CONF-960958--2
SEP 0 9 1996
OSTI

# ENVIRONMENTAL ENHANCEMENT USING SHORT-ROTATION TREE CROPS: RESEARCH RESULTS AND DIRECTIONS [1]

Virginia R. Tolbert[2] and Andrew Schiller[2]

## ABSTRACT

Short-rotation woody crops (SRWC) and perennial grasses used as biomass feedstocks for energy and fiber can provide multiple economic and environmental benefits. Site-specific environmental studies are providing information needed to help evaluate the economic and environmental impacts of biomass production at both local and regional scales.

Erosion and chemical movement from an annual row crop, switchgrass, and tree crop with and without a groundcover are being compared in the Southeast. Studies of SRWC productivity on the South Carolina coastal plain are comparing surface and subsurface movement of chemicals applied under different fertilization and irrigation regimes, and addressing use of mill and agricultural residues to enhance crop production. Results are helping to assess the effects of biomass crops produced on different principal soil types and to match tree species with appropriate sites to maximize productivity and minimize environmental impacts.

Studies are comparing wildlife use of biomass crops to row crops, grasslands, and natural forests. Results to date show that SRWCs support greater bird diversity than row crops, but less than natural forests; switchgrass plantings extend habitat for grasslands birds. Collaboration with an industrial partner on diverse SRWC plantings in the Southeast is addressing the relationship between plantings of different acreage, age, tree species, and landscape context and breeding bird use. Information from wildlife diversity, water, and soil quality studies can be used by the Biofuels Feedstock Development Program (BFDP), researchers, producers, and industry to identify management strategies to maintain productivity while enhancing the environment.

**Keywords:** Environment, Energy Crops, Biomass Crops, Wildlife, Breeding Birds, Small Mammals, Soil, Water Quality, Erosion, Soil Amendments

---

[1] Research sponsored by the Biofuels Systems Division, U.S. Department of Energy under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corp.
[2]Biofuels Feedstock Development Program, Environmental Sciences Division, P.O. Box 2008, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6422 and Oak Ridge Institute of Science and Education, Oak Ridge, TN 37831, respectively.

---

[1]Research sponsored by the Biofuels Systems Division, U.S. Department of Energy under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corp.
[2]Biofuels Feedstock Development Program, Environmental Sciences Division, P.O. Box 2008, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6422.
[3]Oak Ridge Institute of Science and Education, Oak Ridge, TN 37831

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DISCLAIMER

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

## INTRODUCTION

Short-rotation woody crops (SRWC) and perennial grasses, when used as biomass feedstocks for energy and fiber, have the potential to provide multiple economic and environmental benefits. When converted to liquid transportation fuels, directly combusted for production of electricity, or co-fired with fossil fuels as alternative sources of energy, these renewable feedstocks can provide broad-scale environmental benefits by reducing the overall contribution of energy use to global warming. The benefits of using biomass crops to replace conventional fuels can accrue from the global scale (reduction in greenhouse warming) to site-specific (decreases in soil erosion, reduced need for chemicals for production, and improved habitat for native wildlife over traditional agricultural land uses). These benefits vary from region to region because of the differences in feedstock demand, available land, and costs of producing the different biomass crops. However, these benefits are additive both nationally and globally and can help strengthen rural economies in the United States.

In the U.S., meeting projected energy needs using biomass feedstocks could require conversion of tens of millions of hectares of primarily agricultural lands to production of dedicated feedstocks (Ranney and Mann 1994). Production of biomass crops is not seen as competing for land with traditional row crops, e.g., corn and soybeans. Rather, they are alternative perennial crops that can be grown on lands where erosion is a concern, where soil stabilization is needed, or where the economic returns for farmers can be increased.

The type of land base on which biomass crops are planted will determine their environmental risks and benefits. Economic evaluations of biomass crop production being conducted by the BFDP assume use of land that is currently or recently in cultivation (Graham et al. 1996). Of the 74 million ha of cropland in the U.S. estimated by Graham (1994) as not required for agricultural production, only 16 million ha were in regions well suited for energy crop cultivation. This 16 million ha includes pasture land or croplands currently in long-term set-aside programs. These set-aside lands have been removed from production because they are subject to either wind or water erosion or flooding and are at risk for degradation when used to produce annual crops. The U.S. Department of Energy (DOE) is funding research through the BFDP to address specific environmental questions of soil erosion, nutrient changes and availability, water quality changes, and wildlife habitat that can occur as the result of conversion of current agricultural or set-aside lands to biomass crop production. Research on environmental issues associated with SRWC is paralleling research to develop genetically improved clonal tree stocks and identify tree physiology appropriate to different regions.

