SURVIVAL RESULTS OF A BIOMASS PLANTING IN THE MISSOURI RIVER FLOODPLAIN

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ABSTRACT.—A factor essential to successful tree planting in unprotected floodplain environments is survival. Two-year survival results from tree planting in an unprotected floodplain adjacent to the Missouri River are presented. Species planted included silver maple, locally collected cottonwood, and a superior cottonwood selection from Westvaco Corporation. Two spacings, 4 x 4 feet and 8 x 8 feet, were established to evaluate mortality for each species. As a result of recurrent flooding, mortality was high for all tree species. At the end of both the first and second year silver maple had the best survival, averaging 85 and 27.5 percent, respectively. Lessons learned take into account the need to understand the dynamics of floodplain properties prior to reclamation and establishment. These dynamics include the relationship of changes in elevation that result not only in soil depth changes, but also duration of submersion during flood events. Intensive site preparation, as well as documenting the history of flood events, should precede the establishment of tree crops in floodplain environments.

The location of the study site was chosen because it represents the potential of agroforestry in an active floodplain that is subject to periodic flooding. Much of the Missouri River floodplain is in fact not subject to flooding because it is on the protected side of the U.S. Corps of Engineers and privately owned and maintained levee systems. The research site was subject to inundation during flood events. Therefore, it provided an excellent demonstration of how the integration of trees with traditional agronomic cropping practices could help reclaim and protect potentially productive farm ground.

Floodplains are areas adjacent to major waterways that are subject to periodic flooding. These areas have traditionally provided some of the most fertile and productive farmland throughout the United States and are therefore often subject to clearing. The floods that occurred throughout the Midwestern United States during 1993 were of historic (500-year) proportions (Hanback 1994). Because of the duration, velocity, and extent of floodwater, levee failures resulted in extensive damage to agricultural land, water quality, wetland ecosystems, rural and urban infrastructures, and human resources (Scott 1993). In Missouri alone crop losses exceeded $235 million on approximately 1.2 million acres (Center for National Food and Agriculture Policy 1994).

Past research has shown that floodplain corridors with woody trees will slow floodwater velocities, dissipate energy, reduce scouring potential and increase soil shear strengths (Scheifele 1928, Shields and Gray 1993, Young 1994). A study of primary levees along the Missouri River following the 1993 flood showed that, as the width of the woody corridor between the river bank and primary levee increased, the damage both in numbers and size of levee failures decreased (Dwyer and others 1997). Therefore, if trees could be reintroduced to farm landscapes prone to flooding, many benefits can be realized. Trees protect the land and its soil from the erosional effects of water. Benefits from roots include increases in soil stability and increased water infiltration rates (Brooks and others 1991). Leaves, twigs, branches, and trunks, serve to intercept rainfall and slow surface flows prior to the rains' impact on the soil. One mechanism for the reintroduction of trees into traditional agriculture settings is termed agroforestry.

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Agroforestry is defined as "an intensive land-management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops (Garrett and others 1994, 2000)." Agroforestry provides the means of incorporating intensively managed trees and crops on the same land for mutual benefits while at the same time diversifying income opportunities. The purpose of this study was to investigate the potential of Short Rotation Woody Crops (SRWC) as the forestry component in a floodplain agroforestry practice. SRWC, also called short-rotation intensive culture, is a descriptive term for the intensive planting, at close spacings, of fast growing trees to be harvested on short-rotations of 2 to 10 years (Perlack and Geyer 1987, Ranney and others 1987, Colletti and others 1991). Because the harvesting time frame and establishment practices are more similar to agronomic systems than traditional forestry, SRWC is a viable enterprise for incorporation into an agroforestry practice with all the associated benefits. This paper focuses on establishment and survival of trees planted in an active floodplain.

METHODOLOGY

Site Location and Description

The Missouri Department of Conservation (MDC) granted permission to use 20 acres of floodplain ground along the Missouri River in Eagle Bluffs Conservation Area located in Boone County, 6 miles southwest of Columbia near McBaine, Missouri. The study site occupies approximately 18 acres of the piece of land formerly known as the Holiman tract. The location is on the unprotected side of the main levee.

The natural levees, formed from years of sand and silt deposited adjacent to river channels, were broken by the flooding that occurred in 1993. Movement of water and debris in the floodwaters of 1993 and 1995 eroded gaps in the natural levee and resulted in sand splays onto portions of the study site. Those same levee gaps have since allowed annual flood waters (often several times per year) to enter onto the Holiman tract, now an active floodplain. This alluvial floodplain is lower in elevation than the natural levee gap and thus water backs onto the site and ponds.

