (1977). The poor survival and growth of cottonwood in this study is probably due to a combination of factors such as poor quality of cuttings, improper handling prior to planting, genetics and site relationship as well as several factors discussed elsewhere in this paper. Lack of first-year growth and decline

**Table 4—Initial and first-year mean diameters and heights of six bottomland hardwood species mixes on two sites in the LMAV. Values followed by the same letter in the same column are not significantly different at P = 0.05**

| Species | Diameter (mm) | | | Height (cm) | | |
|---|---|---|---|---|---|---|
| | Initial | First year | | Initial | First year | |
| | | Greenville | Cleveland | | Greenville | Cleveland |
| Cottonwood (CW) | 3.11 | 8.92a | 8.93a | 5.25 | 78.90a | 76.93a |
| Red mulberry | 4.21 | 4.24d | 4.63d | 62.79 | 31.41c | 39.50c |
| Oak mix | 5.66 | 5.73bc | 6.21c | 49.24 | 45.40b | 46.00bc |
| CW/Oak mix | 3.39 | 5.51cd | 6.97bc | 39.83 | 47.00b | 53.30b |
| Green ash/ oak mix | 7.16 | 6.79bc | 7.74b | 50.17 | 47.60b | 51.70b |
| NRCS spp mixes | 6.90 | 6.99b | 7.09bc | 49.38 | 50.10b | 46.90bc |

in height of the other species mixtures may be explained by the dry site conditions following planting (April-May 2006) and the extended drought season (4.5 months long) of 2006 (National Weather Service 2006), herbivory, competing vegetation and poor seedling quality for some species. Sumerall (2007) observed various intensities of herbivory due to cotton rats and rabbits on the different species mixtures, notably red mulberry, oak mixture, green ash/oak mixtures and NRCS species mix plots on these same sites. Dense herbaceous vegetation reflected in the biomass data (fig.1) during the summer may have further reduced available soil moisture under already drought stressed conditions. Herbaceous vegetation may out-compete the seedlings for nutrients and water from the soil as well as reduce light levels reaching the seedlings resulting in poor survival and growth. In addition, poor root/shoot ratios of seedlings prior to planting might have also contributed to the low survival and poor growth of bareroot seedlings. The distinct decline in heights of red mulberry may be due to the characteristic large shoots compared to roots of the planting stock. Seedlings with poor root/shoot ratios may experience poor survival and first-year growth, especially in drought conditions. The high survival (72 percent) of red mulberry is a result of rapid resprouting from roots. Thus, red mulberry, just like the oaks, may have high coppicing ability and as such under stressed conditions will resort to resprouting allowing the species to be more effective in afforestation situations.

Studies by Ezell and Cachot (1998) and Groninger and others (2003) indicated that use of pre-emergent sulfometuron methyl and post-emergent glyphosate yielded excellent survival and increased growth in some bottomland hardwood species. Using Goal®2XL, we found no significant differences between herbicide and no herbicide treatments in survival and growth (table 3). The lack of significant results suggests that the rates applied were either too low or that there are too many grass species tolerant to Goal®2XL. Hot field temperatures following herbicide application could have caused rapid breakdown of Goal®2XL. Fertilizer application however significantly decreased survival over the control but no significant differences were observed in growth (table 3). Fertilizer uptake in plant roots requires moisture. Lack of moisture in the plant root system due to early droughts possibly created osmotic stress within the rhizosphere of establishing roots leading to seedling wilt and subsequently a decrease in survival. The combined effects of fertilizer and herbicide treatments significantly increased growth perhaps due to the fact that herbaceous competition was somewhat reduced, increasing water and nutrient availability for seedling uptake.

**Below- and Aboveground Carbon**

Herbaceous biomass constitutes the majority of aboveground carbon in this study. Tree seedling data were not included because previous studies by Zimmermann (2001) on nine year old oak stands indicated less than one percent of the aboveground carbon accrued from trees. Barker and others (1996) noted that grassland provides a substantial C sequestration potential, however afforesting such sites provides seven times greater carbon sequestration than on grasslands. We found approximately 3500 kg/ha carbon in the above-ground vegetation during the active growing season, though this was less than one percent of the total ecosystem carbon (table 5). Above-ground herbaceous vegetation carbon significantly decreased from May to August 2006 (fig.1) indicating that aboveground carbon on grasslands may have rapid turnover rate. The trends in above-ground carbon may be explained by patterns of annual variations in climate.

