ANC93-017

Opportunities for Agroforestry in the Temperate Zone Worldwide:

Proceedings of the Third North American Agroforestry Conference

August 15-18, 1993

Department of Forestry, College of Agriculture
Iowa State University
Ames, Iowa

Richard C. Schultz and Joe P. Colletti, Editors

1994

Design and Placement of a Multi-Species Riparian Buffer Strip System

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ABSTRACT: A multi-species riparian buffer strip study was established along nearly 1000 m of Bear Creek on a farm in Story County, Iowa in 1990. The 20 m wide buffer strip, starting at the edge of the creek, includes five rows of trees, two rows of shrubs, and a 7 m wide strip of native prairie grass. The two tiers of woody plants along with the prairie grass provide increased biodiversity for wildlife and can be used for biomass energy.

Plots are approximately 60 m long and replicated along three stream positions: inside bends and outside bends, and straight reaches. A non-grazed, non-planted "control" is being allowed to revegetate naturally. Three different groundwater aquifers have been identified with the deepest bedrock aquifer having sufficient potential gradient to supply water for the base flow of Bear Creek. Primary emphasis has been placed on analyzing soil and stream water samples for nitrate and atrazine. In addition, sediment content and a number of other stream water parameters also are determined.

Preliminary results show highest nitrate and atrazine levels in water from tiles that drain adjacent cropland, shallow piezometers, and the creek, with none being found in the deep bedrock aquifer. Tile and stream nitrate levels of 25 mg L^{-1} NO_3^-- N and atrazine levels of 0.5 µg L^{-1} in the tiles and 1 µg L^{-1} in the stream have been measured. Water sampled with lysimeters in the buffer strip has concentrations less than 3.6 mg L^{-1} NO_3^-- N after soybeans have been planted in the adjacent field. Visual observations suggest that the buffer strip is effectively trapping sediment carried with surface runoff from the cropped fields. Plants are growing rapidly with the first biomass harvest of trees set for age 7. A small wetland will be constructed at the end of one of the five field tiles to promote denitrification of the tile water before it enters the creek. Willow posts are being used to reduce streambank collapse in one of the bends of the creek. This constructed multi-species riparian buffer strip is effectively reducing non-point source pollution while providing multiple benefits to the landowner.

Agricultural landscapes are a mosaic of crop and pasture lands and human habitations superimposed on natural prairie, wetland, and forest ecosystems. In the Corn Belt of the Midwestern United States most of these natural ecosystems have been cleared for agricultural purposes. In Iowa, for example, 99% of the prairie and wetlands and more than 80% of the forests have been converted to other uses (Bishop and van der Valk, 1982; Thomson and Hertel, 1981). Highly efficient production agriculture has produced many intended benefits such as quantities of high quality and relatively inexpensive food stuffs and industrial raw materials. The production-oriented function of this landscape also has produced unintended and undesirable environmental consequences that include non-point source (NPS) pollution of water, hydraulic alterations of waterways, and disruption of wildlife habitats and populations.

Nationwide, NPS pollution of our water resources is a serious problem. Over 2.7 billion Mg of soil enters surface waters as NPS pollution each year (Welsch, 1991). In Iowa, it is estimated that 240 million tons of Iowa topsoil enter the Missouri River each year (Kelley, 1990). Saylorville Lake, a United States Army Corps of Engineers reservoir, located on the Des Moines River, in Central Iowa, receives an estimated 4,000 Mg of sediment per day whereas Lake Red Rock, another reservoir farther downstream receives about 15,000 Mg per day (Kelley, 1990).

Pesticides and fertilizers also contribute NPS pollution to our nations waters. Atrazine and alachlor have been found in Midwestern surface waters for some time (Kelley, 1990). It was estimated that in 1989, nearly 1 million Mg of phosphorus (P) entered our Nation's waterways. In 1980, an estimated 2.6 million Mg of nitrate-nitrogen became NPS pollution (Welsch, 1991). Kelley (1990) reported that in 1991 many Iowa surface waters had nitrate-nitrogen levels exceeding 10 mg l^{-1} with water flowing from field drainage tiles having nitrate-nitrogen levels of 70-80 mg l^{-1}.

The primary way in which the agricultural community has addressed NPS pollution is to develop upland soil conservation practices such as reduced tillage, no-till, contour tillage, and more accurate and better timed applications of fertilizers and pesticides. These agricultural best management practices (BMPs) also have included vegetative filter strips, comprised primarily of introduced cool-season grass species, that have been applied along ephemeral channels in crop fields. Even with these BMPs in place substantial quantities of sediment and chemicals can still make their way into the riparian zone along streams and lakes. However, in those watersheds where the riparian vegetation is maintained as a well-managed native community most of the sediment and agricultural chemicals from the upland are filtered before they reach the stream (Lowrance et al. 1985). Major water quality problems develop when riparian zones are converted to intensive row crop cultivation or heavy grazing.

The mitigating influence of naturally vegetated riparian zones in reducing the delivery of NPS pollutants from agricultural land to stream channels has only recently been perceived as an important element in overall agroecosystem management (Lowrance, 1992; Lowrance, et al., 1985, 1984a, 1984b, 1984c; Heede, 1990; Magette et al., 1989; Phillips, 1989; Cooper and Gilliam, 1987; Cooper et al., 1987; Jacobs and Gilliam, 1985; Peterjohn and Correll, 1984; Schlosser and Karr, 1981a, 1981b, McColl, 1978). The utility of such buffers as sediment traps has been documented (e.g. Brinson et al. 1981; Mahoney and Erman 1984). Although not much is known about the nutrient uptake and cycling capabilities of vegetated buffers, long-term storage of nutrients and gaseous loss of nitrogen tends to be high in riparian areas (Lowrence et al. 1992, 1985). In Illinois, Kovacic et al. (1990) found that an 80% to 90% nitrate reduction could be achieved in subsurface water after passage through grass and forest buffer strips, respectively. Very little is known about the effects of buffer systems on the fate and transport of pesticides, but it has been suggested that they may at least immobilize or retard movement of pesticides until they naturally detoxify (Pionke and Chesters 1973; Schlesinger 1979).

The National Research Council (1993) has recommended the use of field and landscape buffer zones to improve soil and water quality. They suggest that buffer strips ranging from riparian buffers to grassed waterways and artificial wetlands be used to intercept and process pollutants before they enter surface waters. Riparian buffer strips also have been recommended as a means of enhancing habitat for both aquatic and terrestrial wildlife populations within agricultural ecosystems (Osborne and Kovacic 1993; Armour et al. 1991; Hehke and Stone 1978; Karr and Schlosser 1978). Thus, there is much interest among wildlife managers in rehabilitating riparian zones, especially by enhancing their interconnectedness with each other and with upland natural ecosystem remnants.

