European Bioenergy Conf.
6/28/02
Amsterdam
The Netherland
invited
published in
proceedings

ENVIRONMENTAL SUSTAINABILITY OF DEDICATED BIOENERGY FEEDSTOCKS: SUMMARY OF RESEARCH RESULTS

Virginia R. Tolbert
Bioenergy Feedstock Development Programs, *Oak* Ridge National Laboratory
P.O. Box 2008, *Oak* Ridge, TN 37831, tolbertvr@ornl.gov

ABSTRACT: Dedicated woody and herbaceous crops in the have the potential to provide significant energy resources. Determining the environmental sustainability of these crops prior to their wide-scale deployment is essential for acceptance of these crops by various stakeholder groups. Specific environmental studieswere initiated in 1995 in conjunction with woody and herbaceous research plot and field trial studies across potential production regions of the U.S. Land conversion to woody and herbaceous species were shown to provide soil and water quality benefits across a variety of soil types. Site management practices were important in decreasing runoff, sediment losses, and nutrient transport compared with traditional agricultural crop production. Soil quality parameters and soil carbon storage improved over time with conversion to biomass crop production. Across the spectrum of sites, initial gains in soil carbon were found to be greater at shallow depths (0-10 cm) and in lower organic soils. Timing of application and matching fertilization rates with crop requirements were critical to minimizing off-site transport of nutrients. Efficient water use by the dedicated feedstocks was shown to retain nutrients within the rooting zone and leaching of applied herbicides did not occur. Studies of soil sustainability with potential corn stover removal for ethanol production begun in 1999 are continuing. Biomass crops provide landscape diversity and were shown to provide habitat for wildlife. The data from these studies are providing the initial foundation for U.S. documentation of practices that can maximize environmental quality and minimize risks to ensure environmentally sustainable production of dedicated energy crops.
Keywords: sustainability, environmental effects, soil quality, water quality, biodiversity

1 BACKGROUND

Environmental research became a specific part of the BFDP's feedstock development mission in the mid-1990s. The focus of the researhc was to address questions of environmentally sustainable production of dedicated feedstocks being raised by researchers, the public, and environmental groups. The need to address environmental issues in parallel with crop development, rather than waiting untii production technologies were developed and environmental issues became potential "show stoppers" was recognized. Environmental issues raised by individuals and environmental groups as well as within the National Bioenergy Roundtable and the Northeastern and Southeastern Regional roundtable discussions centered around concerns of adding other "monoculture" crops into agricultural landscapes, their effects on natural plant and wildlife diversity, and their effects on soil and water quality (Cook and Beyea 2000).

Walsh et al. (1999) projected that approximately 6.9 million hectares would be required to meet the demands of 79 million dry tons of feedstocks for production of 1.25 quads of energy. With the documentation of this substantial land use requirement, it became even more important to identify benefits, potential concerns, and any mitigation measures necessary to ensure the environmentally sustainable production of biomass crops. While the economic potential of dedicated energy crops is not a current reality in the U.S., quantifying environmental benefits early in the process may contribute to their value for energy and site quality in the future (McLaughlin et al. 2002). Ugarte de la Torre and Walsh (2002) determined that policy changes will be required for full economic valuation of energy crops; changes that could also contribute to further valuation of environmental benefits for soil and water quality.

Environmental studies conducted through the U.S. Department of Energy's Bioenergy Feedstock Development Program (BFDP)have focused on identifying the potential benefits and impacts of the different energy crops. Biomass crops currently are not economically competitive with traditional crops such as corn and soybeans on more highly productive soils, large-scale production of dedicated energy crops is expected to be more prevalent on more erosive or more marginally productive lands. Production of perennial biomass crops, particularly on more erosive lands has the potential to provide soil and water quality benefits in addition to feedstock supplies (Smith, 1995; Tolbert et al., 1997, Grigal and Berguson, 1998, Mann and Tolbert 2000). The potential for environmental impacts from site preparation and production is greater and the yields potentially less than on more productive agricultural lands. However, the greatest environmental gains and benefits, especially in soil quality and carbon storage with land use conversion to dedicated biomass crops are expected on these lands (Mann and Tolbert 2000, Tolbert et al. 2002). For removal of corn stover, the major questions are associated with erosion and loss of soil quality, particularly soil organic matter (Mann et al. 2002).