On abandoned agricultural lands, soil carbon tends to increase steadily subjective to vegetation composition

**Table 5—Total ecosystem (kt/ha) carbon of abandoned agricultural lands showing the distribution of C below- and above-ground on two soil types in the lower Mississippi alluvial valley**

| Soil Type | Depth | | | | |
|---|---|---|---|---|---|
| | 0-30 cm | 60-100 cm | Soil Total | Herbaceous | Total Ecosystem C |
| Forestdale | 4.50 | 3.80 | 8.30 | 0.30 | 8.30 |
| Commerce | 3.10 | 3.90 | 7.10 | 0.30 | 7.10 |

(Jobbagy and Jackson 2000, Knops and Tilman 2000), soil texture and climate patterns (Jobbagy and Jackson 2000). On both grass and forested lands, soil C has been reported to decrease with depth (Jobbagy and Jackson 2000, Vesterdal and others 2002). Our results show that soil carbon decreased with depth and was somewhat higher in the finer textured Forestdale soils than coarse textured Commerce soils (fig. 2 and table 5). On Forestdale soils in Lake George, Zimmermann (2001) found 4.1 kt-C/ha soil carbon prior to afforestation in the upper 30 cm surface soils. This is similar to 4.5 kt-C/ha of the Forestdale soils found on the Cleveland site in our study. Differences in soil C in the upper 30 cm layer between Commerce and Forestdale soil may be explained largely by the variations in texture, bulk density and past land use. High soil organic carbon was noted to be associated with fine-textured soils (Jobbagy and Jackson 2000). Low bulk density of 0.6 g/cm$^3$ on Forestdale soils may account for the higher carbon and nitrogen concentrations in the upper 0–30 cm layer. The lower carbon content in the upper 30 cm of the Commerce soils may be due in part to past agricultural activities and higher efflux of carbon due to increased decomposition. Disturbance due to tillage coupled with the coarse-textured nature of commerce soils may have fueled decomposition processes. On both soil types, soils in the lower 30–100 cm were similar in carbon content (table 5). Bulk density did not differ with depth on the two sites within the 30–100 cm subsurface soils and may explain the similarity in soil carbon beyond the 30 cm depth. Because soils in this area were formed from alluvial deposits, the similarities in soil C at the deeper 30–100 cm layers are very likely. Total site carbon storage includes the mineral soil, ground cover, and vegetative pools (Londo 2000). Total site carbon in our study was 1.2 kt greater in the fine textured Forestdale soils compared to the course textured Commerce soils of the Greenville site (table 5). In their unforested state, finer alluvial soils, with relatively higher clay contents may be better carbon sinks. However, as the vegetation changes from grassland to bottomland hardwood forest, the distribution of ecosystem carbon is unclear. More carbon is likely to be sequestered in the plantation as it ages (Londo 2000). In general, carbon sequestration levels increase as a plantation progresses through time until it reaches maturity.

## CONCLUSION

Although it is too early to make any useful recommendations from this study, preliminary results suggest that mixed hardwood species plantings on the Cleveland and Greenville sites are relatively better in survival and growth, than the cottonwood and red mulberry monocultures. Thus, the use of species mixtures provides the advantage of potentially overcoming some difficult site conditions. Planting mixed-hardwood species is an appropriate technique for use in afforestation of marginal lands in the LMAV but species selection is critical to achieving satisfactory results, because different site characteristics and variables affect the performance of different species. Other factors such as seedling quality, handling prior to planting may impact first year survival and growth. Because of seedling problems, no one-monoculture or species mixture is best and additional testing should be done to recommend more viable species combination types. Using a combination of 15:10:5 NPK fertilizer and Goal®2XL as early management practices in bottomland hardwood afforestation on Forestdale soils may be worthwhile during the first year.

On unplanted old fields, above-ground C is a small portion (<1 percent) of total ecosystem carbon. Greater quantities of carbon (3.1-4.5 kt-C/ha) tend to accumulate in the upper 30 cm of the soil but this depends on the physical properties of the soil. Soil carbon tends to be similar for different soils at deeper depths. As the vegetation transitions into a forest, the influence of the species mixes and early management practices should redistribute ecosystem carbon pools and fluxes on these afforested sites.

## ACKNOWLEDGMENTS

Financial support for this project was provided by the U.S. Fish and Wildlife Service (U.S. Department of the Interior), the Jack Berryman Institute, and Entergy Corporation. Additional support was provided by the Carbon Fund and the Forest and Wildlife Research Center, Mississippi State University. This paper has been approved as publication number FO360 of the Forest and Wildlife Research Center at Mississippi State University.

## LITERATURE CITED

Allen, J.A. 1990. Establishment of bottomland oak plantations on the Yazoo National Wildlife Refuge complex. Southern Journal of Applied Forestry. 14: 206-210.

Amacher, G.; Sullivan, J.; Shabman, L. [and others]. 1998. Restoration of flooded farmlands. Journal of Forestry. 96: 10-17.