Restoration of riparian buffer strips can be designed to function similar to or even more efficiently than natural riparian communities. Combinations of trees, shrubs, and grasses can be developed that function effectively as nutrient, pesticide, and sediment sinks for NPS pollutants. The design can take advantage of the different above- and below-ground structures of each species to provide maximum year-round interception of surface runoff and vadose zone soil solution. Innovative designs that use specially selected fast-growing tree species can be grown as short-rotation woody crop systems (SRWC). SRWC systems produce biomass for energy in 5-8 years and timber products in 15-20 years (Colletti et al. 1991). These frequent harvests help to maintain active nutrient and pesticide sequestering by the woody plant community and result in minimal site disturbance because the selected species reproduce vegetatively by stump or root sprouts for 3 to 4 harvests. The large root systems allow very rapid regrowth that provide continuity in water and nutrient uptake and physical stability of the soil throughout the life of the stand.

SRWC systems also can include native shrubs which can provide biomass if harvested and demonstrate coppice regeneration. The addition of shrubs will increase species diversity and wildlife habitat, provide yet another rooting pattern which will hold soil, intercept shallow groundwater nutrients, and provide organic matter for soil microbes. Finally, the addition of native prairie grasses to the reconstructed multi-species buffer strip will provide additional species diversity, a very high frictional surface for intercepting surface runoff and a deep and fibrous root system that will play an important role in improving soil quality. Switchgrass is also a potential biomass energy crop.

Although forested riparian buffer strips ahve been shown to be effective there are still major questions on whether forests or grass buffers are best and what optimal widths of strips are needed to provide a specific nutrient and sediment load reduction (Osborne and Kovacic 1993). Even less information exists on the design, technical capabilities, appropriate management approaches, and long-term effectiveness for reconstructed riparian buffer strips in agricultural landscapes (National Research Council, 1993).

This paper presents a model for a multi-species ripairian buffer strip system that will intercept eroding soil and agricultural chemicals from adjacent crop fields, stabilize channel movement, and improve in-stream environments, while also providing wildlife habitat and biomass for energy and high quality timber. This agroforestry model has been developed by an interdisciplinary team of researchers, members of the Iowa State Agroforestry Research Team (IStART) with specialists in forage crops, soils, hydrogeology, forest hydrology, forest ecology, wetland ecology, economics, biometrics, wildlife management, and extension.

Materials and Methods

The multi-species riparian buffer strip (MSRBS) system is being developed in the Bear Creek Watershed is located in north-central Iowa within the Des Moines Lobe, the depositional remnant of the late Wisconsinan glaciation in Iowa. The total length of Bear Creek is 34.8 km (21.6 mi) and it has 27.8 km (17.2 mi) of major tributaries before it empties into the Skunk River. The watershed drains 7160 ha (17,180 acres) of farmland, most of which has been subjected to field tile-drainage during the last 50-60 years. About 87% of the watershed is devoted to corn and soybean agriculture. Prairie vegetation originally dominated most of the undulating to level topography, with the exception of forests that occurred along the lower end of the creek. Soils are well-drained to poorly drained and formed in till or local alluvium and colluvium derived from till. Roland, a town of 1,100 people, is the only community in the watershed and there are no major recreational areas.

Two different levels of research activity are taking place in the Bear Creek Watershed. The Leopold Center for Sustainable Agriculture Agroecology Issue Team is using the watershed to study the condition of the riparian zone at the watershed level. At the present time the team is identifying critical riparian reaches along the creek that need restoration and/or modified management to reduce the impact of NPS pollution on Bear Creek. The long term goal of the project is to help farmers who own land along the creek to develop riparian zone management systems that will intercept surface runoff and subsurface flow and will remove or immobilize sediment and agricultural chemicals before they enter the creek.

IStART has been working on one farm in the watershed and developing a model sytem for restoring a MSRBS that could be used along the critical reaches of Bear Creek as well as other waterways in Iowa and the midwest. The system also includes soil bioengineering features to stabilize streambanks and small wetlands placed at the outlets of field tiles to denitrify the tile flow before it enters the creek. The Agroecology Issue Team will use this model to help demonstrate the MSRBS concept to farmers and to provide design specifications for similar buffer strips on their farms.

The site MSRBS system lies along a 1000 m reach of Bear Creek on a private farm approximately 2.4 km north of Roland, Iowa. At this location the creek is a third order stream with average discharge rates varying between 0.3-1.5 m^3 sec^{-1}.

Corn, soybeans, and alfalfa hay are produced on this farm and the corn and soybeans are rotated on an annual basis. During the past four years, pesticides applied on the farm have included Commence (chlomazone) in 1989 and 1991, Extrazine (atrazine and cyanazine) in 1990, 1992, and 1993, and Eradicane (EPTC) in 1990 and 1992. During the past twelve years, impregnated urea pellets have been applied at the rate of 134 kg ha^{-1} (120 lb ac^{-1}). On legume fields, 90 kg ha^{-1} (80 120 lb ac^{-1}) of 120-60-60 (N-P-K) are applied annually. Until 1988, livestock were also allowed to graze along parts of the creek riparian zone, which caused severe stream bank erosion and impact on the riparian plant and animal community.

The MSRBS system site is set in Pleistocene sediment deposited by the Des Moines Lobe (Alden and Morgan Members) and Holocene age sediment overlying Mississippian age bedrock, which is composed of primarily limestone, dolomite, sandstone and shale. Perhaps the most surprising feature of the geology at the site is the depth to bedrock. Although maps provided by the IDNR-Geological Service Bureau (GSB) indicated that the Pleistocene sediment is probably less than 30 m thick and there are no visible bedrock outcrops near here, bedrock was encountered at depths of 6.7 m near the entrance to the farm and at depths of 3.7 to 4.6 m below the alluvium. Excavations of the creek bed for weir installations indicated that weathered limestone and siltstone lie only 1.5 m below the channel. Shallow bedrock complicates the hydrogeology of the site to the extent that much of the hydrogeological research has been directed towards distinguishing groundwater flow in the shallow unconfined and the deeper bedrock aquifer.

In order to objectively evaluate the MSRBS, sections of the Bear Creek reach were divided into a split block statistical design. The reach of the creek under study was divided into three blocks: inside bend, outside bend, and straight reaches (Figure 1). Five 90-m plots were located within each block. Treatments consisting of three combinations of planted trees, shrubs, grass, and two controls, were randomly assigned to the plots within each block. The planted treatments consisted of five rows of trees planted closest to and parallel to the creek at a 1.2 x 1.8 m spacing. Different species of trees were used in each of the three treatments. One treatment consisted of a poplar hybrid (*Populus* X *euramericana* 'Eugenei') which has been extensively tested and is readily available in Iowa. The second treatment contained green ash (*Fraxinus pennsylvanica* Marsh.) and the third treatment contained a mixture of four rows of silver maple (*Acer saccharinum* L.) with a center row of black walnut (*Juglans nigra* L.). Upslope from the trees are a row of red-osier dogwood (*Cornus stolonifera* Michx.) and a row of ninebark (*Physocarpus opulifolius* L.). The shrubs were planted at a 0.9 x 1.8 m spacing. Finally, a 7.3-m-wide strip of switchgrass (*Panicum virgatum*) was planted upslope from the shrubs. Controls consist of pasture grasses similar to those that were present on areas that were grazed prior to the study. Most trees are being grown on a 8- to 10-year rotation, depending on the species. Black walnut is being grown on a 45- to 55-year rotation. Two small plots of 'Austree' willow (*Salix matsudana x alba*), a sterile male hybrid from New Zealand have also been planted.

