ENSURING ENVIRONMENTALLY SUSTAINABLE PRODUCTION OF DEDICATED BIOMASS FEEDSTOCKS

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ABSTRACT

Ensuring acceptance of dedicated biomass feedstocks by landowners, agricultural communities, environmental and public interest groups, requires that the environmental benefits, concerns, and risks associated with their production be quantified. Establishment and management measures to benefit soil and water quality are being identified by ongoing research. Field studies are showing that nutrients are retained within the rooting zone of dedicated feedstocks, subsurface herbicide transport does not occur, and off-site chemical transport is minimal compared with traditional agricultural crops. The amounts and timing of fertilizer application were critical to minimizing off-site transport of nutrients. Maintaining soil cover decreased runoff, sediment losses, and nutrient transport compared with traditional agricultural crops. Conversion of traditional croplands to biomass and no-till crop production improved soil quality and soil carbon storage. Subsurface nutrient losses were less from biomass crops than adjacent natural forests or agricultural crops in Minnesota. Data across the spectrum of climates and soils from North to South show initial gains in soil carbon are greater at shallow depths (0-10 cm) and in lower organic soils. Addressing environmental questions across planting scales and documenting changes in soil and water quality with biomass crop production on former agricultural lands is critical to identifying production options to (1) maximize environmental quality, (2) minimize environmental risks, and (3) ensure economic benefits for growers.

Key Words: environmental effects, soil quality, water quality, carbon sequestration

INTRODUCTION

Dedicated short-rotation woody crops (SRWC), perennial herbaceous crops, as well as residues have the potential to provide significant feedstocks to support viable biomass to bioenergy and bio-products industries. These feedstocks can provide the raw materials for ethanol, power, and bio-based products as well as contributing substantially to sustainable fiber production. Using intensively managed biomass crops and residues as energy feedstocks can provide local economic benefits and both local and broad-scale environmental benefits. Broad-scale environmental benefits can accrue by reducing the overall contribution of fossil fuels to global warming and greenhouse gas production and at individual production scales by reducing erosion and chemical use.

On August 12, 1999, President Clinton called for tripling U.S. energy production from renewable resources to 6 quads of primary energy by 2030 (Federal Register, 1999). As a consequence, the role of alternative energy feedstocks, including dedicated energy crops and residues, takes on increased importance. Walsh et al. (1999) projected that approximately 6.9 million hectares were be required to meet the demands of 79 million dry tons of feedstocks for production of 1.25 quads of energy. With this substantial land use requirement, the environmental aspects of dedicated production must be addressed simultaneously with crop development and deployment to identify benefits, potential concerns, and any mitigation measures necessary to ensure sustainable production of biomass crops. Demonstration of sustainable biomass crop production will be required for acceptance at this scale by producers, the general public, and environmental groups.

Biomass crops currently are not economically competitive with traditional crops such as corn and soybeans on more highly productive soils. Consequently, large-scale production of dedicated biomass crops is expected to be more prevalent on lands that are more erosive or may be more marginally productive for traditional crops. Because the economic returns are generally less, these lands may be available for longer-term commitment to rotations of biomass crops. Production of perennial biomass crops on these lands can provide soil and water quality benefits in addition to being a source of dedicated feedstocks (Smith, 1995; Tolbert et al., 1997, Grigal and Berguson, 1998). The potential for environmental impacts from site preparation and production on these lands is greater and the yields probably less than would occur on more productive agricultural lands. However, the greatest environmental gains and benefits, especially in soil quality and carbon storage with land use conversion to biomass crops are expected on these lands. Determining management measures that can minimize both on-site and off-site effects, e.g., erosion and chemical transport, and matching biomass crop types to appropriate sites, can maximize the environmental potential and sustainability of biomass crop production for energy, bio-products, and fiber.

The site-specific research described here summarizes the ongoing collaborative research at locations in the southeastern and north-central U.S. that is quantifying differences in soil chemical and physical properties and water quality with production of biomass crops, agricultural crops, and natural forests. The research locations span the North-South range of woody and herbaceous crops in the US and encompass areas with identified potential for biomass crop production (Walsh et al., 1999; Graham and Downing, 1995). Thornton et al. (1998), Tolbert et al. (1997, 1998), and Perry et al. (1998) have summarized some of the earlier surface water and nutrient transport results from these studies.