The environmental studies reported here were designed to determine management measures that can minimize both on-site and off-site effects, e.g., erosion and chemical transport, and maximize the environmental potential and sustainability of biomass crop production for energy, bio-products, and fiber.

2 RESULTS **AND** DISCUSSION

Site-specific environmental studies for dedicated energy crops were established in 1995-1997 in response to the identified need for environmental data on production of hybrid poplar and switchgrass in the mid-West and sweetgum, cottonwood, and sycamore in the Southeast. Studies were designed to answer questions and concerns of surface and groundwater contamination, soil losses, nutrient movement, and losses of biodiversity with large-scale production of biomass crops across different regions of the U.S.

Water Quality

Side-by-side plantings of hybrid poplar, switchgrass, and an agricultural crop (wheat) were used by University of Minnesota researchers to compare subsurface movement of applied chemicals. Herbicide movement from the energy crop plantings did not occur nor did movement of nutrients below the rooting zone. Comparison plantings of hybrid poplar and adjacent natural forests were used to determine water use efficiency and nutrient transport. Greater water use efficiency by the faster growing poplars resulted in less nutrient movement from the poplar plantings than from the older natural forests (Perry et al. 2001).

Comparisons of soil frost and snow accumulations in open fields, hybrid poplar stands, and native forest in Minnesota were made during the winters of 1999-2000 and 2000-2001. Snow accumulations were greatest under natural forest stands and the switchgrass plots, lowest in open agricultural fields, and intermediate for the hybrid poplar stands. Soil frost was the deepest in the open fields and was less in the hybrid polar, natural forest and switchgrass sites. Importantly, concrete frost occurred in the open fields, but under the hybrid poplar and natural forest stands, the frost was of a porous nature. The implications are important for snowmelt runoff in the springtime, in which hybrid poplar stands do not exhibit as much surface runoff as from cultivated fields (Christopherson 2002). In the Red River watershed in northern Minnesota, production of hybrid poplar for energy and fiber can also contribute to water quality and quantity protection to provide environmental benefits.

In the Southeast, chemical transport from cottonwood in Mississippi, sweetgum and switchgrass in Alabama, and sycamore in Tennessee was compared with agricultural crops. These comparisons showed that in the years after the initial year of establishment nutrient movement from the perennial tree crops was less than from the annual agricultural crops (Green et al. 1996, Thornton, et al. 1998, Tolbert et al. 2000). These comparisons have allowed identification of management modifications such as selection of appropriate cover crops (e.g., crimson clover) during establishment that can minimize erosion **as** well **as** contribute to nutrient availability. The southeast studies showed that those agricultural crops produced using no-tillage practices also provided greater nutrient retention capacity that traditionally tilled crops. Both the Minnesota and southeastern studies concluded that nutrient movement through the soil was less for the faster growing woody crops because of the more extensive perennial rooting systems which provided greater soil penetration and nutrient uptake.

In South Carolina nutrient movement from both sycamore and sweetgum with and without water level management was compared at field (20-40 ha) production scales. Increasing concentrations of nitrate, calcium and magnesium in soil water seen over the first four years was indicative of increased leaching of applied nutrients with rainfall. The combination of the results from these studies as well as meta-analyses conducted by Johnson and Curtis (2001) show that timing and matching the amounts of fertilizer application with specific tree crop requirements in conjunction with subsequent rainfall timing and amounts are critical to minimizing off-site transport of nutrients. Demonstrating the need for matching nutrient application rates with crop requirements to minimize nutrient transport and water quality protection provides the opportunity not only for

Soil Quality

Determining whether changes in soil quality - increases in soil carbon pools, soil organic matter, soil stability, and ultimately nutrient use efficiency - can occur with production of both woody and herbaceous energy crops are important components of both environmental and crop development research (Mann and Tolbert 2000). Studies in the upper mid-West and southern U.S. have shown that increases in soil carbon and soil organic matter accumulation on sites converted from annual agricultural crops to energy crop production vary according to soil type, initial organic matter content, and crop type. The greatest increases in soil carbon are being observed on soils that are lower in initial organic matter and carbon content (Ma et al. 2000, Garten and Wulschleger 1999, Tolbert et al. 2002, Isebrands and Coleman 2002). The initial increases in soil carbon were most pronounced in the upper few centimeters from surface and shallow organic matter incorporation and turnover. With increasing time, considerable increases in soil carbon have been observed at greater depths under switchgrass (Ma et al. 2000, Garten and Wulschleger 1999) and on woody crop sites where cover crops were established to minimize soil erosion during initial establishment and growth (Tolbert et al. 2002). These results provide important input to verify for stakeholders that bioenergy crops can contribute to site quality through improvements in soil quality.