Deposition affecting this study is predominantly a result of backswamp and overbank flooding. Waters which either overflow river banks or back fill onto lower lying areas (backswamps), resulting in little or no water movement, create situations where overbank deposits form (Schmudde 1963). Thus, periodic flooding creates multiple layered soils of varied depth and differing texture according to duration and movement of floodwaters. Often abrupt soil variation makes soil predictions within small floodplains difficult (Daniels and Hammer 1992).

Soils Information

Ten-baseline soil samples were taken from two transects by extracting soil to a depth of 60 inches. From these samples of the soil horizons, their structure and texture were identified, as well as the depth of the perched water table. Except for the northeastern corner where slope can be closer to 2 percent, the site has a slope of 1 percent or less. In the absence of water current, the only erosion that results is in the form of wind-wave action. Consequently, these soils are mostly depositional material. In general, the soil profile is as follows:

1) AP horizon: 0 to 7 inches, 10YR 3/2, silt loam, 18 percent clay;
2) Bg1: 7 to 24 inches, 2.5Y 3/2, silty clay loam, 32 percent clay;
3) Bg2: 24 to 38 inches, 2.5Y 4/2, silty clay loam, 30 percent clay;
4) Bg3: 38 to 48 inches, 2.5Y 4/2, silty clay loam, 34 percent clay;
5) 2C1: 48 to 54 inches, 2.5Y 5/3, sandy clay loam, 28 percent clay; and
6) 2C2: 54 to 60 inches, 2.5Y 6/3, very fine sandy loam, 19 percent clay.

Across the site the depth of perched water table varied from 34 to 46 inches beneath the surface. This may represent water perched from above or below. Redoximorphic features, indicated in part by the presence of oxidized iron, typically identified these areas.

Study Design

A Complete Randomized Block Design (CRBD) was chosen for tree planting design. This allows for the comparison of three tree species planted at two spacing treatments. The tree species chosen were local cottonwood (*Populus deltoides* Bartr.), a superior cottonwood clone donated by Westvaco Corporation, and silver maple (*Acer saccharinum* L.). Seedlings of these species were each planted at two spacings of 4 x 4 feet and 8 x 8 feet. Each treatment plot measured 96 x 72 feet. These plots, representing each species at one of the two spacings, were randomly placed in larger blocks of 96 x 504 feet (figs. 1 and 2). These larger blocks were replicated four times. Each replication contains a control where the naturally occurring regeneration was recorded.

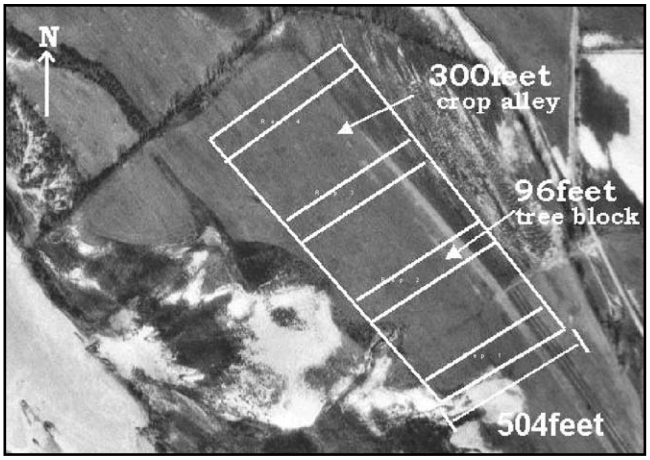

Figure 1.—*Site layout, with tree replication and alley crop areas identified.*

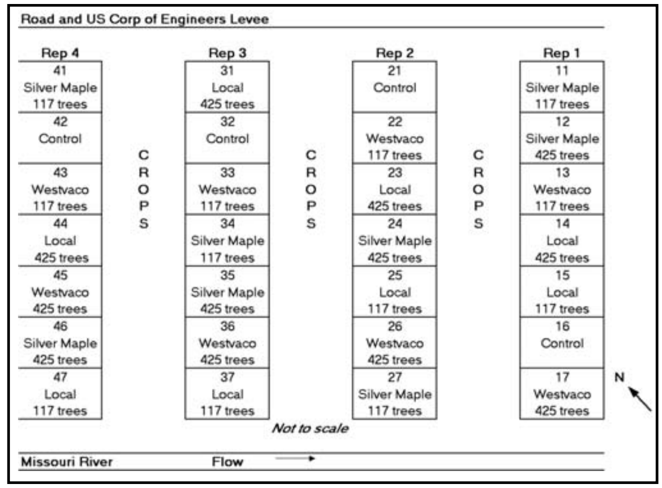

Figure 2.—*CRBD layout of each replication by species and spacing treatment location.*

The total acreage of the four replications that were planted in trees was 4.4 acres. Between each replication was a 300 x 504 feet alley (fig. 1). Within this alley the crop component of the agroforestry system was planted. The species chosen were switchgrass (*Panicum virgatum* L.), alsike clover (*Trifolium hybridum* L.), and redtop grass (*Agrostis stolonifera* L.).