## APPROACH

The BFDP has increased emphasis on environmental studies over the past three years as development of both SRWC and herbaceous crops has progressed. Large-scale production trials and commercialization of woody crops for pulp fiber has increased the opportunities and need to address environmental questions associated with conversion of agricultural and fallow lands to biomass crop production. Current research is addressing questions of how both planting scale and crop maturation affect various environmental parameters on research sites ranging from less than one hectare to several hundred hectares.

Wildlife habitat studies are being conducted in several regions of the U.S. while erosion, soil nutrient, and water quality studies are currently limited to a few sites in the northcentral and southeast states-- regions of the U.S. with the greatest potential for biomass crop production. Research across regions with differences in current land use, climate, soils, rainfall, temperature, and topography will insure that theses factors are considered in determining locations for future biomass crops and management practices for their production.

Emphasis on collaborative studies with industry is offering opportunities to address environmental questions at different scales. These studies are focusing at a research-scale on subsurface movement of water and fertilizer, and on alternative nutrient sources to maximize production. At a larger landscape scale, questions of how biomass plantings can be located and sized to maximize habitat for wildlife are being addressed on existing plantings of widely different acreages, ages, tree species, and land use contexts.

Site-specific environmental studies of biomass crop production are providing the information needed to evaluate the environmental and economic impacts of biomass production at both local and regional scales. The information from these studies can be incorporated into regional analyses to help identify the best locations for biomass crops to increase their environmental benefits and to enhance sustainability.

## PROJECT DESCRIPTIONS AND RESULTS

The environmental studies currently funded independently by the U.S. DOE or in collaboration with the Tennessee Valley Authority or with private industry include studies on wildlife diversity, changes in soil characteristics, chemical fates in surface and ground water, and application of residues as soil amendments.

### Diversity of Breeding Birds and Small Mammals

Studies of wildlife use of biomass plantings were first funded by the U.S. DOE in 1992. These studies in the north-central U.S. (Minnesota, Wisconsin, and South Dakota) were conducted in eight 4-8 ha (10-20 acre) hybrid poplar (*Populus*) trials. Christian et al. (1994) found avian abundance and species richness to be consistently higher in these 4-5 year old hybrid poplar plantings than in rowcrop or small grain fields. However, use of these plantings was more similar to that of forests than to crop lands. Few differences in small mammal abundance and diversity were found between the poplar plantings and row crops. The absence of ground cover was the single most important factor in reducing the abundance of small mammals using plantings compared with hay/pasture lands and grain crops. Both birds and small mammals used plantings in open landscapes of agricultural settings more extensively than those in more forested areas. Little overall change in the biodiversity of birds and small mammals was projected if annual row crops or small grain fields were replaced with hybrid poplar plantings (Christian et al. 1994).

Wildlife studies in the north-central U.S. entered a second phase in 1994 and 1995 with the establishment of larger-acreage plantings of hybrid poplars in 20 to 140 ha (50 to 350 acre) blocks within a 60-km (50-mile) radius of Alexandria, Minnesota. These plantings and the smaller research plantings discussed above are being used to identify wildlife habitat and landscape context at individual farm scales and across the broader landscape. Results from these larger blocks are showing that open habitat bird species, such as killdeer (*Charadrius vociferus*), horned lark (*Eremophila alpestris*), vesper (*Pooecetes gramineus*) and savannah (*Passerculus sandwichensis*) sparrows , and red-winged blackbirds (*Agelaius phoeniceus*), dominate these 1-2 year old plantings. However, these plantings were found to experience high species turnover rates which are indicative of bird community instability (Hanowski and Niemi 1996). More vegetatively heterogeneous sites, as the result of weediness or failed tree clones, had more bird species present. Early-successional species such as common yellowthroat (*Geothlypis trichas*), clay-colored sparrow (*Spizella pallida*), song sparrow (*Melospiza melodia*), and American goldfinch (*Carduelis tristis*), were found to be most common on sites of 3 to 5 years of age.