The Minnesota soil quality/soil carbon project addressed the potential to develop agroforestry and riparian management alternatives that include use of hybrid poplar, hybrid willow, native cottonwood and willow, and switchgrass in flood-prone areas as measures to reduce non-point pollution compared to current agricultural crop management practices in the Minnesota River basis. This ongoing study is helping to develop management practices/options for farmers and resource managers that can increase the potential for and value of biomass crops as alternative **crops** within **a** river basin and provide environment benefits for both soil stability and water quality protection.

In 2000, DOE's Office of Transportation Technologies began to focus more on the short-term goal of producing ethanol from corn stover. The BFPD conducted an initial review of the effects of stover removal on soil quality as background for identifying specific questions to be addressed (Mann et al.. 2002). The BFDP has been working with the USDA Agricultural Research Service at five sites in the mid-western U.S. to determine the environmental implications and sustainability of harvesting corn stover for ethanol production (Wilhelm 2001). These studies are addressing how soil quality, soil carbon, soil organic matter accumulation, and soil stability would be effected both short- and long-term by varying percentages of corn stover removal. The overall goal of these studies is to determine whether stover removal is compatible with soil quality and sustainability. Questions of both water and wind erosion of soils and volatilization of carbon from the soil surface with different cultural and removal practices are being addressed. These data are providing initial input to a life-cycle analysis of biomass ethanol production from corn stover. Determining the effects of stover removal on **soil** quality will **help** identify on soil and water quality. The field research studies and ongoing life cycle analysis for ethanol production from corn stover will ultimately to provide guidance on sustainable practices for stover removal for ethanol production to minimize soil carbon and erosion impacts.

Biodiversity

Biodiversity questions raised early in consideration of energy crops as dedicated feedstocks focused on whether these bioenergy crops could provide habitat for wildlife and increase biodiversity or whether these crops would be just other "monoculture" crops and traps for wildlife. Questions were whether the habitat provided by these crops would be better than that of annually harvested agricultural crops, would be traps for wildlife, or whether they would be used similarly to natural prairies or forests (Ranney and Mann 1994, Cook and Beyea 2000). Studies in the early 1990s showed woody crops provided breeding bird habitat (Hoffman et al. 1995) and that woody crops were used more extensively than agricultural crops but use was not equivalent to natural forests (Christian et al. 1994, Hanowski and Niemi 1997). Later studies (1996-98) compared plantings and natural forest patches of similar sizes and ages and determined that both supported greater species diversity when young and were used by similar species assemblages when mature (Schiller et al. 2002). Comparison of the effects of harvesting and management practices for switchgrass on breeding bird diversity has shown that both harvested and unharvested switchgrass provided habitat for a variety of species including species of concern (Sample 1989). Current studies of switchgrass habitat quality and use by wildlife are being conducted on larger-scale plantings established to provide feedstocks for large-scale testing of energy use potential in Iowa.

3 CONCLUSIONS

Many of the studies both completed and in progress, while dealing with either woody or herbaceous crops or in some instances both crops, provide data upon which to base cross-cutting conclusions for establishment, management, and ultimately harvesting practices that can be beneficial to both energy crops. These data may also provide guidance to the studies of corn stover removal to identify areas where the greatest potential for soil quality from residue accumulation/retention lie. The BFDP has been actively engaged with a variety of environmental groups and other stakeholder groups (e.g., Peelle 2002) and government organizations to help ensure that appropriate issues continue to be addressed and that the information from the ongoing research is available to them. Identification of issues and dissemination of results is an interactive process that must remain such to identify how energy crops and residues can be sustainably produced and harvested as energy feedstocks. Identifying sustainable practices can help ensure protection of soil and water quality and biodiversity and responsiveness to concerns of environmental, agricultural, and other stakeholder groups.