Cottonwood and silver maple were chosen because they are both indigenous species of the floodplain that also exhibit excellent growth characteristics desirable for biomass and other wood products. The total sample size of 2,168 bareroot seedlings and cuttings were comprised of the following species: cuttings of a superior cottonwood clone (Westvaco), cuttings of cottonwood collected adjacent to the site (local), and silver maple bareroot seedlings. Numerous studies have been done to compare various spacings with densities as low as 1,000 trees per acre and some as high as 43,500 trees per acre, the effect on yield versus economic viability (Elk and others 1983, Ranney and others 1987, Torreano and Frederick 1988, Geyer 1989). For comparison, the spacing treatments of 4 x 4 feet and 8 x 8 feet were selected. These two spacing treatments resulted in 425 and 117 trees in each plot, respectively. Tighter spacings dictate earlier harvest or, at minimum, thinning operations. Data on survival was measured by species/spacing treatment.

Treatment Establishment

In preparation for spring planting we did fall site preparation to control undesirable vegetation. This vegetation included willow, cottonwood, and vegetation such as cocklebur, sunflower, smartweed, ragweed, morning glory, nutsedge, panicum grass, and johnson grass. Because of the thickness of existing vegetation we had initially planned to clear the site by controlled burn, but the Missouri Department of Conservation had reservations about burning the area and this method of clearing was not allowed. Our second option, to brush hog and disc the site, was done the fall of 1997 and winter (February) 1998. This resulted in good organic matter incorporation into the soil and initial site preparation was considered complete.

Studies have shown that the control of vegetative competition is essential for maximization of biomass production in SRWC systems (Ranney and others 1987, Torreano and Frederick 1988, Mitchell 1995, Buhler and others 1998). During the establishment phase, Mitchell (1995) points out that survival and growth of unrooted cuttings will be affected by any competition.

Following the planting of silver maple (May 5-12, 1998) Scepter® (registered trademark of American Cyanamid Company) was applied to all tree planting treatments. Scepter is primarily recognized as a pre-emergent herbicide, yet it will control young weeds as a post-emergent if a surfactant is used. Since some trees had broken dormancy and begun to grow, Scepter was applied without surfactant. Using a backpack sprayer and a stovepipe section to cover seedlings, Scepter was sprayed in a 2- to 3-foot radius circle around each of the silver maple seedlings. The cottonwood received a broadcast spray application of Scepter between each row. Though an effort was made to avoid emerging leaves, Scepter has been approved for application overtop of actively growing *Populus* species. The application rate was 3.2 oz. per acre, and was well within the prescribed 2.8 to 5.6 oz. per acre guidelines.

Following flooding, at the end of June 1998, a new crop of weeds began to grow. Some of the weeds on the site included cocklebur, Johnson grass, dogbane, water hemp, and ragweed. Thus, from July 13 through August 4, Roundup® was applied as a 2 percent mixture. The Roundup was applied using a backpack sprayer and stovepipe to insure no chemical contacted the seedlings and rooted cuttings. Because of the height of some of the cottonwood (over 3 feet tall) the stovepipe could not be used to insure against herbicide contact, so that cottonwood did not receive this second herbicide application.

In addition to herbicide, we also tried to establish a cover crop in order to control undesirable weed growth. At the end of February 1999, we used broadcast spreaders to frost-seed alsike clover into all tree replications. Seeded at a rate of approximately 6 pounds per acre, we hoped to utilize the clover's nitrogen fixing capabilities for benefits to the trees while creating a cover crop which would out compete weeds yet be no taller than 3 feet. At this height the cover crop should not over top the trees.

Data Analysis

Survival of all live trees was recorded for each species and treatment. The presence of dead or not yet fallen leaves, and stem flexibility and color were used as indicators of a potential live tree. To test whether replication, species, or spacing influenced survival a Chi-square test was used on a random sample of 30 trees from each species/spacing treatment. Statistical analysis was performed using SAS (SAS Institute, Inc., Cary, NC) with all significance tests performed at a confidence level of 95 percent, or P=0.05. The row-by-column Chi-square test on survival was used to test the following hypothesis:

1) H_o: Number of live trees does not vary by replicate, species, or spacing; and
2) H_a: Number of live trees does vary by replicate, species, or spacing.

RESULTS

At the end of the first and second growing seasons a complete survey was done of all trees growing within the control treatments. The only control treatment in which natural regeneration occurred was in replication one. By the end of the first growing season, three cottonwoods had become established. Their diameters for the first year were 0.44, 0.56, and 0.42 inches. The same trees had heights of 5.17, 6.25, and 6.0 feet, respectively. By the end of year 2 only two of these trees had survived. Each measured 8.0 feet in height and had diameters of 1.43 and 1.49 inches.