Avian studies have shown that birds use more mature plantings in a manner similar to natural forests (Hoffman et al. 1995, Beyea et al. 1996). Hoffman et al. (1995) found in Oregon that breeding birds used hybrid poplar plantings more extensively than fall migrants and that the use of these plantings peaked following canopy closure. In Minnesota, Hanowski and Niemi (1996) found that the similarity between bird species occupying hybrid poplar plantings and surrounding forests increased as the maturity of the plantings increased.

A wildlife study began in the Southeast in 1996 as a collaborative effort with an industrial partner on their existing production lands. Breeding bird surveys in 1996 and 1997 across a broad array of site characteristics in southeastern Virginia and northeastern North Carolina are addressing differences in use of plantings of sweetgum (*Liquidambar styraciflua* L.), sycamore (*Plantanus occidentalis* L.), and naturally regenerating hardwoods of (1) different ages (5 and 20 years) and (2) acreages [small (3 - 16 ha or 7 - 40 acres) or large (30 - 120 ha or 75 - 300 acres)]. These studies are also addressing how the location of the sites in the existing landscape (e.g., adjacent to agricultural lands, pine plantings, natural regeneration, or wetlands) affects use by breeding birds. Use of interiors of the plantings vs. edge by breeding birds is being compared to determine if there are differences. Information from this study will be used to identify how plantings can be located and sized to maximize habitat for breeding birds. These studies will help the BFDP determine the cumulative effects of extensive plantings of SRWC on breeding birds as indicators of effects on wildlife populations in general, and to help address how plantings can be used to maximize habitat value, particularly for species of concern. The information on acreage, location, and landscape context can provide direction to both the BFDP and industry in identifying management strategies that maintain productivity while enhancing biodiversity.

Soil Nutrient and Water Quality Studies

Research projects in the North-central and Southeastern U.S. are addressing soil nutrients and water quality changes associated with conversion of agricultural and set-aside lands to biomass crop production. Research, funded cooperatively by the BFDP and the Tennessee Valley Authority (TVA), began in 1995 at universities in Alabama, Mississippi, and Tennessee to quantify erosion, surface water runoff, and chemical movement from annual row crops, switchgrass, and tree crops both with and without a groundcover at a research-site scale (0.2 - 0.4 ha or 0.5 - 1 acre) (see also Thornton et al.1996 and Green et al. 1996). This study is also identifying changes in soil resources associated with conversion of agricultural lands to perennial tree or grass crops. Resource characteristics being addressed include below-ground storage of nutrients and agrochemicals, carbon sequestration, and changes in soil physical properties. Results show that during the first year of crop establishment there was little difference in runoff or sediment loss among the four crop treatments. Most of the total runoff volume occurred during a few runoff events (Thornton et al. 1996). With development of canopy cover and a buildup of a litter layer, there were dramatic differences in sediment transport between the cotton crop (2.0 Mg) and the cottonwoods (0.08 Mg) in Mississippi in response to a 41 mm (1.6 in) rainfall event (Thornton et al. 1996). Greater nutrient loss in surface water runoff from the row crop plots (corn or cotton) during establishment was attributed to fertilization of these crops compared with no fertilization of the switchgrass and tree crop treatments during establishment (Green et al. 1996). The Alabama study is also addressing the effects of different cover crops (both winter annuals and growing season perennials) on soil movement and tree growth (Malik et al. 1996). The results to date show that during the first year all cover crops reduced growth of the sweetgum plantings but that there were no detectable differences among treatments in the volume of sediment leaving the sites.

Several additional studies have been initiated in 1996 to address the potential effects and benefits for soil and water quality from conversion of agricultural crops to biomass crop production. These studies are addressing these questions within different regions of the U.S. with the greatest potential for biomass crop production to insure that biomass crops are produced in a manner which enhances environmental sustainability. A study in Minnesota is addressing movement of nutrients and herbicides through soils and their potential for groundwater contamination. This study will compare subsurface movement of chemicals from switchgrass, hybrid poplar plantings (with and without a cover crop), and an agricultural crop (corn or wheat). In addition, soil characteristics of the sites prior to tree crop establishment will be compared with those after five years of tree growth to address whether perennial biomass crops can increase soil nutrient retention and carbon sequestration compared with production of agricultural crops. Like the studies in the southeastern U.S., the Minnesota study is being established on a site with a soil type and topography typical of those where biomass crops are most likely to be grown in the region.