METHODS

In the Southeast, replicated small-scale research plots (0.5 to 1.2 ha) and catchment-scale (20-40 ha) studies were established on agricultural sites historically in conventional tillage for corn, soybeans, or cotton. The individual small-scale plots established in 1995 were enclosed within earthen berms to exclude off-site runoff and planted to the appropriate agricultural or biomass crops selected for each particular location. Individual plots were instrumented for long-term monitoring to quantify differences in runoff as well as sediment and nutrient transport. Sweetgum with an approximately 2-m wide fescue cover crop between 1.5 x 3 m rows, sweetgum without a cover crop, switchgrass, and no-till corn for grain plots were established at a site in northern Alabama (AL). Eastern cottonwood was established in western Mississippi (MS) on 2 m x 3.3 m spacing for comparison with conventional-till cotton, and American sycamore was established at 2 m x 3.3 m spacing in western Tennessee (TN) for comparison with no-till corn for silage. On the coastal plain of South Carolina (SC), sycamore and sweetgum with open drainage and sycamore with closed drainage were established (1997) on 2 m x 3.3 m spacing to compare the potential to manage water levels to increase productivity. Soil physical characteristics (bulk density, penetration resistance, and aggregate stability) were measured prior to crop establishment and again at the end of each growing season to determine changes in soil quality over time.

Aboveground biomass for the tree crops in the Southeast has been measured annually and belowground biomass measured after three years at the AL, TN, and MS sites and annually at the SC site. Soil carbon within the upper 60 cm was measured at the southeastern sites for both the biomass and agricultural crops and in the north-central region on twenty hybrid poplar plantings ranging in age from 3 to 12 years. More detailed descriptions of the sites, methods, and results of water quality monitoring can be found in Joslin and Schoenholtz (1998), Thornton et al. (1998), Tolbert et al. (1997, 1998), and Perry (1998).

In Minnesota, subsurface transport of chemicals (herbicides and pesticides) and nutrients from newly established plantings of switchgrass, hybrid poplar, and wheat have been the main focus of biomass and agricultural comparisons since 1997. Water use and nutrient use efficiency by 10-12 year old hybrid poplar plantings were compared with nearby natural mixed aspen forests 34 years of age.

RESULTS AND DISCUSSION

Changes in both soil and water quality parameters have been observed following establishment of biomass crops on former agricultural sites in the southeast (Tolbert et al., 1997, 1999) and north-Central regions (Perry 1998, Perry et al. 1998). Selected examples are presented here to illustrate differences in soil physical parameters, nutrient transport, and carbon storage that have and are continuing to be quantified over time with conversion of agricultural lands to biomass crop production.

Soil Quality. In the Southeast at the MS site, aggregate stability, as a measure of decreased soil erodiblility and increased organic matter, increased from 2.8 percent to 5.6 percent three years after conversion to cottonwood production. Most of the increase occurred within the upper 3 cm of the silt loam soil (Pettry et al., 1997). After four years of growth at the TN site, aggregate stability had significantly increased ($p > 0.05$) on the no-till corn but not the young sycamore plots. The increased aggregate stability with no-till corn production is believed to result from the change in tillage practice as well as the more extensive root system developed by the no-till corn, grown with an annual winter wheat cover crop. The rooting system of the young sycamore was more spatially and structurally restricted and less fibrous than the no-till corn (Tyler et al., 1999). Differences in the decomposition and incorporation rates of the leathery sycamore leaf litter and the more friable corn stover into the shallow soil layers may also partially account for the differences in soil structure.

Penetration resistance and bulk density decreased with time and infiltration increased with cottonwood production compared with cotton at the MS site. After the first growing season, the roots of the fast growing cottonwood penetrated and eliminated the soil traffic pan (initially at a depth of 15 to 30 cm). The plow pan persisted under the cotton rotation. After three years, the bulk density at a depth of 0-3 cm had declined significantly ($p > 0.05$) under the young sycamores (1.17 Mg/m^2) compared with the initial site characterization and the no-till corn production (1.34 Mg/m^2) (Tyler et al., 1999). At the AL site, the average bulk density after three years was 1.0 Mg/m^2 for sweetgum with and without a cover crop compared with 1.3 Mg/m^2 on traditionally cultivated corn sites. Bulk densities at the SC site averaged 1.8 Mg/m^2 (at the 15-30 cm "plow pan" depth) between rows and 1.5 Mg/m^2 in the planting ridge.

