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ENVIRONMENTAL EFFECTS OF PLANTING BIOMASS CROPS AT LARGER SCALES ON AGRICULTURAL LANDS [1,2]

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Abstract

Increasing from research-scale to larger-scale plantings of herbaceous and short rotation woody crops on agricultural land in the United States has raised questions about the positive and negative environmental effects of farmland conversion. Research currently underway at experimental plot scales enables us examine runoff quality and quantity, erosion, and changes in soil characteristics associated with these energy crops compared to conventional row crops. A study of the fate of chemicals applied to the different crop types will enhance our knowledge of uptake, release, and off-site movement of nutrients and pesticides. Ongoing biodiversity studies in the North Central U.S. allow us to compare differences in scale of plantings on bird and small mammal populations and habitat use. Plantings of 50-100 or more contiguous acres are needed to allow both researchers and producers to determine the benefits of including temporal energy crop rotations in the landscape. Results from these larger-scale plantings will help identify 1) the monitoring requirements needed to determine environmental effects of larger-scale plantings, 2) the best methods to determine the environmental effects of rotation length and the best crop management strategies for full-scale production. Because of the variations in soils, temperature, rainfall and other climatic conditions, as well as differences in the types of energy crops most suited for different regions, monitoring of large-scale plantings in these different regions of the U.S. will be required to predict the environmental effects of regional agricultural land-use shifts for full-scale plantings.

Introduction

Biomass has the potential to provide significant sources of energy and fiber in selected regions of the country while providing both economic and environmental benefits to the agricultural community. To achieve large scale biomass production, tens of millions of hectares of primarily agricultural land will have to be converted to produce large amounts of biomass feedstocks (Ranney and Mann 1994). Because of the variability in climate, soils, and biomass crops that could contribute to large scale biomass production , the environmental effects of converting a broad land base to support biomass production cannot be easily generalized.

Over the past fifteen years, development of both short-rotation woody crops and herbaceous energy crops has moved from small -scale [< 4 ha (< 10 acres)] research plantings of multiple clonal trials per acre to recent demonstration plantings of several hundred acres. Initial studies of the small-scale plantings of these crops indicate that energy crops can provide environmental benefits (e.g., soil conservation, increased biodiversity, and reduced fertilizer runoff) while improving farm income (Wright et al. 1992). Currently available information shows that the environmental effects from conversion of crop land to biomass production may range from negative effects of erosion, habitat destruction, and nutrient runoff during initial site preparation and establishment Hughes and Ranney (1993) to positive effects from decreased long-term erosion, reduced nutrient requirements, increased wildlife habitat, and increased soil stability.

Recent large-scale plantings of switchgrass and hybrid poplar are providing research sites to address the environmental effects of land conversion from traditional row crops and grasslands to dedicated biomass crops at larger scales. Data from these large-scale plantings can be used to determine the accuracy of conclusions drawn from research level plantings of both switchgrass and poplars. Research on genetic improvements of hybrid poplar in the Pacific northwest has lead from small-scale clonal trials (Heilman et al. 1990) to commercial plantings of thousands of acres of hybrid poplar clones in this area; these plantings are serving as fiber sources for the pulp and paper industry in this region. Deployment of new switchgrass clones in additional large-scale plantings can increase production for both warm-season forage and biomass sources over broad regions of the U.S. (McLaughlin et al. 1994).

Moving from research on small experimental plots to large-scale demonstration plantings allows the Biofuels Feedstock Development Program (BFDP) to address questions of scale relative to environmental effects of energy crop production. Currently, data do not exist to determine the accuracy of predictions of the environmental effects of commercial-scale production of biomass crops based on studies of small-scale research plantings. Application of these results to commercial production may not accurately guide crop deployment to maximize environmental benefits. The potential environmental effects being addressed for both short-rotation woody crops and herbaceous energy crops compared to traditional row crops include soil characteristics, erosion, surface and groundwater movement, nutrient requirements, and use of biomass plantings by wildlife. Larger-scale plantings allow validation of research results from region-specific small-scale trials. The information derived from these large-scale plantings can facilitate address of potential effects of wide-spread deployment of biomass plantings as sources of both energy and fiber.