Analysis of Survival

I found no published research to document seedling survival of plantings in active floodplains. Other studies have shown that survival will vary by site. From uplands to riparian zones survival typically falls in the range of 70 to 100 percent for both cottonwood and silver maple (Geyer 1989, Schultz and others 1995, DeBell and others 1996, Geyer and Walawender 1997). In addition to the key role survival plays in the creation of a demonstration site, it is also one of the keys to maximizing production of biomass on a given area, and the other is fast growth. At the end of both the first and second growing seasons survival was measured.

The total number of trees (all species combined) that survived in each replication was low. Of the total 180-tree sample (3 species *x* 2 spacings *x* 30 trees sampled per treatment) first year survival from replications 1, 2, 3, and 4 was 32, 28, 32, and 37 percent, respectively (fig. 3). The Chi-square test did not indicate significant differences (P=0.05) in survival between replications.

By the end of the second year, survival percentages by replication had decreased. Figure 3 shows the decrease in survival for each replication, and the tests of second year survival by replication were significantly different. Replication 2, having the lowest percentage survival (2 percent), and replication 4 with the highest percent survival (almost 23 percent) were significantly different. Replications 1 and 3 were statistically similar having survival of 15 and 12 percent, respectively.

When survival within each replication was tested by individual species group, there were significant differences. Across all replications first year survival was significantly higher for silver maple (fig. 4). Comparisons between replications of silver maple showed replication 1, with 97 percent survival, to be significantly higher than replications 2, 3, and 4. Survival of silver maple within the replications was significantly higher than either cottonwood variety. The test between replications of survival within each cottonwood variety showed that the local cottonwood in replication 1, with no surviving trees, was significantly different than replications 2, 3, and 4, which were tested as not statistically different. For the Westvaco

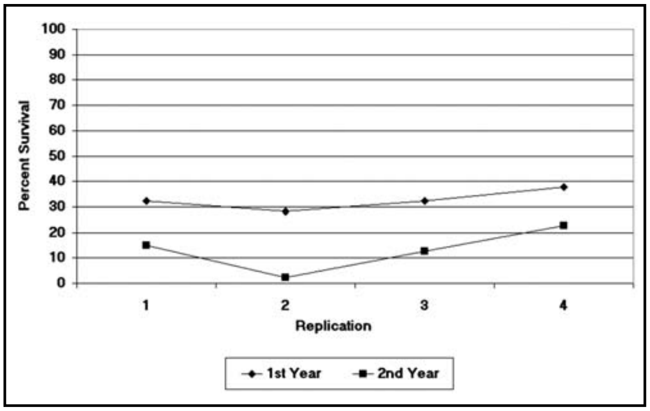

Figure 3.—*Percent survival of all species combined by replication.*

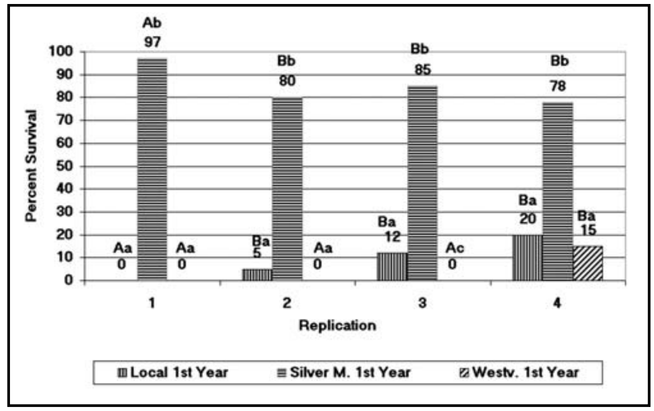

Figure 4.—*Percent survival for year 1 by replication and species. Different capital letters indicate significant differences (P=0.05) between percentage survival by species over replications; different lower case letters indicate significant differences between survival of species within replications.*

cottonwood that only had surviving trees in replication 4, there was a significant difference between the other replications. Yet, comparing the survival of both local and Westvaco cottonwood in replication 4, it was found that they were not statistically different.

By the end of year 2, survival comparisons by species across replication and species-to-species comparisons within replications had decreased (fig. 5). While silver maple still had higher survival in each replication, the number of surviving trees in replications 1, 3, and 4 were not significantly different. To summarize, in both years 1 and 2 silver maple had significantly better survival than either cottonwood selection, but the difference in percent survival had decreased by the end of year 2.

Species and Spacings Analysis

The hypothesis that survival did not change from year 1 to year 2 for each species was tested, and silver maple was the only species that had a statistically significant reduction in survival, from 85 percent in year 1 to 27.5 percent in year 2 (fig. 6). Though having low overall survival percentages, neither local nor Westvaco cottonwood varieties experienced a significant change in total survival between years 1 and 2.