As the BFDP summarizes and draws twenty-two years of feedstock research and ten years of environmental research to a close, the experience gained and the results obtained to date have provided initial representatives of various environmental, agricultural, and other appropriate stakeholder groups will determine whether data have answered questions raised and what data are yet needed/requested for broad-based support of intensively managed biomass crops to occur. The results of the 1995 conference the BFDP held in Oak Ridge "What we know, and what do we need to know?" and the ensuing research have been revisited to be sure that we have addressed environmental concerns, have conducted appropriate research, and have identified key concerns remaining. Based on the ongoing data summary, we will be able to determine key issues remaining and what will be required to proactively obtain the data necessary to increase the environmental benefits of bioenergy feedstocks. The existing data on soil and water quality benefits and habitat creation/availability and the identified areas where data are required can feed into decisions about which crops and where individual crops can best be established to increase environmentally and economically sustainability production. Integration of these environmental data with results of economic models can ultimately provide support for decisions about locations, yields, costs, and economic returns to ensure that biomass crop production is environmentally sustainable across the range of soils, climates, and regions with identified production potential.

4 ACKNOWLEDGEMENTS

The contributions of Bioenergy Feedstock Development Program contractors W.E. Bandaranayate, D.I. Bransby, T.H. Green, D.A. Mays, F.C. Thornton, B.R. Bock, J.D. Josh, A.E. Houston, D.D. Tyler, D.E. Pettry, C.C. Trettin, K.E. Brooks, C.F. Perry, J. Christopherson, J.G. Isebrands, M.D. Coleman, W.E Berguson, D.P. Christian, J.M. Hanowski, G.J. Niemi, W. Hoffman, J. Beyea, J.H. Cook, A. Schiller, J. Lindberg, W. Wilhelm, J. Schepers, S.D. Wullschleger, C.C. Trettin, and C. Jawdy are gratefully acknowledged. The research reported was supported by the **U.S.** Department of Energy's Biofuels Systems Division under contract DE-AC05-00OR22725 with UT-Batelle, LLC.

5 REFERENCES

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

Christopherson, J.A. 2001. Hybrid poplar plantation effects on frost depth and snow deposition on agricultural lands in northwestern Minnesota. Master's Thesis. University of Minnesota, St. Paul.

Cook, J.H. and Beyea, J. 2000. Bioenergy in the United States: progress and possibilities. Biomass and Bioenery 18(6):441-455.

de la Torre Ugarte, D.G. and Walsh, M.E. 2002. Synergism between agricultural and energy policy: the case of dedicated bioenergy crops. Southern Ag. Econ. Assoc. Annual Meeting, Orlando, FL, February 2-5, 2002.

Measurement limitations. J. Environ. Quality 28(4):1359-1365.

Green, T.H., Brown, G.F., Bingham, L. Mays, D. Sistani, K., Josh, J.D., Bock, B.R., Thornton, F.C., and Tolbert, V.R. 1996. Environmental impacts of conversion of cropland to biomass production. Proc. Bioenergy '96 - The 7th National Bioenergy Conference, pp 918-924, Nashville, TN. Southeastern Regional Biomass Energy Program.

Grigal, D.F. and Berguson, W.E. 1998. Soil carbon changes associated with short-rotation systems. Biomass and Bioenergy 14:371-377.

Hanowski, J.M. and Niemi, G.J. 1997. Bird use of hybrid poplar plantations. Report to **U.S.** Forest Service and U.S. Department of Energy. NRRI/TR-97/01.

Hoffman, W., Beyea, J. and Cook, J.H. 1995. Ecology of agricultural monocultures: some consequences for biodiversity in biomass energy farms. In Proc. 2nd Biomass Conf. Of the Americas: Energy, Environment, Agriculture, and Industry. Portland, OR. NREL/CP-200-8098, pp. 1618-1627. National Renewable Energy Laboratory, Golden, CO.

Isebrands, J.G., and Coleman, M.D. 2001. Annual report to U.S. Department of Energy's Bioenergy Feedstock Development Program.

Johnson, D.W., and P.S. Curtis. 2001. Effects of forest management on soil carbon and nitrogen storage: Meta Analysis. For. Ecol. Management. 140:227-238.