Two soil bioengineering systems have been developed as part of the MSRBS system. These developments use live staking and dead tree fascines to stabilize severely eroding banks on two outside streambanks. Live willow posts were installed on the outside of the bend along plot 2 in the spring of 1992. From the planting of the buffer strip in early 1990 until spring of 1992 at least 3.6 m of bank, 90 m in length, had collapsed into the creek in this bend. Two newly planted rows of silver maple had been lost. In the spring of 1992, 1 m long and 5-7.5 cm diameter cuttings of 'Austree' willow were pounded into the creek bottom and along the toe of the bank of the first two thirds of the collapsed area. Three or four rows of posts were pounded in at a spacing of about 0.3 x 0.3 m. Also, smaller cuttings were pushed into the perpendicular bank wall at a similar spacing. Most of these cuttings took root and grew. The planting was extended in the spring of 1993 after more cuttings became available and had just become established when the major floods of June and especially July 1993 occurred. Although the plantings withstood the 155 cm of rainfall (79 cm is normal), the record 500 year flood plus at least 5 other over-bank flows of 1993, a dead fascine system, using bundles of harvested, 6 year old silver maple was added to this planting in the spring of

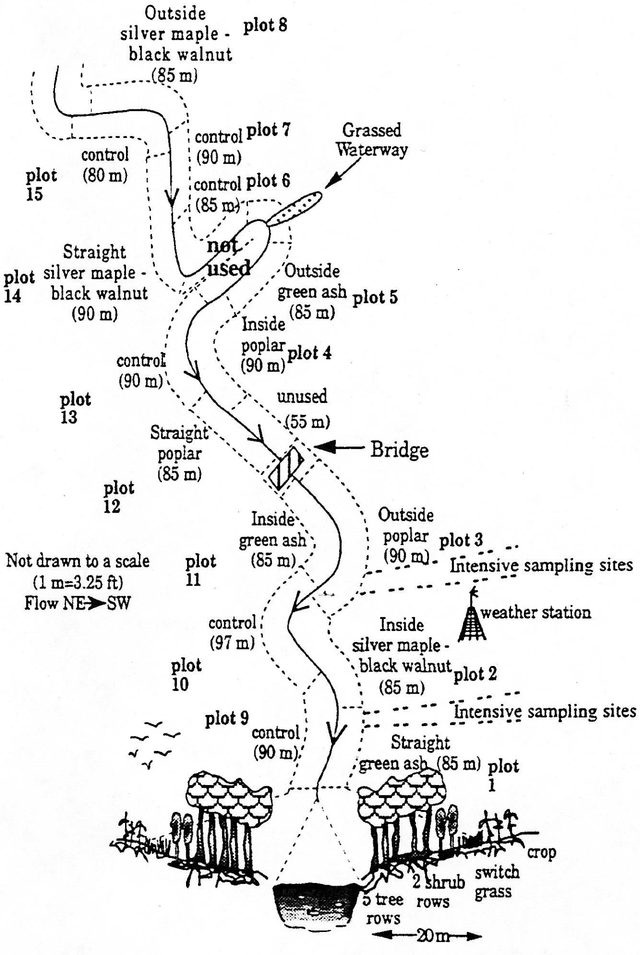


Figure 1. Plot layout of the CMRBS project located in Story County, IA.

1994. Two or three complete trees were bundled together and placed in cribs of 3-4 bundle height. Additional live willow stakes were added to the system. Another system was also developed along 200 m of the outside bend of plots 4 and 5. The stability of these two bends are being compared to bends in plots 6 and 10.

Finally, a 400 m^2 wetland has been installed at the end of a field drainage tile flowing into the creek in plot 3. This wetland was developed by minimal excavation and installation of a berm that varies in height from 0.5-1 m in height. Cattails (*Typha* spp.) were planted into the wetland to provide the organic matter for denitrifying microbs. The wetland will process tile water from a 5 ha cropped area.

Above-ground plant growth and biomass production are measured using permanent measurement plots in each of the treatment plots. Two permanent measurement plots were established in each of the approximately 90 m long tree and shrub plots during the summer of 1990. The measurement plots consist of 4 trees in each of the 5 consecutive rows of trees and 4 shrubs in each of the 2 consecutive rows of shrubs. The height and diameter at 20 cm above the ground of each surviving tree have been measured annually during the dormant season. The tree measurements are used to estimate average height, diameter, biomass, and survival for each species. Biomass is estimated by using the height and diameter of each tree and regression equations. Equations that were developed for estimating the biomass of poplar in a study at the nearby Hickory Grove Biomass project site (Colo, IA) are used to estimate the biomass of poplar and green ash. Equations developed to estimate the biomass of silver maple at Hickory Grove are used to estimate the biomass for silver maple and walnut. There is a probable bias in the estimation of the ash and black walnut biomass, but the trees are so small at this time that the error is likely insignificant. As the ash and walnut get larger, species specific equations will be developed by harvesting some of the trees that are in the tree plots but a reasonable distance from the measurement plots.

Shrub biomass will be determined after the fifth growing season during the 1994 dormant season when subsamples of shrubs will be measured for stem numbers and stem diameters and heights. Subsamples will be coppiced and dry weights will be determined. Switchgrass and pasture grass (control plots) biomass are determined by clipping 1 m x 1 m plots and determining dry weights.

Results and Discussion

This buffer strip project differs from most of the forested riparian buffer strip studies that have been reported in the literature because this system had to be established on cultivated or heavily grazed ground. It is inherent in getting a perennial plant ecosystem restored on such sites that time is required before the system begins to function as it is ultimately expected to function. Eary results from restortation projects such as this one do not accurately reflect the remediation potential of the plant community. However, it is important to report early results of such as system to demonstrate the potential of the system throughout the establishment phase. Visual contrasts also are useful to demonstrate the changes that have take place on the site over time. Although these visible changes are difficult to quantify, it is often the visual impact that results in landowner adoption of a demonstrated technology.

The plants for this demonstration buffer strip were selected to serve multiple purposes. Those purposes included rapid growth, perennial rooting habits along the streambank and dense annual rooting habits at the crop field interface, coppice regeneration ability for the trees and shrubs, stiff stems for the grass, a good form and/or fruits for wildlife habitat, and a potential for being used as biomass for energy or fiber. The desire was to develop an effective buffer in as short a time as possible to effectively trap sediment and process chemicals and to demonstrate to landowners that a buffer strip with woody plants can be rapidly grown.

Survival of the trees, shrubs, and switchgrass in the CMRBS has generally been very good. Only red-osier dogwood has shown significant mortality. After the first growing season (1990) 50% of the dogwood seedlings died. The mortality showed an interesting pattern with some plots having good survival and others almost 100% mortality. Seedlings were replanted in 1991 and most of these also died during the first season. This would suggest that there might be a soil problem that has, as of yet, not been identified. Nannyberry and Nanking Cherry have now been replanted in those locations and are showing better survival.