A watershed-scale research project is currently being established on a 1,600 ha (4000 acre) production site located on the coastal plain of South Carolina in cooperation with a forest products industry partner. This study will address water quality effects of large-scale production of biomass crops on surface water quantity and quality, soil erosion, and subsurface transport using replicated study plantings within the confines of a 12 ha (30 acre) watershed. This study builds upon the three-site research-plot [0.2 - 0.4 ha (0.5 - 1 acre)] study discussed above. This larger-scale research project will allow a comparison of production-scale and research-scale results to identify the ability to use research-scale results to predict the environmental effects of establishment of biomass crops on a variety of sites in the southeastern U.S. This information can also be used by the forest products industry to address questions regarding sustainability of high intensity forestry with respect to site productivity and water quality.

A cooperative research effort between the BFDP and a forest products industry is addressing productivity of clones of several short-rotation woody crop species [sweetgum, sycamore, and cottonwood (*Populus*)] under different fertilization and irrigation regimes. The research site (approximately 10 ha or 24 acres) was established in 1995 on former agricultural land on the South Carolina coastal plain. Tension lysimeters located at 0.5, 1.0, and 2.0 meter depths on individual plantings and wells to groundwater (approximately 5 meters) are being used to monitor soil water and nutrient movement associated with the different treatments. This study provides an opportunity to address the potential for movement of chemicals into groundwater beneath intensively managed biomass plantings under different irrigation regimes and to identify measures to minimize potential nutrient migration.

A study, jointly funded by the BFDP and the National Council for the Pulp and Paper Industry for Air and Stream Improvement (NCASI) at the same production site in South Carolina, is addressing nutrient availability from paper mill residues and agricultural residues. The study is addressing the addition of paper mill residues as soil amendments either alone or in combination with lime to raise the pH of the soil (pH < 5.5) one or two units to determine the optimum pH for production of biomass crops on sandy coastal plains soils. The study is also addressing the use of agricultural residues in combination with mill residues to increase the water-holding capacity of well-drained soils (e.g., Norfolk) and as soil amendments to provide short-term nutrient (primarily nitrogen) sources to complement the slower release of nutrients from the mill residues. This study will determine if mill and agricultural residues can be used either alone or combined to enhance productivity while minimizing the potential for subsurface migration of chemicals including sodium and heavy metals from the mill residues and nutrients from the mill and agricultural residues. Soil and groundwater sampling will identify the potential buildup of nutrients, e.g., potassium and phosphate, in the soil at application rates necessary to provide the desired levels on nitrogen. Daliparthy et al. (1996) emphasized the importance of matching the amounts of residues applied to the nutrient requirements of the receiving crop to insure that nutrients are taken up by the crop rather than being lost to either surface or groundwater. Research to match soil types, biomass crop type, and nutrient needs and application rates is essential to maximizing production and minimizing potential soil and water quality impacts.

## DISCUSSION

Avian studies have shown that birds use more mature plantings in a manner similar to natural forests (Hoffman et al. 1995, Hanowski and Niemi 1996). Although Christian et al. (1994) concluded that there appeared to be no negative habitat effects for birds and small mammals from including biomass tree crops in the landscape, it is important to remember that different animal species have different environmental requirements and that the positive habitat provided for some species by including trees or switchgrass in the landscape may be a negative factor for other species. For example, placement of short-rotation tree plantings within the agricultural landscape in prairie landscapes of the north-central region of the U.S. may interfere with the broad skyline expanse required by species such as the sharp-shinned grouse (a species experiencing severe decline in numbers). This interference may be particularly during their breeding season as the tree crops mature to a taller, more closed canopy and provide a larger, more extensive presence on the horizon. Studies of wildlife use of both SRWC and perrenial switchgrass plantings as these crops move from the research scale to the demonstration scale and results from commercial scale operations of different acreages, ages, and landscape contexts can provide answers to questions from producers, researchers, environmental groups, the public, and industry on how biomass plantings can be located within the landscape on both local and regional scales to benefit wildlife while providing economically vaible production of biomass crops.