First year survival comparisons between the 4 x 4 feet and 8 x 8 feet spacings showed a significant difference within both local and Westvaco cottonwood. Survival for local cottonwood showed a statistically significant increase from 5 percent on the 4 x 4 foot spacing to 13.3 percent on the 8 x 8 foot spacing (fig. 7). Although identified as significant, the trend was reversed for the Westvaco cottonwood that had 7.5 percent survival on the 4 x 4 foot spacing and 0 percent on the 8 x 8 foot spacing. Though not

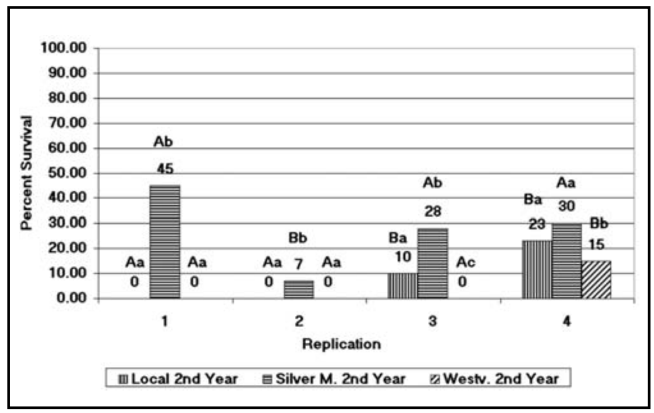

Figure 5.—Percent survival for year 2 by replication and species. Different capital letters indicate significant differences (P=0.05) between percentage survival by species over replications; different lower case letters indicate significant differences between survival of species within replications.

significant, the silver maple survival decreased from 85.8 percent (4 x 4 foot spacing) to 84.2 percent (8 x 8 foot spacing).

The influence of spacing treatment on species survival was significant. Survival of local cottonwood at the end of year 2 underwent a significant increase in survival, from 2.5 percent on the 4 x 4 foot spacing to 14.2 percent on the 8 x 8 foot spacing (fig. 8). The Westvaco cottonwood survival was significantly higher (7.5 percent) on the 4 x 4 foot spacing than on the 8 x 8 foot spacing (0 percent). By the end of year 2, silver maple survival had decreased to 22.5 percent on the 4 x 4 foot spacing and 32.5 percent on the 8 x 8 foot spacing, a difference that was not identified as significant.

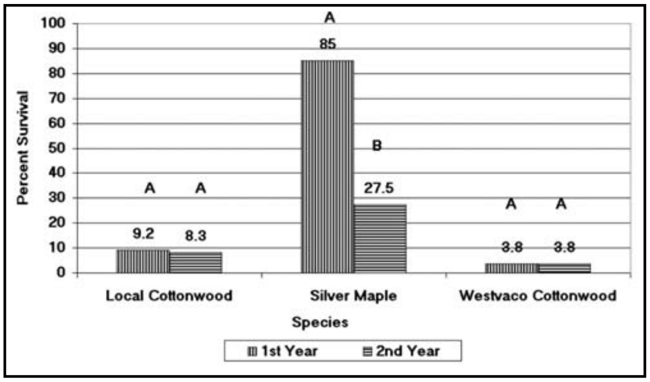

Figure 6.—*Percent survival of each species for years 1 and 2 Different capital letters indicate significant differences (P=0.05) between year 1 and year 2 means pooled over replications.*

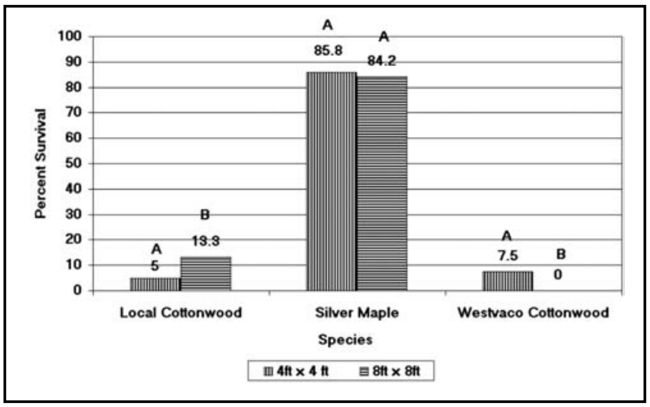

Figure 7.—*Percent live trees at the end of year 1 by species and spacing. Different capital letters indicate significant differences (P=0.05) between spacings for each species from means pooled over replications.*