Silver maple and green ash have had the highest survival over the life of the project (Table 1). Poplar survival was adversely influenced on plot 12 by the two major floods of 1990 and 1991. Seedlings in over half of plot 12 were washed away in 1990 and 1991 and had to be replanted. There also has been some mortality in plot 3 where survival and growth on the portion of the plot that had been cultivated prior to establishment of the MSRBS, has not been very good. These two incidents account for most of the mortality in the poplars.

Black walnut survival was adversely influenced in the second year of growth because of intense grass competition. Strips of pasture grass into which the trees were planted were treated with Round-up™ herbicide at the time of establishment. The survival of walnut was 96% after the first growing season. No herbicides were used in the second year because of the desire to keep the surface covered with dense vegetation. Walnut seedlings are very susceptible to grass competition and that effect can be seen in the second-year survival and growth. Once the seedlings had completed their third growing season they were able to compete more effectively with the grass but still did not grow very rapidly.

Of the tree species that were planted in the MSRBS plots, poplar hybrids are the tallest after four growing seasons, averaging 4 m in height. The poplars are followed in height by silver maple, green ash, and black walnut. The poplars show very rapid initial growth that has been maintained throughout the four growing seasons. Diameter responses for the trees has been similar to the height responses. Most of the trees on the site have single stems, except for silver maple whose individuals have an average of 1.8 stems per plant. This added stem produces a denser canopy structure than for poplar which is taller and single stemed. The result

Table 1. **Mean and standard deviation (S.D.) of % survival, height, diameter at 20 cm, biomass and number of stems for poplar, green ash, silver maple, and black walnut in 1990, 1991, 1992, and 1993. Means and S.D.'s are calculated from individual tree measurements, not plot means.**

Poplar	1990 (140)*		1991 (140)		1992 (120)		1993 (120)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
% Survival	87.00		85.00		83.00		87.00	
Height (m)	1.03	0.36	2.08	0.87	3.42	1.32	4.00	1.67
Diameter (mm)	11.50	4.80	25.20	12.10	46.00	22.90	55.00	28.80
Biomass (Kg)	0.04	0.04	0.33	0.25	1.44	1.35	2.43	2.52
# of stems per seedling	1.20	0.50	1.10	0.30	1.10	0.30	1.00	0.17
Green ash	1990 (100)		1991 (100)		1992 (120)		1993 (120)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
% Survival	96.00		95.00		97.00		92.00	
Height (m)	0.45	0.14	0.84	0.23	1.12	0.36	2.40	1.59
Diameter (mm)	5.80	1.80	10.90	3.60	14.00	5.30	31.00	16.30
Biomass (Kg)	0.01	0.00	0.03	0.02	0.07	0.07	1.02	1.80
# of stems per seedling	1.10	0.30	1.00	0.10	1.20	0.40	1.10	0.30
Silver maple	1990 (96)		1991 (96)		1992 (96)		1993 (96)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
% Survival	98.00		97.00		98.00		98.00	
Height (m)	0.82	0.19	1.26	0.37	1.89	0.60	3.02	0.75
Diameter (mm)	10.10	2.80	18.80	6.80	28.00	11.50	44.00	17.50
Biomass (Kg)	0.03	0.02	0.14	0.11	0.46	0.40	1.82	1.40
# of stems per seedling	1.00	0.20	1.00	0.00	1.50	0.80	1.80	1.00
Black walnut	1990 (24)		1991 (24)		1992 (24)		1993 (24)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
% Survival	96.00		71.00		75.00		75.00	
Height (m)	0.61	0.12	0.61	0.18	0.63	0.21	1.14	0.43
Diameter (mm)	6.90	1.50	8.40	3.10	10.00	4.40	20.00	9.20
Biomass (Kg)	0.01	0.00	0.04	0.01	0.04	0.02	0.15	0.14
# of stems per seedling	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

* Numbers in parentheses represent number of seedlings initially planted in permanent tree plots. The means for size and number of stems are based on measurements of survivors. Willow data is not available because they are not planted in replicated plots.

is a different habitat opportunity for wildlife and a different distribution of biomass per plant.

Although willow was not planted as part of the design, two plots of 15 'Austree' willow trees each are planted on the project site. One is planted on the end of a sandbar in plot 11 and the other is planted near the creek parallel to plot 3. The trees in plot 11 were coppiced in the spring of 1992 while those in plot 3 were not. The trees in plot 3 average almost 5.5 m in height and 10 cm in diameter. The trees which were coppiced have an average of 5 stems per stump with diameters greater than 3.8 cm and average heights of 5 m.

Biomass per plant and per hectare is less for the trees in this MSRBS than in SRWC experimental plots at the Hickory Grove Energy Plantation site, near Colo, IA. For example, the poplar in the MSRBS has the equivalent of 4.4 Mg ha^{-1} and the silver maple has the equivalent of 3.3 Mg ha^{-1}. Leaves and twigs for these trees adds approximately 1 Mg ha^{-1}. At the Hickory Grove site the same species produce about twice those amounts in half the time. Part of the reason for the differences is that the MSRBS is managed for multiple uses while the SRWC system is managed primarily for biomass. As a result, more attention is given to weed control in the SRWC system and those plantations are nearly weed free. In the MSRBS the objective is to maintain a continuous cover of grasses on the ground for sediment trapping and these grasses compete heavily with the trees, especially in the early years of establishment. The trade-offs of the MSRBS are necessary to meet the major objective of reducing NPS pollution.

Clipping plots in the switchgrass and the control plots of mixed pasture grasses show that the switchgrass produced about 9.4 Mg ha^{-1} of dry above-ground biomass in 1993 while the pasture grasses produced about 5.1 Mg ha^{-1}. The switchgrass biomass is almost twice as great as that of the pasture grasses and much larger than that of the trees. Although samples were not collected to test the following, the pasture grasses growing between the tree and shrub plots would contribute enough biomass toothe poplar plots to provide a total above-ground weight similar to that of switchgrass (4.4 + 5.1 Mg ha^{-1}). However, it would not be economical to try to harvest the pasture grasses in the tree strips. This system of narrow strips of trees and sthrubs provides enough light to the ground vegetation that grasses and herbs are able to grow providing excellent sediment trapping.

The preliminary root biomass data is encouraging. During early September, 1993, two 6,000 cm3 cores of soil were removed from between the tree rows and shrub rows of a measurement plot in each species, from the center of two switchgrass and control (pasture grasses) plots, and from between two sets of soybean and corn plants. Roots were extracted from these cores by depth, dried, and weighed. The dry weights were used to estimate the weight of roots in each depth category on a per hectare basis (Figure 2). The vegetation in Figure 2 is arranged in the order that it is planted in the MSRBS to show root distribution in relation to the stream channel.