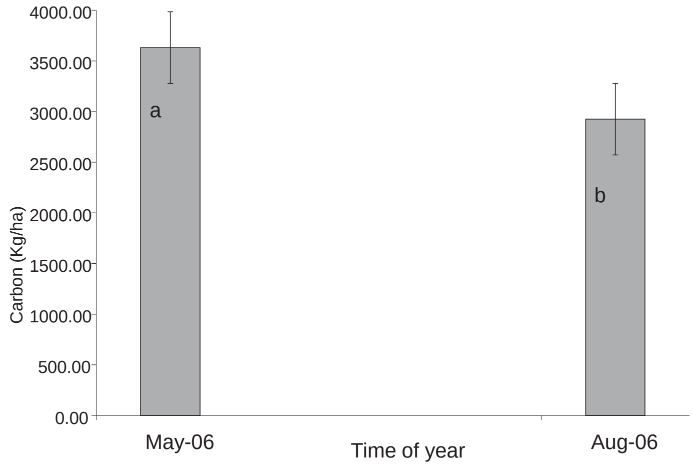


Figure 1—Above-ground carbon at different times of the year on former agricultural lands at the LMAV.

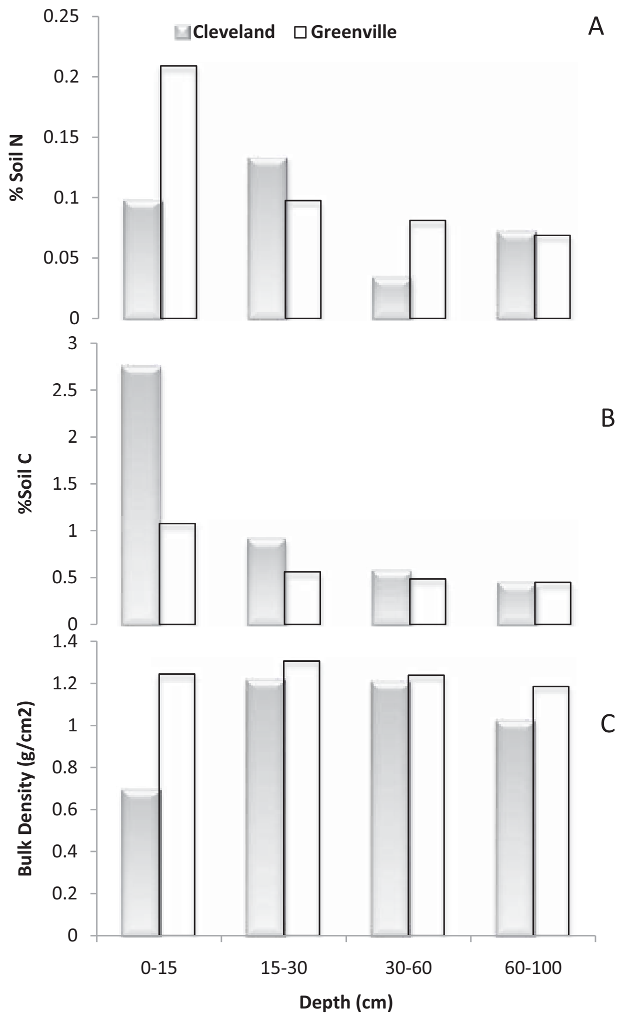


Figure 2—Changes in soil properties with depth: (A) mean amount soil N, (B) mean amount soil C, and (C) bulk density of the soil with depth on two former agricultural sites at the LMAV.

Baker, J.B.; Blackmon, B.G. 1976. Growth of planted yellow-poplar after vertical mulching and fertilization on eroded soils. Res. Note SO-215. New Orleans, LA: U.S. Department of Agriculture, Southern Forest Experiment Station. 5p.

Barker, J.R.; Baumgardner, G.A.; Turner, T.D. [and others]. 1996. Carbon dynamics of the Conservation and the Wetland Reserve programs. Journal of Soil and Water Conservation. 51: 340-346.

Ezell, A.W.; Catchot Jr., A.L. 1998. Competition control for hardwood plantation establishment. In: Waldrop, T.A. (ed.) Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 42-43.

Ezell, A.W.; Shankle, M.W. 2004. Effects of subsoiling and competition control on first year survival and growth of four hardwood species. In: Connor, K.F. (ed.) Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep-SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 571-573.

Groninger, J.W.; Baer, S.G.; Babassana, D. [and others]. 2003. Planted green ash (Fraxinus pennsylvanica Marsh.) and herbaceous vegetation responses to initial competition control during the first 3 years of afforestation. Forest Ecology and Management. 189: 161-170.