Soil and Water Chemistry. Nutrient and chemical contributions to water in either shallow or deep lysimeters were no different from switchgrass, hybrid poplar, or the annual agricultural crops on the same research site in MN during the first year of establishment. Throughfall in 8 to 9-year-old short-rotation hybrid poplar plantings and 22 to 34-year-old natural mixed aspen stands were also not significantly different ($p > 0.05$). The hybrid poplar plantings and natural mixed aspen stands are contributing similar amounts of water to shallow ground water - the consumptive water use by the younger hybrid poplar plantings was similar to that of mature forest stands. Nutrient export of total nitrogen and total dissolved phosphorus were not different between the 8 to 9 year-old hybrid poplar plantings and 22 to 34- year-old natural mixed aspen stands. The nutrient export rates from the natural forest stands are comparable to those reported elsewhere for similar forest stands (Perry, 1998). Consequently, in the north-central region conversion of agricultural lands to hybrid poplar production should not result in increased nutrient and chemical transport and ground water contamination. For cottonwood, sycamore, sweetgum with a cover crop, and switchgrass in the Southeast, nitrate (Fig. 1) and sediment losses (Fig. 2) were generally less than from the agricultural crops, particularly after the initial year of establishment.

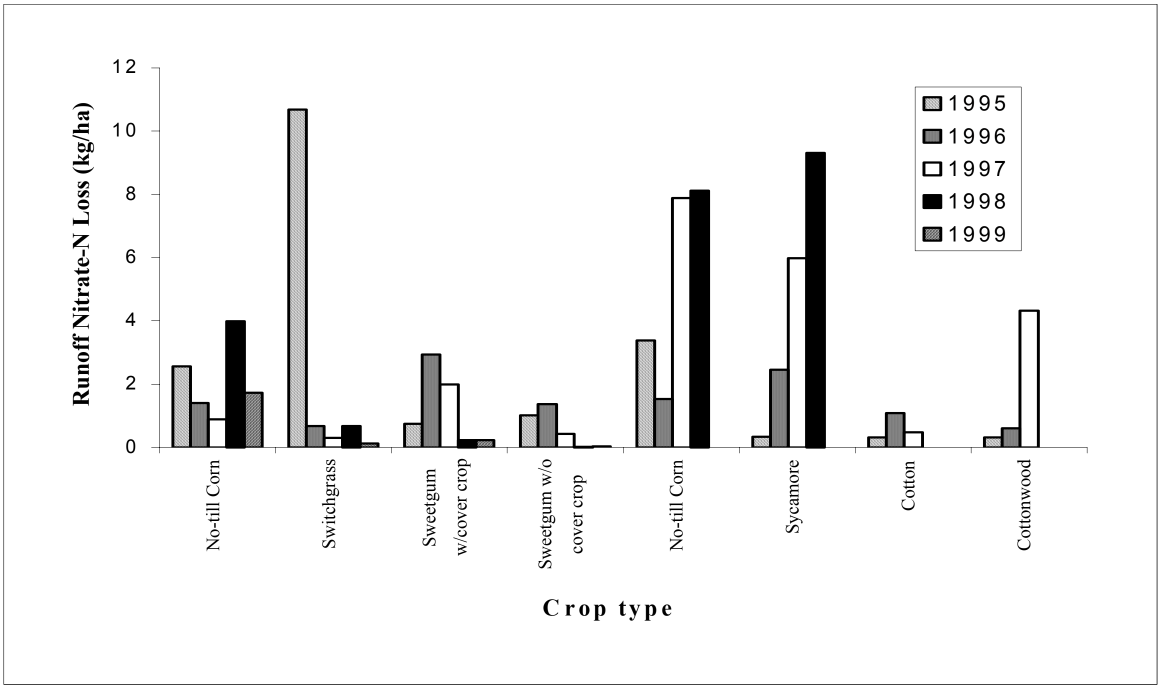

Figure 1. Nitrate losses in runoff from biomass and agricultural crops at three southeastern research sites from establishment (1995) through 1999, except cotton and cottonwood at the MS site where the cottonwood were harvested at the end of the 1997 growing season.