The implications of this root data are profound. Plant roots increase soil stability by mechanically reinforcing soil and by reducing the weight of soil through evapotranspiration (Waldron and Dakessian, 1982). Deeper rooted plants extract more water from greater soil depths than shallow rooted plants. Woody plant roots provide superior soil stabilization when compared to herbaceous plants because of their deeper rooting habit and their larger roots (Waldron et al., 1983).

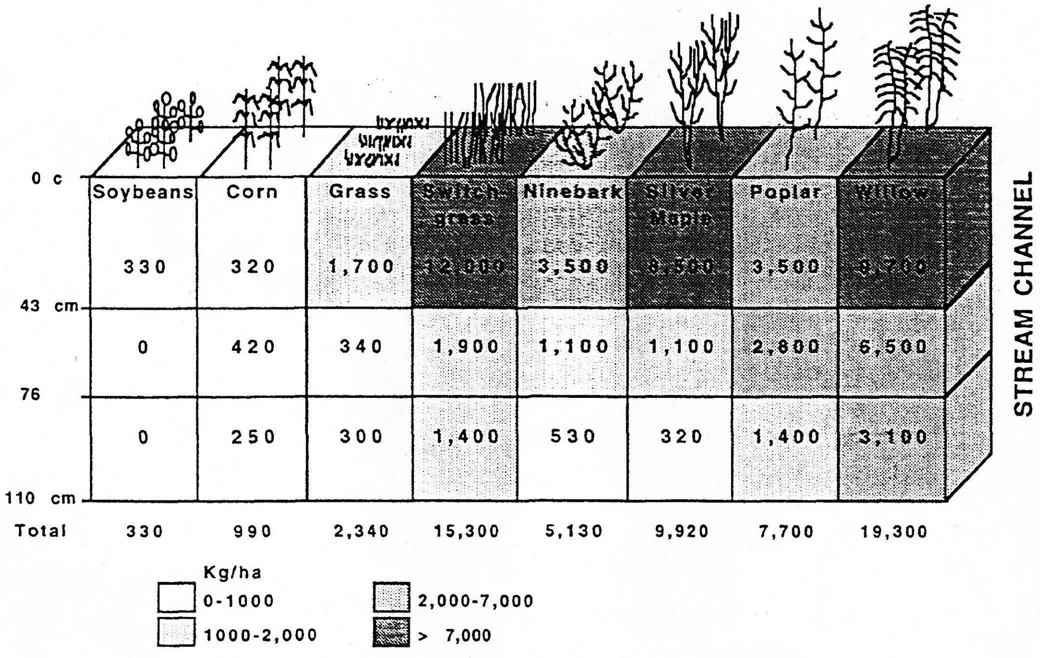
Corn and soybeans have only minimal root biomass and that is only present during and shortly after the growing season, a period of 5-6 months. Cool season pasture grasses provide significantly more roots than corn or soybeans in the top 43 cm of the soil but are similar to corn at lower depths. The grass roots are present for a longer time during the year and provide more organic matter for maintaining soil quality. The limited biomass of these grasses below 43 cm reduces their ability to stabilize soil and extract water and associated agricultural chemicals. The limited influence of shallow roots can be seen along collapsing streambanks of grazed riparian pastures. Even when these pastures are abandoned, bank stability is minimal because of the lack of root mass with increasing depth.

The MSRBS design provides superior rooting to filter or buffer strips consisting of only cool season pasture grasses. At the interface between the crop field and the MSRBS lies a strip of switchgrass with 38 times more root biomass in the top 43 cm of soil than corn and 12 times more biomass than the cool season grasses. The greater root biomass of the switchgrass at the lower depths, 5 times that of the pasture grasses, provides more surface area for absorbing soil solution. This coupled with an above ground biomass which is almost twice that of the pasture grass makes the switchgrass far superior for trapping sediment and absorbing the water which infiltrates into the soil as a result of the slowed surface water movement.

The tree strip adjacent to the creek can provide the second largest root biomass in the surface 43 cm and the highest biomass at depths below 43 cm depending on the tree species. Willow and silver maple both have high root biomass in the upper 43 cm while poplar and willow have high root biomass in the 43-76 cm depth. Poplar and switchgrass have about equal biomass in the lowest measured depth and willow has about twice as much as both of these species. These root biomass results would suggest that willow is the species that should be planted nearest the creek, especially in those areas where bank stability is needed. In areas such as straight reaches poplar could also be planted along the streambank. In both cases at least two rows of these species should be planted to provide the root mass necessary for soil stability.

Beyond these rows of trees silver maple would make a good candidate because its large surface root mass would help reestablish high soil infiltration rates and provide a large root volume to absorb the infiltrated water. Especially in the case of willow and poplar it is likely that the vadose zone could be fully exploited by tree roots which would intercept soil solution that is moving as subsurface flow through the MSRBS.

Soil stability from tree roots comes not only from the high biomass that is present but also from the fact that many of the tree roots have a larger diameter and are perennial when compared to any of the grasses. This is very important immediately adjacent to the streambank where bank erosion can contribute up to 50% of the annual stream sediment load. However, development of woody plant root systems takes longer than that for switchgrass. Thus, it could be expected



	Soybeans	Corn	Grass	Switchgrass	Ninebark	Silver Maple	Poplar	Willow
0 cm – 43 cm	330	320	1,700	12,000	3,500	8,500	3,500	9,700
43 cm – 76	0	420	340	1,900	1,100	1,100	2,800	6,500
76 – 110 cm	0	250	300	1,400	530	320	1,400	3,100
Total	330	990	2,340	15,300	5,130	9,920	7,700	19,300

Figure 2. Root distribution of MSRBS vegetation by depth and arrangement.

that the root biomass for the trees will continue to increase at each depth over the next few years.

The frictional surface, and above-ground and below-ground biomass of the MSRBS are superior to that of the pasture grass buffer strips. These are the major attributes needed for a buffer strip to function effectively in reducing NPS pollution. The MSRBS provides the additional benefits of wildlife habitat, improved aesthetics, and potential fiber and biomass energy crops.

One of the best ways to demonstrate the results of a restoration project is to keep a visual record of the progress of restoration from the beginning of the project. To that end a series of three sets of photos are provided to show visible changes on the site. Because this site was devoid of any significant plant cover other than closely grazed grass and tilled fields, the change in vertical and horizontal structure of the vegetation community over the past four growing seasons has been very dramatic. This change in structure serves both as a physical barrier to water and wind movement across the buffer strip, provides a rather diverse wildlife habitat, dramatically changes the aesthetic impressions that visitors have of the site, and suggests that significant biomass can be produced that could provide potential commercial products for the landowner.

The photos also are evidence that the buffer strip can withstand large volumes of water that can move through the system during storm events. There are no areas along the buffer strip that have been breached by concentrated flow from the uplands during 1993, one of the wettest years on record. A large portion of the buffer strip was inundated by flood waters from the creek itself and was subjected to movement of large debris which floated with the water. There is no evidence that any major damage was done by either the flood water or the debris.