Discussion

Over the past 15 years, research supported by the BFDP has addressed a number of environmental changes that would be expected to occur with conversion from traditional agricultural crops to biomass crops (Wright et al. 1992). Most of these studies have been associated with conversion of agricultural lands to tree crop production and have occurred on small-scale research sites in the Pacific Northwest and the north-central and northeastern states. Many of the studies were designed to address the viability and growth of various poplar clones on homogeneous soils and at close spacings and do not accurately reflect the responses to environmental factors that would be expected to occur with a variety of soil types and under a variety of environmental conditions (Hansen 1991). In addition, these small-scale plantings do not allow adequate characterization of environmental changes (e.g., soil carbon, soil composition, and nutrient availability) that would be expected to occur on sites converted from traditional agricultural crops to either switchgrass or trees.

Studies of small-scale plantings of hybrid poplar in the north-central states (Hansen 1993) showed that over time trees grown on tilled agricultural lands previously in prairie sequestered significant quantities of soil carbon compared to row crops and grasslands. Early soil carbon loss was found to occur during establishing and tending poplar plantings over the first 2-3 years because of initial erosion and soil exposure but with canopy closure and increased tree age (6-12 years) a net addition of soil carbon was found to occur beneath the plantings (Hansen 1993). Soil carbon loss occurred primarily from the top 30 cm of the soil horizon as the result of mineralization. Increases in soil carbon with tree age was most significant at a depth of 30-50 cm; the depth with the greatest root development (Hansen 1993).

Two thousand acres of demonstration plantings of hybrid poplar were established in 1994 and 1995 within 80 km (50 mi) of Alexandria, Minnesota. These large-scale planting [12 to 120 ha (30 to 300 acres)] (Kroll and Downing 1995) provide the opportunity to address questions of scale and logistics of planting and maintenance on a variety of soils and under different environmental conditions. These plantings also provide the opportunity to address environmental questions of soil changes, nutrient requirements, and changes in biodiversity with conversion from agricultural land use to long-term perennial crops at a larger scale for comparison with data from small-scale research sites. For example, studies have been initiated on the large-scale plantings to quantify soil carbon changes over time for comparison with results of the earlier studies of small-scale research sites in the area (Hansen 1993). These studies will allow researchers to determine if there are clonal differences and scale differences in the amount and timing of soil carbon sequestration beneath poplar plantings.

Studies of soil nutrients have shown that with cultivation and cropping of annual crops nutrient loss occurs from denitrification, leaching, accelerated erosion, and nutrient removals at harvest (Heilman 1992). The addition of significant quantities of organic matter to soils by prolific rooting systems of perennial grasses have been shown to improve soil structure, increase water-holding capacity and infiltration through structural and porosity changes, improve nutrient conservation and availability, and decrease soil erosion. Switchgrass varieties have been found by Parrish et al. (1990) to add significant quantities of organic matter to soils following row crops. Bransby et al. (1994) found that as much as 8 metric tons of organic matter were added to the upper 75 cm of southeastern soils. Switchgrass has been found to provide environmental benefits by requiring approximately half the nitrogen of a representative agricultural crop (corn) as well as normally requiring herbicide application only during the establishment year (McLaughlin et al. 1994). Using fertilizer application rates, crop nutrient use, land quality, and erosion models, Graham and Downing (1995) projected that conversion of row crops to switchgrass improved water quality associated with both reduced contributions to groundwater and reduced soil erosion and evapotranspiration.

The Department of Energy through the BFDP began studies in 1995 to develop the initial comprehensive data on the fate of chemicals applied to herbaceous crops and tree crops both with and without cover crops for comparison with a traditional agricultural crop. These studies, one conducted in Minnesota; the other in Alabama as part of a three state southeastern project directed by the Tennessee Valley Authority will quantify movement of nutrients and herbicides applied to energy crops into the soil and groundwater beneath research-scale sites. The southeastern study is also addressing the volume and chemical composition of surface water runoff from switchgrass, corn, and tree crop plantings (0.5 and 1 acre bermed sites) with and without a ground cover to quantify erosion and nutrient movement above ground as well as through the soil. These research projects will provide information on uptake, release, and off-site movement of nutrients and pesticides and will help predict the hydrologic and environmental pathways of chemicals applied to energy crops and the long-term effects of energy crop systems on the environment. The data on surface water movement will be used by ongoing efforts by the BFDP to model surface water movement at a watershed scale.