Soil Carbon. Soil carbon under cottonwood at the MS site increased by 19 % by the end of the third growing season with most of the increase occurring within the upper 3 cm (Fig. 3). Soil carbon with sycamore and no-till corn production at the TN site increased within the upper 15 cm by 27 % and 34%, respectively, by the end of the third growing season (Fig. 3). The increase in soil carbon storage under the sycamore was approximately 1.3 Mg/ha/yr. Soil carbon under sweetgum with a cover crop, switchgrass, and no-till corn increased significantly ($p \geq 0.02$) over the first 3-year period at the AL site while decreasing by 6% on the plots of sweetgum without cover. This difference in carbon accumulation at the AL site has persisted over five years of growth (Fig. 4). Johnson (1993) concluded that land management practices were an important contributor to carbon storage. The loss of carbon on the sweetgum plots maintained without cover or weeds during the early years of the rotation at the AL site is consistent with Hansen's (1993) results which showed that, on hybrid poplar plantings maintained in a clean-tilled state, initial carbon losses occurred as a result of surface exposure and carbon mineralization. After the initial losses, Hanson projected increases in carbon storage over the next 12 years of the tree crop rotation.

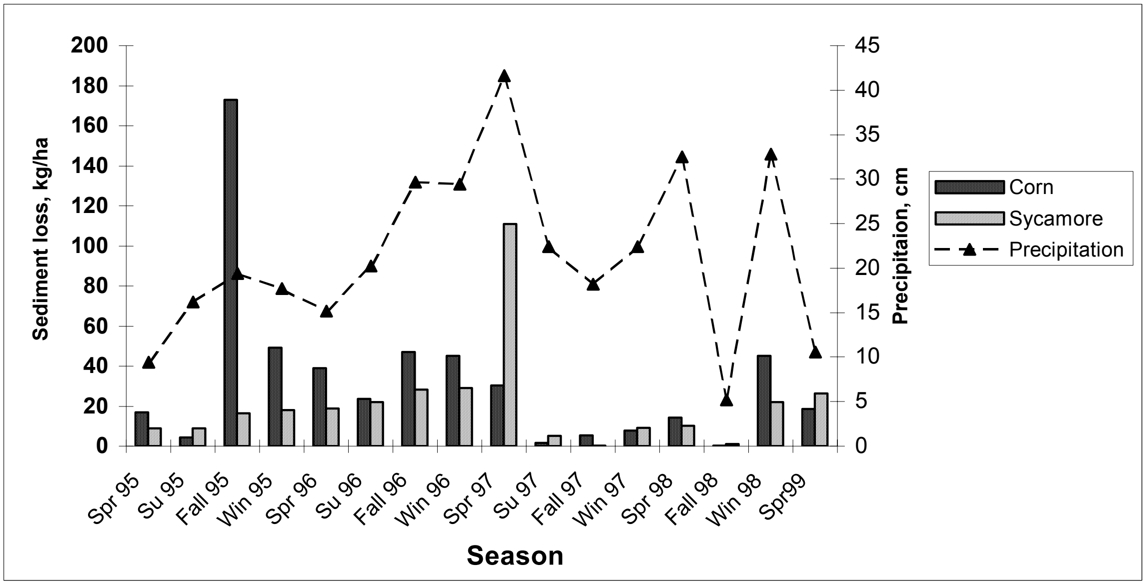

Figure 2. Total sediment losses from the agricultural and biomass crops across the three research sites from initial establishment (1995) through 1998. Data for cotton and cottonwood at the Mississippi site are through October 1997 only; trees were harvested in November 1997.