Studies of changes in soil nutrient and physical characteristics with conversion of agricultural croplands to biomass production and during SRWC rotation will allow the BFDP, researchers, and industry to assess the environmental effects of biomass crops produced on different principal soil types. Information gained from these studies can be used to match tree species to specific sites to maximize productivity while providing environmental benefits at both local and regional scales. This information can also provide guidance on the need for nutrient addition and sources, amounts, and timing of either commercial or alternative nutirent sources to enhance productivity while minimizing the potential for water quality degradation. Addressing environmental questions as research continues to develop both SRWC and perennial grass crops offers the opportunity to identify and incorporate environmental benefits for individual producers and the public with minimal economic cost as these crops are deployed across the landscape.

## REFERENCES

Beyea, J., W. Hoffman, J. H. Cook. 1996. Vertebrate species diversity in large-scale energy crops and associated policy issues. Annual Progress Report 1995. National Submitted to Biofuels Feedstock Development Program, Oak Ridge National Laboratory, Oak Ridge, TN.

Christian, D. P. 1996. Small mammal usage of hybrid poplar plantation. Annual Progress Report 1995. University of Minnesota, Duluth. Submitted to Biofuels Feedstock Development Program, Oak Ridge National Laboratory, Oak Ridge, TN.

Christian, D. P.; G. J. Niemi; J. M. Hanowski; and P. Collins. 1994. Perspectives on biomass energy tree plantations and changes in habitat for biological organisms. Biomass and Bioenergy 6(1/2):31-39.

Daliparthy, J., S. J. Herbert, T. Akin, and B. O'Toole. 1996. Best nutrient management practices on watersheds to protect water quality in Massachusetts. p. 203-208. In W. Lockeretz. Environmental Enhancement Through Agriculture. Tufts University, Medford, MA.

Graham, R. L. 1994. An analysis of the potential land base for energy crops in the conterminous United States. Biomass and Bioenergy 6(3):175-189.

Graham, R. L., M. E. Downing, M. E. Walsh. 1996. A framework to assess the regional enviornmental impacts of dedicated energy crop production. J. Environmental Management. In Press.

Green, T. H.; G. F. Brown; L. Bingham, D. Mays; K. Sistani. 1996. Environmental impacts of conversion of cropland to biomass production. Alabama A& M University. Annual Progress Report. Submitted to Biofuels Feedstock Development Program, Oak Ridge National Laboratory, Oak Ridge, TN.

Hanowski, J. M. and G. J. Niemi. 1996. Bird usage of hybrid poplar plantations. Annual Progress Report 1995. Submitted to Biofuels Feedstock Development Program, Oak Ridge National Laboratory, Oak Ridge, TN.

Hoffman, W., J. Beyea, and J. H. Cook. 1995. Ecology of agricultural monocultures: Some consequences for biodiversity in biomass energy farms. In Proceedings of the Second Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry. Portland, Oregon. NREL/CP-200-8098. National Renewable Energy Laboratory, Golden, Colorado. pp. 1618-1627.

Hohenstein, W. G. and L. L. Wright. 1994. Biomass energy production in the United States: An overview. Biomass and Bioenergy 6(3):161-173.

Malik, R. K., T. H. Green, D. Mays, B. R. Bock, J. D. Joslin, F. C. Thornton, V. R. Tolbert, G. F. Brown, and K. Sistani. 1966. Using clover crops for erosion control in bioenergy hardwood plantations. IN Proceedings of the Bioenergy'96 Conference. Nashville, Tennessee.

Ranney, J. W. and L. K. Mann. 1994. Environmental considerations in energy crop production. Biomass and Bioenergy 6:211-228.

Thornton, F. C., T. H. Green, J. D. Joslin, A. Houston, B. R. Bock, S. Schoenholtz, D. D. Tyler, and D. Pettry. 1996. Environmental impacts of converting cropland to short-rotation woody crop production: first year results. IN Proceedings of the Bioenergy96 Conference. Nashville, Tennessee.

Tolbert, V. R. and A. Schiller. 1996. Environmental Enhancement Using Short-Rotation Woody Crops and Perennial Grasses as Alternatives to Traditional Agricultural Crops. In

W. Lockeretz (ed.) Environmental Enhancement Through Agriculture. Nov. 1995, Tufts University, Medford, MA. pp. 209-216.

## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.