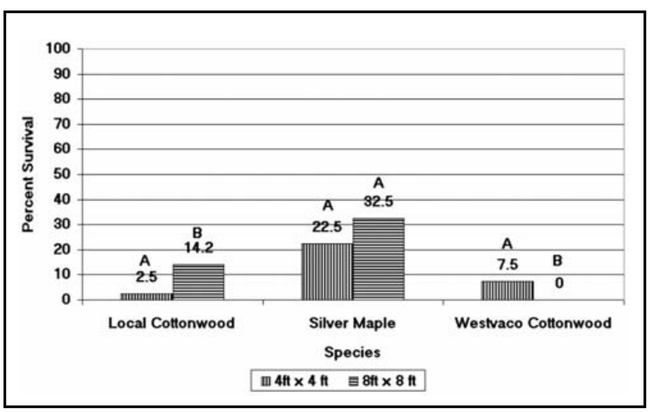

Figure 8.—Percent live trees by species and spacing at the end of year 2. Different capital letters indicate significant differences (P=0.05) between spacings for each species from means pooled over replications.

DISCUSSION

Survival

One of the reasons to use both a locally selected and superior cottonwood (Westvaco) was to provide a comparison based on the premise that the superior cottonwood clone would have greater growth than the local cottonwood. Silver maple was also used as a species that grows quickly and has the ability to coppice. Symonette (1988) and others have noted its potential for biomass utilization in products that use small wood particles. Both species should have been well matched to growing conditions in a floodplain environment.

By the end of the second year, the percentage survival by species and spacing was not high enough for an effective demonstration. Survival was at best poor. Silver maple had the best overall survival, yet total survival was only 27.5 percent (fig. 6). The poorest survival was Westvaco cottonwood at 3.75 percent and the local cottonwood was only slightly better at 8.33 percent survival.

In order to help understand the differences in total survival (all species combined) from year 1 to year 2 it is useful to look at the percentage survival by replication. The linear trend indicated that survival increased across the study site from replication 1 to replication 4 (fig. 9). It is likely that the survival trend lines in figure 9 are indicative of an increasing change in elevation from replication 1 to replication 4. Changes in elevation across all but the northwestern corner (fig. 2), were 1 percent or less. During the floods, measured depths of water across the replications indicated that the topography was hummocky due to uneven silt deposition. Though not consistent, these changes in elevation resulted in water depths as much as 2 feet deeper on replication 1 compared to replication 4.

The elevational change created a scenario whereby portions of replication 1 emerged from the floodwater as much as 2 weeks later than replication 4 (dependant in part on wind, solar radiation, and subsequent intervals between precipitation events). Therefore, it is likely that the trend in increased survival from replication 1 to replication 4 (fig. 9) reflects the difference in duration of submersion. It is also likely that submersion and the resultant decreased rates of photosynthesis, caused stunted growth in all tree species. Submersion of seedlings creates an oxygen-limiting situation that not only hinders their growth but may be fatal, also damage to the leaves and root structures in response to flooding must affect tree growth (both height and diameter) which is dependent on photosynthesis and O_2 exchange (Bratkovich and others 1993, Colbert 1998, Kozlowski and Pallardy 1997, Peterson and Bazzaz 1984). The early emergence from floodwaters of replication 4, compared to replication 1, improved the survival of its seedlings.

Weed Control

In any agronomic system it is essential that competition for nutrients and water be eliminated. Similarly, in order to maximize the growth potential of a forest crop, competition must also be controlled. Given flooding dynamics of the area, the second year a cover crop was seeded in an effort to control weed competition. Neither accomplished the intended result. Herbicide was only partially effective and survival of the cover crop establishment was negatively affected by fall flooding.

In one respect the herbicide worked as intended. The silver maple had a good kill of the weeds within an effective zone of approximately 3-feet around each seedling. However, the weeds outside the spray zone grew so prolifically that they overtopped the growing space of each seedling. Also, by creating an open growing space around each seedling, there may have been a tendency to create a target for rodent damage. Many of the silver maple suffered from substantial rabbit damage, which resulted in a definite setback in growth.

The effectiveness of herbicide application was compromised by flooding which occurred four times during the establishment year (fig. 10). It is likely that these floods either washed out or diluted the preemergent herbicide from the soil. Flooding served to reestablish the previously eradicated weeds. Weed seed from areas adjacent to the site was visible, floating on top of waters over the research site. Flooding reduced our ability to control the weedy competition on the study site, which impacted the survival and ultimate biomass yield.

Flooding

Flooding was potentially the most influential factor affecting survival. Yet, the study design was not intended to test the effects of flooding. Though the influence of flooding was recognized at the onset of this project, the abnormal frequency and duration of the multiple floods could not have been foreseen as one of the most critical factors in survival.