Ma, Z., Wood, C.W., Bransby, D.I. 2000. Carbon bynamics subsequent to establishment of switchgrass. Biomass and Bioenergy 18(2):93-104.

Mann, L.. Tolbert, V., and Cushman, J. 2002. Potential environmental effects of corn (*Zea mays* L.) stover removal with emphasis on soil organic matter and erosion: a review. Ag., Ecosystems and Environ. 1752(2001): 1-18.

Mann, L.K. and Tolbert. V.R. 2000. Soil sustainability in renewable biomass plantings. Ambio 29(8):492-498.

McLaughlin, S.B., De La Torre Ugarte, D.G., Garten, C.T., Jr., Lynd, L.R., Sanderson, M.A., Tolbert, V.R., and Wolf, D.D. 2002. High-value renewable energy from prairie grasses. Env. Sci. & Tech. 36(10):2122-2129.

Peelle, E.B. 2002. Bioenergy stakeholders see parts of the elephant. Bioenergy 2002, September, 23-25, 2002, Boise, ID.

Perry, C.H., Miller, R.C., Brooks. K.N. 2001. Impacts of short-rotation hybrid poplar plantations on regional water yield. Forest Ecol. Management 143(2001):143-151.

Ranney, J.W. and Mann, L.K. 1994. Environmental considerations in energy crop production. Biomass and Bioenergy 6(3):211-228

Sample, D. 1989. Grassland birds in southern Wisconsin: habitat preference, population trends, and response to land use changes. M.S. Thesis, University of Wisconsin, Madison, **WI.**

Schiller, A., Cresko, W.A., Lindberg, J.E., Tolbert, V.R. Bird communities on intensively managed forests from planting to harvest in the southeastern United States. Submitted.

Smith, C.T. 1995. Environmental consequences of intensive harvesting. Biomass and Bioenergy 9:161-179.

Thornton, F.C., Josh, J.D., Bock, B.R., Houston, A., Green, T.H., Schoenholtz, S., Pettry, D. and Tyler, D.D. 1998. Environmental effects of growing woody crops on agricultural land: first year effects on erosion and water quality. Biomass and Bioenergy 15:57-69.

Tolbert, V.R., Lindberg, J.E., Green, T.H., Malik, R. Bandaranayake, W.E., Josh, J.D., Thornton, F.C., Tyler, D.D., Houston, A.E., Pettry. D. Schoenholtz, S., Bock, B.R., and Trettin, C.C. 1997. Soil and water quality implication of production of herbaceous and woody energy crops. pp. 195-206. Proc. International Workshop on Environmental Aspect of Energy Crop Production, International Energy Agency Bioenergy Liquid Biofuels Activity and Lignocellulosic Solid Fuels Activities, Brasimone, Italy, October 9-10, 1997.

Tolbert, V.R., Thornton, F.C., Josh, J.D., Bock, B.R., Bandaranayake, W.E., Houston, A.E., Tyler, D.D., Mays, D.A., Pettry, D.E, Green, T.H. 2000. Increasing below-ground carbon sequestration with conversion of agricultural lands to production of bioenergy crops. NZ J Forestry Sci. 30(1):138-142.

Tolbert, V.R., Todd, D.E., Mann, L.K., Jawdy, C.M., Mays, D.A., Malik, R., Bandaranayake, W., Houston, **A.H.,** Tyler, D.D., Pettry, D.E. 2002. Changes in **soil** quality and below-ground carbon storage with conversion of traditional crop lands to bioenergy crop production. Environmental Pollution 116:S97-106.

Walsh, M.E., Ince, P.J., de la Torre Ugarte, D. Adams, D. Alig, R., Mills, J. Spelter, H. Skog, K., Slimsky, **S.P.,** Ray, D.E., Graham, R.L. 1999. Potential of short rotation woody crops as a fiber and energy source in the U.S.. pp. 195-206, Proc. 4th Biomass Conf. Of the Americas. Elsevier Science, Ltd, Oxford, UK.

Wilhelm, W. 2001. Implications of using corn stalks as a biofuel source. Annual Report for 2000 submitted to U.S. Department of Energy's Bioenergy Feedstock Development Program.