Energy crops offer opportunities to increase biodiversity in agricultural landscapes, particularly in areas where forest and prairie grassland fragmentation is extensive. How large a role these crops can play has been an area of active research on small-scale plantings since 1992. Bird and small mammal use of small-scale plantings in the North-Central U.S. (Christian et al. 1994) has shown that use of young plantings (1-3 years) by small mammals is more similar to grassland than to forest habitat. The number of individuals, species, long-distance migrants, and permanent residents were higher in forest and shrub habitats adjacent to plantings than they were in the actual plantings but were more abundant in plantings than in non-hay crops (Hanowski et al. 1994). National Audubon Society surveys of poplar plantings in the Pacific northwest and Ontario and switchgrass plantings in Iowa determined that short-rotation tree plantations support large populations of some birds, but not all of the species that are using the surrounding landscape (Hoffman et al. 1993). Hoffman also determined that plantations are used to different extents by bird species during different seasons. Christian et al. (1994) and Hoffman et al. (1993) concluded that short-rotation plantations can benefit regional biodiversity if they are planted as buffers for natural forests or as corridors connecting forest tracts. Both research groups concluded that interior habitat is increased by including some heterogeneous vegetation within the plantations.

The Audubon Society surveys of switchgrass plantings in Iowa showed that these plantings provided significant habitat for several prairie specialist birds (e.g., Sedge Wren, Dickcissel, and Grasshopper Sparrow) (Beyea et al. 1995). This habitat availability is particularly important for those midwestern species which have seen significantly reductions in prairie grasslands as the result of extensive conversion of prairie to agricultural lands. Surveys showed that use of the switchgrass fields by these prairie species occurred relatively late in the overall nesting season, probably in response to the seasonal growth patterns of this warm-season grass. Sedge Wrens were found to be most numerous in the purest, densest stands, while Grasshopper Sparrows tended to use more weedy areas. Continued studies of use of large-scale plantings of switchgrass by prairie species will address the deployment, maintenance, and harvesting of this energy crop to provide a biomass source while enhancing habitat for wildlife.

Biodiversity research in Minnesota is moving from the small-scale plantings of a few acres to the large-scale sites planted in 1994 and 1995. These large-scale plantings are allowing researchers to address the effects of land use change on the biodiversity of birds and small mammals at a larger scale starting with the first year of establishment compared to the existing sites for the small-scale studies of diversity. The ongoing biodiversity studies are addressing changes in use of the large-scale plantings by birds and small mammals as the plantations mature and go from open canopy (1-5 years) with varying amounts of ground cover compared to those with closed canopy (6-8 years) and a limited ground cover. The Minnesota study of the large-scale plantings is addressing how size of the plantings can effect nest predation and how plantings can be used to maximize habitat for interior species. Additional studies of these large-scale plantings are addressing whether food source plantings in or adjacent to planting sites can enhance habitat and increase biodiversity and how adjacent land use (e.g., row crops, grasslands, or wooded areas) effects biodiversity.

Studies of both large-scale switchgrass and poplar plantings are addressing questions of planting design and location within a landscape context to increase connectedness between fragmented grassland or woodland habitat, respectively. These studies are examining how the size and shape of plantings and their location within the existing landscape, i.e., adjacent to existing grassland or woodland habitat, effect habitat availability and planting use by wildlife species.

Information from the studies of large-scale plantings will be compared with the results from the small-scale sites to determine the effects of scale on the ability to most accurately predict the environmental effects of converting potentially scattered planting sites to biomass production. The results of these comparisons of scale can inform how to best design large scale plantings to maximize both economic and environmental benefits.

Conclusions

Environmental research on small-scale plantings funded through the BFDP has shown that there are significant environmental benefits of biomass crop production that can contribute to the economic viability of biomass energy crops and diversification of agricultural communities. Based on the small-scale studies, biomass crops, particularly those grown on the more erodible agricultural lands, have been shown to provide greater soil stability, increased nutrient retention and soil organic matter, and greater habitat diversity for wildlife. Expanding environmental studies to large-scale plantings is enabling the BFDP to develop the data necessary to address questions of scale as biomass production moves from research to demonstration to commercialization scale. Conversion of agricultural lands to energy crop production is being closely monitored to determine the environmental effects and benefits of production. The data from these larger-scale studies will be used to predict the environmental effects of commercial-scale plantings of switchgrass and hybrid poplar and to develop the best crop management strategies to enhance the environmental benefits from biomass crop production. The results of the larger-scale studies occurring primarily in the midwest and north central states can provide initial guidance in determining potential environmental effects of conversion of agricultural lands to biomass production in other regions of the U.S. Addressing these questions in regions of the U.S. that have the greatest potential for biomass crop production and use can help determine the best measures to deploy and manage commercial-scale plantings to achieve regional environmental benefits.

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