During the establishment year the research site flooded on four separate occasions. Similarly, site flooding occurred in April, May, and the end of June during the 1999 growing season. This was documented using a river gauge located at Boonville, Missouri, which is the closest gauging station upriver from the research site. I observed and documented that at a Boonville river stage of 23 feet, water began to enter and cover the site (fig. 10). The flooding was a direct result of natural levee failures that occurred during the flood of 1993 and 1995. One of the main problems associated with this levee break was its proximity to the research site. The break is actually higher in elevation than the planting. Therefore, when water entered the site, it did not leave at the same rate. When water came onto the study site, it remained for approximately 30 days, dependent on subsequent rainfall, seasonal temperatures, and wind.

In retrospect then, one of the foremost considerations prior to planting in a floodplain

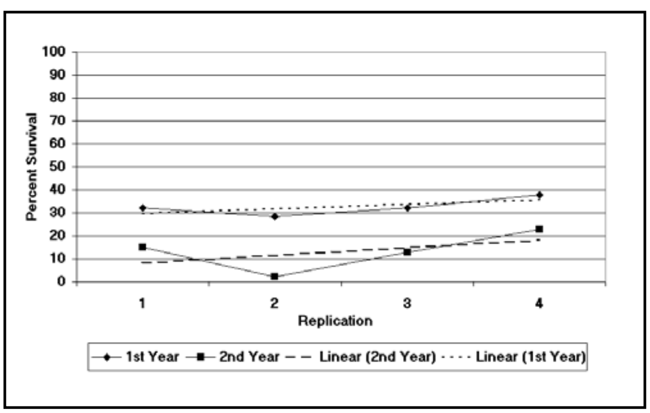

Figure 9.—*Percent survival for each replication by year with linear trend line plotted.*

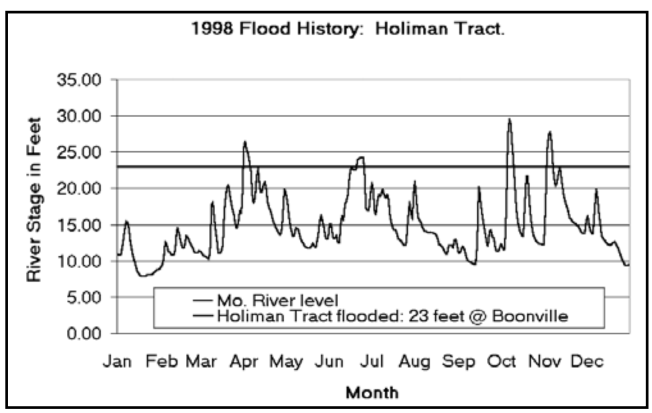

Figure 10.—H*istory of actual flood events on the Holiman tract for the calendar year 1998.*

should be to document its history of flooding. This should include the time of year and frequency of flooding events, as well as the duration flood waters remain on a specific site. Historic records were useful in determining the frequency of flooding over the past 10 years. Estimation of historic flooding was based on the observed flood level for the study site of 23 feet at Boonville and was used to create a history of flooding based on current natural levee and site conditions. Apart from the years 1993 and 1995, flooding most often occurred from February through July. Based on this data it might have been best to try fall planting on this site, though, for this site and the years of this study, that too would have failed. Raised-bed plantings with tall seedlings might also be a valid option to improve survival of trees established in floodplains.

CONCLUSION

The primary influence that detracted from this becoming an effective demonstration of the potential of SRWCs was the flooding and the associated mortality that took place. Yet, what we have learned from efforts to establish this agroforestry system in an unprotected floodplain will be useful in directing future attempts to utilize similar ground. One lesson we learned was that elevation plays an important role in survival during establishment. Floodplains by nature are relatively flat. But on large acreages of land a 1 percent change in topography can make a several foot difference in depth of floodwaters. Also, this most often equates to a shorter duration for submersion. Both depth and duration may mean the difference between the survival or death of a plantation.

Second, we learned it is also important to ascertain as much about the land and its flood history as possible. Past flood history may identify certain times of the year in which it is more likely that plantings will succeed. Finally, site preparation a year in advance may be necessary. The dynamics of these areas are so powerful that intensive work will be required far in advance of plantation establishment in order to successfully control competition.

ACKNOWLEDGMENT

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LITERATURE CITED

Bratkovich, S.; Burban, L.; Katovich, S.; Locey, C.; Pokorny, J.; Wiest, R. 1993. Flooding and its effect on trees. Information Packet. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry, Forest Resources Management and Forest Health Protection.

Brooks, K.N.; Ffolliott, P.F.; Gregersen, H.M.; Thames, J.L. 1991. Hydrology and the management of watersheds. Ames, IA: Iowa State University Press. 392 p.

Buhler, D.D.; Netzer, D.A.; Riemenschneider, D.E.; Hartzler, R.G. 1998. Weed management in short rotation poplar and herbaceous perennial crops grown for biofuels production. Biomass and Bioenergy. 14(4): 385-394.