Figure 3

This series of photos are all taken from the same location, looking upstream to the northeast from the center of plot 3. Note the bridge across the stream in each picture. This bridge was washed out by the flood of 1990. Numerous planks from the replaced bridge also have been washed out by subsequent floods. The bridge is substantial enough to support large tandem wheeled gravel and concrete trucks as well as large combines. Photo A was taken in March, 1990. Note the irregular and steep banks along the west side of the creek and the more gradual but bare banks on the east side. This area was previously grazed. Also note that there are a number of large dead willows that were removed prior to establishment of the MSRBS.

Photo B was taken in June of 1990 after the site had been planted and photos C and D were taken near the end of the growing seasons in 1992 and 1993, respectively. Plot 12, in the distance on the left side of the creek and plot 4 on the right side of the creek are both poplar plots. The plot on the

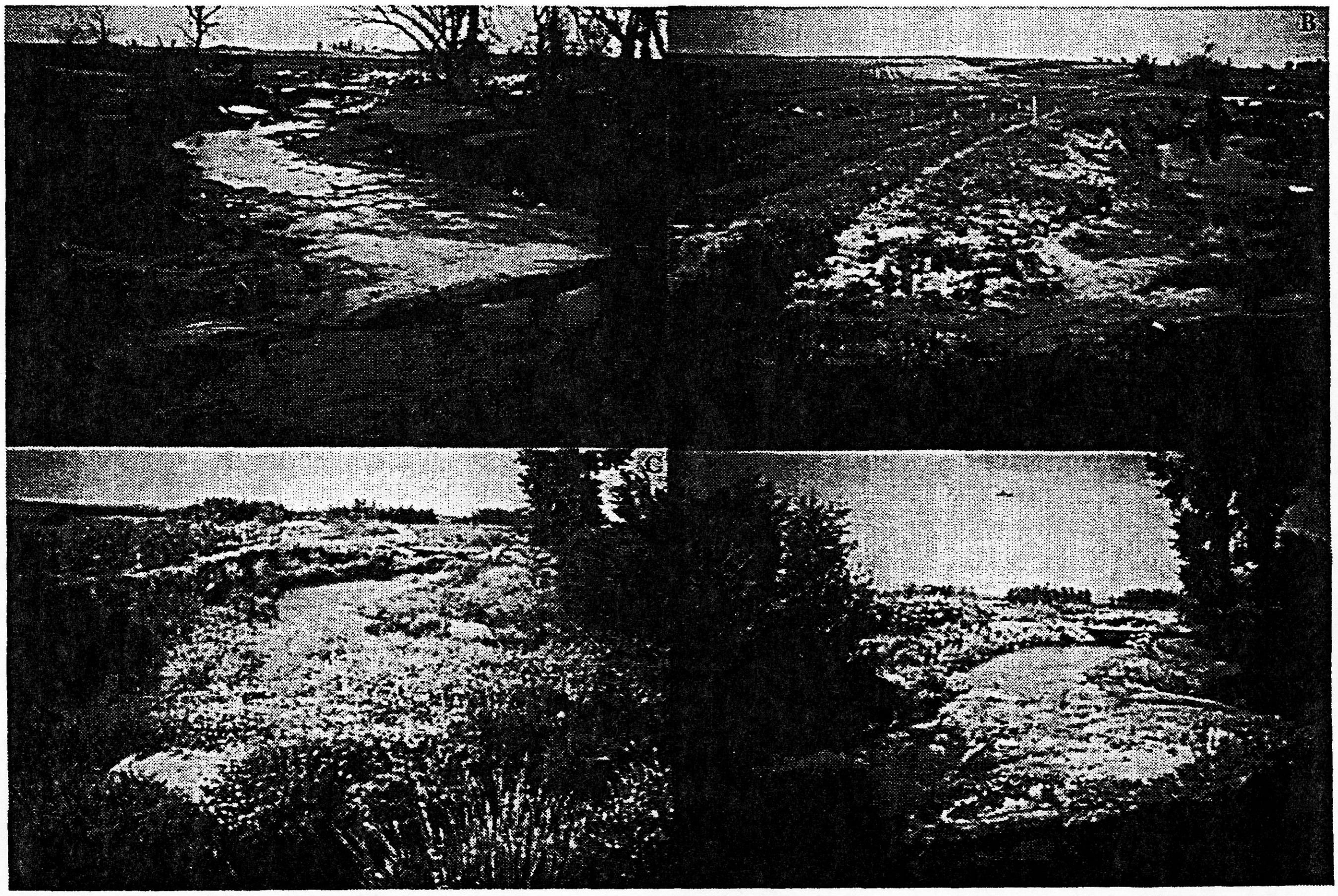


Figure 3. Looking across upstream to the northeast from the center of plot 3 in the CMRBS. A) Before planting, March 1990; B) June 1990; C) September 1992; and D) September 1993.

left side of the creek below the bridge is plot 11, an ash plot. Note in photos C and D that the poplar is much taller than the ash. At the end of the 1992 growing season the ash and poplar were 1.1 m and 3.4 m tall, respectively. At the end of the 1993 season they were 2.4 m and 4.0 m tall, respectively. It also is obvious that the streambanks on both sides of the creek have become covered with vegetation. Although it is not easy to see, willow stakes were pounded into the west-side bank at the beginning of 1993 because installation of the new bridge had caused some new bank cutting.

Note the large mass of growth on the left-hand side of photo D. These are stump sprouts of "Austree" willow which were coppiced (cut off and allowed to resprout) after the 1992 growing season. The willow was planted in 1990 at the end of a point bar, one month after other trees had been planted. It was cut to provide unrooted cuttings for the streambank bioengineering project. This sterile male willow clone from New Zealand grows very rapidly on the sandbar site. A similar planting can be seen on the east side of the creek in photo D which was planted at the same time but not coppiced. These willows are the fastest growing trees on the project site.

Figure 4

This series of photos also was taken from the same spot at the upstream end of plot 12 seen in the Figure 4. Photo A was taken in March, 1990, photos B and C in 1992 and photo D in 1993. Note the point bar in the left center portion of each photo. The grass and forb cover reestablished itself on the bar from 1990 to 1992. Note after the 1993 floods (Photo D) that the bar did retreat some as the channel got wider. However, streambank integrity was maintained throughout the flood events. Although the bank on the right side of the creek is one of the highest on the project site, this is one of the most obvious reaches along the creek where streambank stability improvement after cessation of grazing is evident. There is not evidence that flooding activity was detrimental to any of the plant populations in the buffer strip and there is evidence that those plants reduced the flow rate of the flood water because of their high frictional profiles. Poplar trees in photo B and C were 3.4 m tall and those in photo D were 4 m tall.