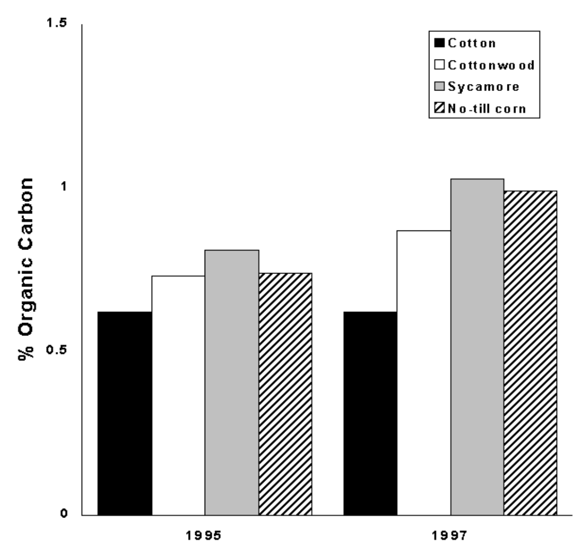

Figure 3. Comparison of baseline (1995) percent soil carbon on agricultural sites in MS and TN with changes after three years of agricultural (cotton and no-till for silage) and biomass crop (cottonwood and sycamore) production.

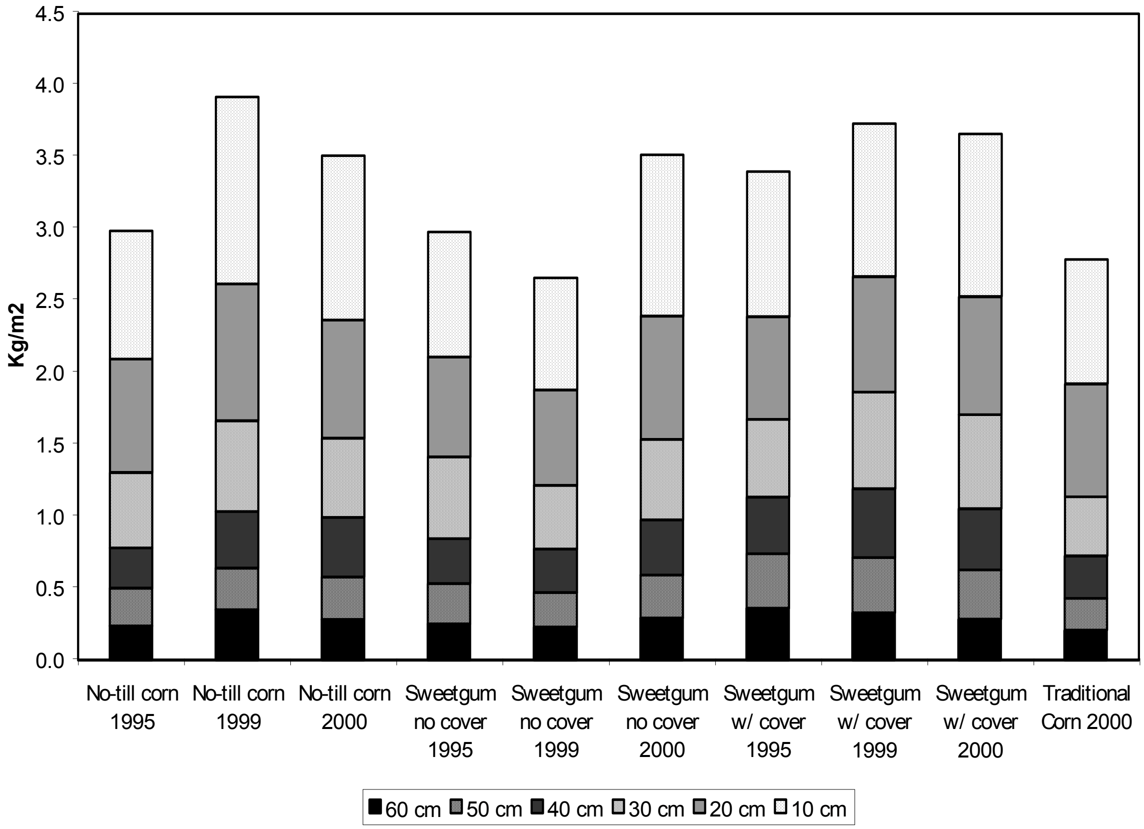

Figure 4. Comparison of soil carbon (kg/m^2) in the upper 60 cm on a traditional agricultural crop production site in northern Alabama from establishment in 1995, 1999, and 2000 for sweetgum w/cover and no/cover, no-till corn for grain, and traditional corn. No-till corn in 1995 is representative on traditional corn on the site.