Center for National Food and Agricultural Policy. 1994. An economic analysis of floodplain management options. Rep. #26-94. Columbia, MO: Center for National Food and Agriculture Policy. 30 p.

Colbert, K. 1998. Height diameter equations and mortality rates for thirteen Midwest bottomland hardwood species. Columbia, MO: University of Missouri-Columbia. 68 p. M.S. thesis.

Colletti, J.P.; Schultz, R.C.; Mize, C.W.; Hall, R.B.; Twarok, C.G. 1991. An Iowa demonstration of agroforestry: short-rotation woody crops. The Forestry Chronicle. 67(3): 258-262.

Daniels, R.B.; Hammer, R.D. 1992. Soil geomorphology. John Wiley & Sons, Inc.

DeBell, D.S.; Clendenen, G.W.; Harrington, C.A.; Zasada, J.C. 1996. Tree growth and stand development in short-rotation *Populus* plantings: 7-year results for two clones at three spacings. Biomass and Bioenergy. 11(4): 253-269.

Dwyer, J.P.; Wallace, D.; Larsen, D.R. 1997. Value of woody river corridors in levee protection along the Missouri River in 1993. Journal of the American Water Resources Association. 33(2): 481-489.

Elk, A.R.; Lenarz, J.E.; Dedek, A. 1983. Growth and yield of *Populus* coppice stands grown under intensive culture. In: Intensive plantation culture: 12 years research. Gen. Tech. Rep. NC-91. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 64-71.

Garrett, H.E.; Buck, L.E.; Gold, M.A.; Hardesty, L.A.; Kurtz, W.B.; Lassoie, J.P.; Pearson, H.A.; Slusher, J.P. 1994. Agroforestry: an integrated land-use management system for production and farmland conservation. The Agroforestry Component of the Resource Conservation Act Appraisal. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 58 p.

Garrett, H.E.; Rietveld, W.J.; Fisher, R.F., eds. 2000. North American agroforestry: an integrated science and practice. Madison, WI: Agronomy Society of America.

Geyer, W.A. 1989. Biomass yield potential of short-rotation hardwoods in the Great Plains. Biomass. 20: 167-175.

Geyer, W.A.; Walawender, W.P. 1997. Biomass properties and gasification behavior of young silver maple trees. Wood and Fiber Science. 29(1): 85-90.

Hanback, M. 1994. The deluge of '93: litmus test for floodplain forests. American Forests. 100(5/6): 17-21.

Kozlowski, T.T.; Pallardy, A.G. 1997. Growth control in woody plants. New York, NY: Academic Press. 641 p.

Mitchell, C.P. 1995. New cultural treatments and yield optimisation. Biomass and Bioenergy. 9(1-5): 11-34.

Perlack, R.D.; Geyer, W.A. 1987. Wood energy plantation economics in the Great Plains. Journal of Energy Engineering. 113(3): 92-101.

Peterson, D.L.; Bazzaz, F.A. 1984. Photosynthetic and growth responses of silver maple (*Acer saccharinum* L.) seedlings to flooding. American Midland Naturalist. 112(2): 261-272.

Ranney, J.W.; Wright, L.L.; Layton, P.A. 1987. Hardwood energy crops: the technology of intensive culture. Journal of Forestry. 85(9): 17-28.

Scheifele, O.S. 1928. Protection of river banks and levees. The Canadian Engineer. 1928 January 10: 1-7.

Schields, F.D., Jr.; Gray, D.H. 1993. Effects of woody vegetation on sandy levee integrity. Water Resources Bulletin. 28(5): 917-931.

Schmudde, T.H. 1963. Some aspects of land forms of the lower Missouri River floodplain. Annals of the Association of American Geographers. 52(1): 60-73.

Schultz, R.C.; Collettii, J.P.; Isenhart, T.M.; Simpkins, W.W.; Mize, C.W.; Thompson, M.L. 1995. Design and placement of a multi-species riparian buffer strip system. Agroforestry Systems. 29: 201-226.

Scott, J. 1993. Relentless rivers. Missouri Resources Review. 10(3): 8-13.

Symonette, T.A.; Kuo, M.L.; Hall, R.B. 1988. Properties of flakeboard from short-rotation, intensive culture silver maple (*Acer saccharinum* L.). Forest Products Journal. 38(5): 46-48.

Torreano, S.J.; Frederick, D.J. 1988. Influence of site condition, fertilization and spacing on short rotation hardwood coppice and seedling yields. Biomass. 16: 183-198.

Young, S. 1994. Tree corridors control sand damage. All Outdoors Weekly News Stories. Jefferson, MO: Missouri Department of Conservation. 4 p.