The impact of the developing MSRBS are being intensively monitored. Initial results for nitrate nitrogen (NO_3^--N) and atrazine are shown in Figures 4 and 5. The results are means from 10 lysimeters at each of the identified positions in five transects across the MSRBS. Lysimeters are located at 30 and 75 cm depths at each location. The within field lysimeters are reinstalled 15 m from the field border with the MSRBS each year after the crops have been planted. As a result no data was available in 1993 until the June 29, 1993 sampling date. The field border lysimeters are located at the edge of the switchgrass and the crop field which was planted to corn in 1993. As can be seen the NO_3^--N concentrations in the buffer strip never exceed 2 mg l^{-1}. Atrazine

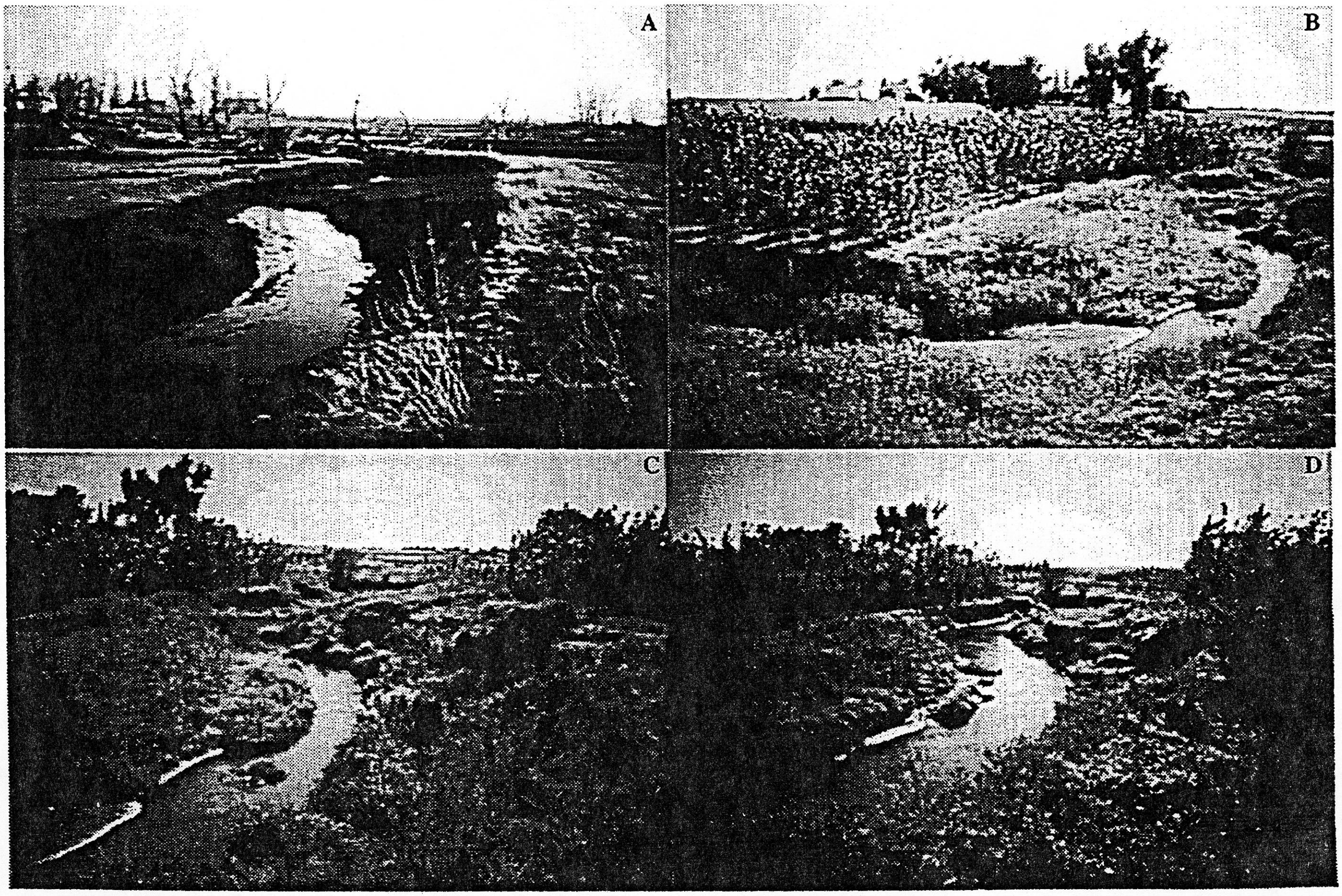


Figure 4. Looking downstream to the southwest from the east end of plot 12 in the CMRBS. A) Before planting, March 1990; B) during planting; C) September 1992; and D) September 1993.

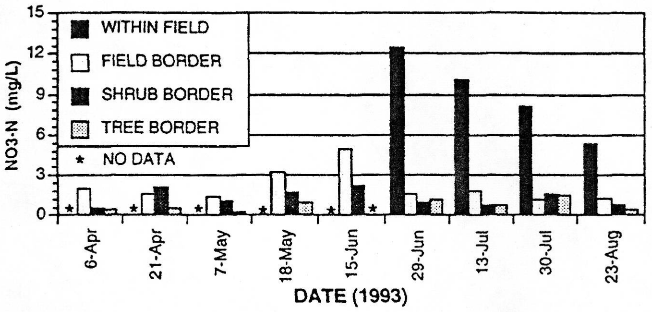


Figure 4. 1993 mean nitrate nitrogen concentrations at the field-switchgrass, switchgrass-shrub, and shrub-tree borders in plots 1 and 3 of the CMRBS.

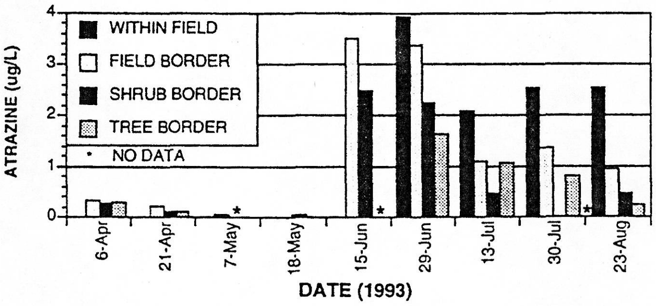


Figure 5. 1993 mean atrazine concentrations at the field-switchgrass, switchgrass-shrub, and shrub-tree borders in plots 1 and 3 of the CMRBS.

concentrations were high during the rainy months of June, July, and August and exceeded the EPA Maximum Contaminant Level (3 mg l^{-1}) in the field and at the field border with the MSRBS immediately after application in the middle of May. In each of the measurement periods atrazine concentrations decreased across the MSRBS. These data suggest that the MSRBS is effective in reducing NPS pollutant levels in the vadose zone across the buffer strip. The data does not indicate how much of the pollutants are moving below the MSRBS in the shallow ground water. Piezometers are being installed to answer that question.

The Recommended Model Tree/Shrub/Grass Buffer Strip

The following figures demonstrate the MSRBS design that is recommended by IStART. Figure 6 shows the general concept of a 20 m wide filter strip. Starting at the stream, four or five rows of trees, two rows of shrubs and a 7 m wide band of switchgrass are recommended. Other native prairie grasses could be mixed with the switchgrass as long as the switchgrass dominates the site.