Hansen (1993) and Grigal and Berguson (1998) projected increases in soil carbon with biomass crop production on former agricultural sites. The changes in soil carbon from samples collected in 1998 from hybrid poplar planting of various ages and in various locations in the north-central region were highly variable. Changes in carbon storage were minimal on sites with high initial soil carbon, while on sites with low organic matter content, there were measurable increases in carbon storage. Soil carbon was greater near the surface and decreased with depth. The increased carbon levels in the shallow soil (0-10 cm) on sites with more mature trees were attributed to leaf litter accumulation and incorporation. For the north-central region, more intensive sampling and understanding the role of surface layer texture is required to accurately determine changes in soil carbon storage. Soils in the southeastern U.S. are generally lower in organic matter content from a long history of agricultural crop production and from exposure to higher temperatures and rainfall than soils in the north-central region. These warmer, low-organic soils have been projected to have greater potential for soil carbon sequestration than cooler, more organic rich soils (Garten, personal communication). The increase in soil carbon across sites converted from traditional agricultural crops to no-till or biomass crop production in the Southeast is consistent with the projections made by Smith (1995) that reforestation of agricultural lands could increase carbon sequestration in soils.

The studies in the southeastern and north central regions are providing the opportunity to begin to quantify the effects of different management practices, e.g., use of cover crops between rows, water level management, and fertilization and weed control practices on soil carbon storage in intensive production systems. The data from these sites are showing that many of the soil quality benefits that occur with conversion of traditionally cultivated agricultural lands to conservation tillage and perennial biomass crop production accrue primarily from adoption of practices that minimize soil disturbance and maintain soil cover. The comparisons of biomass crops and agricultural crops in both the Southeast and North-Central regions demonstrate that biomass crops can be expected to provide soil physical benefits, soil stability, water quality benefits, and varying carbon sequestration potential on former agricultural lands. The extent of the soil carbon benefits depends on the soil and climate. On sites with initially poorer soil quality and greater erodibility, the environmental benefits are expected to be more pronounced.

SUMMARY

Conversion of traditional agricultural lands to production of short-rotation woody and herbaceous crops is showing considerable potential to provide soil and water quality benefits as well as a source of biomass feedstocks. Documenting and assigning value to these environmental benefits can increase their acceptance by the public, environmental groups, and the agricultural community. Determining methods for establishment and crop management that can increase the environmental value of biomass crops without adding to the cost of production can further increase their acceptance as renewable energy feedstocks for liquid fuels or co-firing or as feedstocks for fiber or bio-products. Data from the three southeastern sites are showing the value of soil cover provided by surface residues from switchgrass, sweetgum with a cover crop, no-till corn, sycamore, and cottonwood after the initial year(s) of establishment. Biomass crops can contribute to soil quality and sequestering carbon in the belowground components over the life of their rotation. The conversion from conventional-till agriculture to no-till agricultural crop production and the development of extensive rooting systems and incorporation of litter from the perennial biomass crops appear to be major factors accounting for the increasing carbon sequestration. Crop rotations of 5 to 20 years for both woody and herbaceous perennial biomass crops offer the potential to provide long-term storage of carbon in the aboveground components and below ground in roots and as soil carbon. Continuing to measure changes in soil carbon with biomass crop production across a variety of sites in the Southeast and North-Central regions offers the opportunity to quantify changes over time, on different soil types, in different climates, and with different management practices. The ongoing research is providing data to answer questions of how the distribution of soil carbon within the soil column changes and can be increased with time, and the fate of the sequestered carbon with conversion of sites to subsequent biomass or agricultural crop production. These data will allow us to identify where and how the greatest potential for soil carbon sequestration can be achieved. Matching the environmental data with productivity data can ultimately identify soil and water quality and carbon sequestration potential with biomass crop production as the U.S. moves toward the goal of tripling renewable energy production by 2030.

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