Hodges, J.D.; Switzer, G.L 1979. Some aspects of the ecology of southern bottomland hardwoods. In: Proceedings Society of American Foresters' annual meeting, St. Louis Missouri, 1978. Society of American Foresters, Bethesda, MD: 22-25.

Intergovernmental Panel on Climate Change (IPCC) 2007. Climate change 2007: the physical science basis. Summary for policymakers. Contribution of working group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change. 21 p.

Jobbagy, E.G.; Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications. 10: 423-436.

King S.L.; Keeland, B.D. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. Restoration Ecology. 7: 348-359.

Knops, J.M.H.; Tilman, D. 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. Ecology. 81: 88-98.

Londo, A.J. 2000. The effects of bucket mounding site preparation on the processes and functions of a subboreal mineral wetland. Ph.D. Thesis. Michigan Technological University. 101 p.

Lee, K-H.; Jose, S. 2004. Belowground processes in nitrogen fertilized cottonwood and loblolly pine plantations. In: Connor, K.F. (ed.) Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep-SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 446-449.

Lockhart, B.R.; Keeland, B.; McCoy, J. [and others]. 2003. Comparing regeneration techniques for afforesting previously farmed bottomland hardwood sites in the Lower Mississippi Alluvial Valley, USA. Forestry. 76: 169-180.

Morris, W.M. 1961. Soil survey, Washington County, Mississippi. USDA Soil Conservation Service in cooperation with Mississippi Agricultural Station. No. 3.

National Weather Service. 2006. Storm data and unusual weather phenomena, http://www.srh.noaa.gov/jan/stormdata/data/sep2006.pdf. [Date accessed: July 2, 2007].

Nilsson S.; Schopfhauser, W. 1995. The carbon-sequestration potential of a global afforestation programme. Climatic Change. 30: 267-293.

Randall, W.K.; Krinard, R.M. 1977. First year survival and growth of long cottonwood cuttings. Res. Note SO-222. U.S. Forest Service, Southern Forest Experiment Station, New Orleans, LA. 3 p.

Rogers, G.E. 1958. Soil survey of Bolivar County, Mississippi. Series #5. USDA soil conservation service and Mississippi Agricultural Experiment station. 42p.

Shoenholtz, S.H.; Stanturf, J.A.; Allen, J.A. [and others]. 2005. Afforestation of agricultural lands in the Lower Mississippi Alluvial Valley: the state of our understanding. In: Fredrickson L.H., King S.L., and Kaminski, R.M. (eds.) Ecology and management of bottomland hardwood systems: the state of our understanding. University of Missouri-Columbia. Gaylord Memorial Library special publication No. 10. Puxico, MO: 413-431.

Schoenholtz, S.H.; James, J.P.; Kaminski, R.M. [and others]. 2001. Afforestation of bottomland hardwoods in the Lower Mississippi Alluvial Valley: Status and trends. Wetlands. 2: 602-613.

Schweitzer, C.J.; Stanturf, J.A. 1999. A comparison of large scale reforestation techniques commonly used on abandoned fields in the Lower Mississippi Alluvial Valley. In: Heywood, J.D. (ed.) Proceedings of the 10th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. U.S. Forest Service, Southern Research Station, Asheville, NC: 136-141.

Stanturf, J.A.; Conner, W.H.; Gardiner, E.S. [and others]. 2004. Recognizing and overcoming difficult site conditions for afforestation of bottomland hardwoods. Ecological Restoration. 22: 183-193.

Stanturf, J.A.; Schoenholtz, S.H.; Schweitzer, C.J. [and others]. 2001. Achieving restoration success: myths in the bottomland hardwood forests. Restoration Ecology. 9: 189-200.

Stanturf, J.A.; Gardner, E.S.; Hamel, P.B. [and others]. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. Journal of Forestry. 98: 10-16.

Stanturf, J.A.; Schweitzer, C.J.; Gardner, E.S. 1998. Afforestation of marginal agricultural lands in the Lower Mississippi River Alluvial Valley, USA. Silva Fennica. 32: 281-297.

Sumerall D.C. 2007. Measuring the biological and economic effects of wildlife herbivory on afforested carbon sequestration sites in the Lower Mississippi Alluvial Valley. M.S. Thesis, College of Forest Resources, Mississippi State University. 138 p.

Vesterdal, L.; Ritter, E.; Gundersen, P. 2002. Change in soil organic carbon following afforestation of former arable land. Forest Ecology and Management. 169: 137-147.

Vogt, 1991. Carbon budgets of temperate forest ecosystems. Tree Physiology. 9: 69-86.

Zimmermann, G. 2001. Restoration of wetland site nine years after afforestation. M.S. thesis College of Forest Resources, Mississippi State University. 74 p.