If a drainage tile runs through the filter strip, tree roots from cottonwood hybrids, silver maple and willow are likely to plug these tiles. To alleviate problems with tree roots, the portion of the tile which passes under the filter strip could be replaced with a solid PVC pipe. Alternatively, a strip of grass (or even shrubs) might be used in the vicinity of the tile. This grass strip should be 4.5 - 6 m wide and centered over the tile.

This model system also recommends the use of small constructed wetlands at the end of tiles if there is room for there construction. At a ratio of 100:1 only a small space is needed for an effective wetland. The system also suggests using willow stakes or other soil bioengineering techniques along steeply eroding streambanks. The wetland and soil bioengineering components are important parts of an overall MSRBS management system.

There are numerous tree combinations that can be planted in the four or five rows of trees. The fastest growing trees such as willow, poplar hybrids, and/or silver maple should occupy the first three rows closest to the stream bank. Any of these three species could be planted immediately adjacent to the stream. But where steep, potentially eroding streambanks are a problem, willow, because of its root intensive and extensive root system would be the best choice. In these situations, the willow-stake bioengineering system would also be an appropriate component of the MSRBS system. These species would become established quickly and begin to provide filtering and stabilizing effects within the first 3 years.

The next two rows also could be planted to any of the three species already mentioned (or green ash or even hackberry). If the soils are moderately well drained and the seasonal water table does not stay above three feet for more than one month during the early growing season, red oak, white oak, or bur oak or black walnut could also be planted. The figure shows a 1.8 m spacing between tree and shrub rows. That spacing could be increased to 2.4 m between rows which would reduce the number of tree rows to four. At this width, it is easier to get between the rows for maintenance and the cost of establishment is reduced because fewer seedlings are needed.

Figure 7 shows a design for a reach of a stream which runs primarily east and west. Because the sun travels through the southern sky, it is important not to shade the slower - growing trees with faster - growing ones so that the faster - growers and taller trees should be on the north side of the plantings. On the south side of the stream, it is recommended to plant ash, oak, or black walnut on the outside rows be-

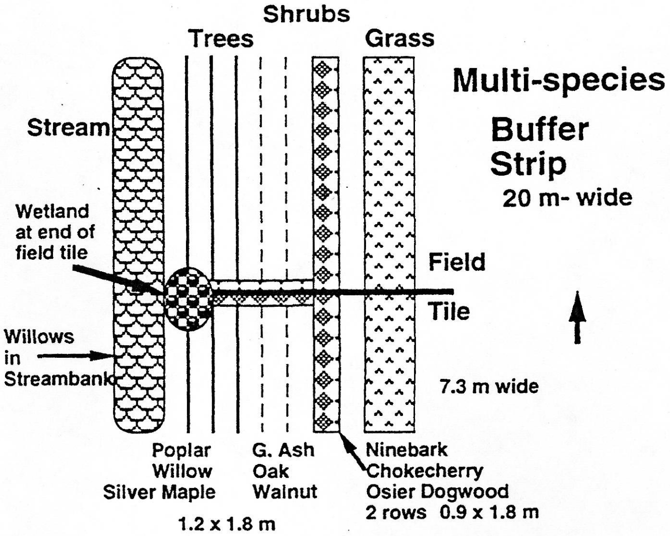


Figure 6. Layout for a multi-species buffer strip riparian zone management system that includes soil bioengineering as well as a small wetland at the end of a field tile.

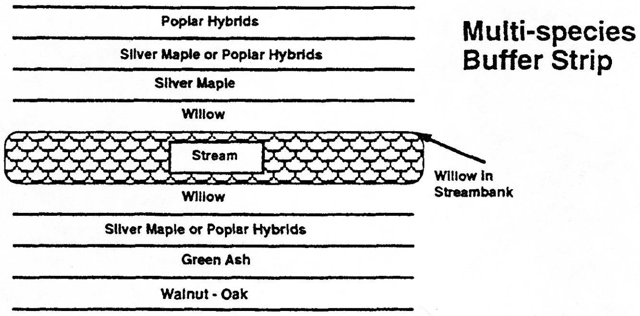


Figure 7. Planting layout for stretches of buffer strip that lie in an east-west direction. The top of the figure is north.

cause of the lack of shade from taller and faster - growing trees. Because green ash grows slower than either the poplar hybrids, willow, or silver maple, it should not be part of the planting on the north side of the stream.

The two rows of shrubs could be any of a combination of shrubs. Past experience dictates planting at least two different species of shrubs for diversity and to reduce the risk of losing all the shrubs to a pest or drought. Ninebark, chokecherry, nannyberry, and red osier dogwood are well suited to these buffer strips.

Spacing between trees and shrubs in the rows is 1.2 m. A 20 m width by 200 m length is 0.4 ha. If there are 5 rows, 200 m long, and with a spacing of 1.2 m between trees, there would be 825 trees per 0.4 ha (4 rows of trees would need ~660 trees). For two rows of shrubs at 0.9 m between shrubs, there would be an additional 440 plants for a total of 1,265 woody plants (1,100 for the 4 row design) per 0.4 ha or 200 m of length. Along 1,600 m of stream, a 20 m buffer strip on one side would total 3.2 ha. If that strip were on both sides of the stream there would be a total of 6.4 ha in buffer strip.

If there were specific requirements for governmental and non-governmental organizations (NGO) cost-share programs, the numbers of trees could be increased by not planting shrubs and by making the grass strip 6 m wide and adding an additional row of trees. The grass strip should not be any narrower than 6 m.

Riparian zone management is a very 'hot' topic at the present time. To manage the agricultural landscape for sustainable agriculture means that NPS pollution must be controlled and that water quality is maintained at a high level. Sustainable agriculture also means diversifying the opportunities for the farmer as well as diversifying the landscape. MSRBS provide an opportunity to accomplish these objectives. To date most riparian zone research has been conducted either in existing naturally vegetated riparian zones or using cool-season grass buffer strips. It would seem that a MSRBS offers numerous additional advantages over the traditional cool season grass buffer strips and could be designed to be more efficient at trapping sediment and reducing chemicals than existing natural systems.

The USDA Soil Conservation Service (SCS) has recently published its new riparian forest buffer guidelines (SCS September, 1993) and that the MSRBS fits the guidelines very well. The guidelines that the SCS developed resulted from work that the USDA Forest Service had conducted along wooded riparian zones. As a result, the SCS/Forest Service guidelines are geared to traditional forest management opportunities whereas the MSRBS is designed to provide NPS control benefits and woody and perennial fiber products including both traditional forest products and biomass for energy. The MSRBS is also designed to diversify the agricultural landscape by introducing wildlife corridors with a variety of habitats along streams and provide for enhance aesthetics.

There are still many of unanswered questions about the functions of MSRBS or any buffer strip. Among the most important are quantification of the sediment trapping ability and the nutrient and pesticide reduction ability of the buffer strips as related to buffer strip width. Changes in soil quality resulting from the presence of the permanent MSRBS buffer strip system also are needed. The quantification and use of wildlife that use this or other buffer strips and the economic benefits and costs of these systems must also be established. MSRBS offer numerous benefits to the agricultural landscape but they are only a part of a well designed landscape management system.

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