THE IMPLICATIONS OF BIOFUEL PRODUCTION ON SOIL PRODUCTIVITY

J.L. Hatfield
National Soil Tilth Laboratory, Ames, IA
jerry.hatfield@ars.usda.gov (515) 294-5723

ABSTRACT

Production of biomass from agricultural crops as a source of energy generated either as a primary or secondary source from agricultural systems has the potential to provide a portion of the nation's energy needs. Removal of crop residue after harvest is viewed as a major source of cellulosic material; there are challenges that arise with biomass removal in cropping systems in which the crop residue has remained on the soil surface after harvest. The potential impacts of biomass removal on soil productivity and subsequent environmental problems need to be discussed as part of a strategy to improve agricultural production systems. Corn residue is considered one of the largest sources of cellulosic material for energy and may account for over 60% of the biomass production and provides an example for assessing the impacts from other crops. Large amounts of nutrients are removed in corn residue that would have to be incorporated back into the soil and removal of corn residue will lead to decreases in soil organic carbon (SOC). Decreases in SOC reduce water holding capacity and the ability of a plant to extract water during short-term water deficits. Placement of residue on the soil surface protects the surface from water and wind erosion and also moderates the extremes in soil temperature and moisture required for optimal microbial activity. The decline in SOC and extreme microclimate can lead to crusting which limits water infiltration and gas exchange. These have both impact soil productivity and could have subsequent negative impacts on crop production and environmental quality. To avoid long-term environmental and crop production problems a comprehensive assessment of the impacts of biomass removal on the stability of United States crop production systems is needed.

INTRODUCTION

The potential replacement of a portion of the nation's energy resources with bio-based materials has created excitement in terms of the utilization of agricultural crops. It is estimated that nearly one billion dry tons of cellulosic biomass could have to be available from agricultural lands to supply this demand. This biomass would be obtained from crop residues and energy crops (Perlack et al., 2005). The current estimate for removable biomass from corn is approximately 75 million tons and accounts for nearly 60% of the potential biomass production required (Perlack et al., 2005). In a recent analysis, Graham et al. (2007) stated that 64 million tons of corn stover could be removed under the constraints of erosion, soil moisture, or nutrient replacement in agricultural production systems. Given the predominant distribution of corn across the Midwest, the majority of this stover would be collected from the areas of greatest corn production as shown in Fig. 1.

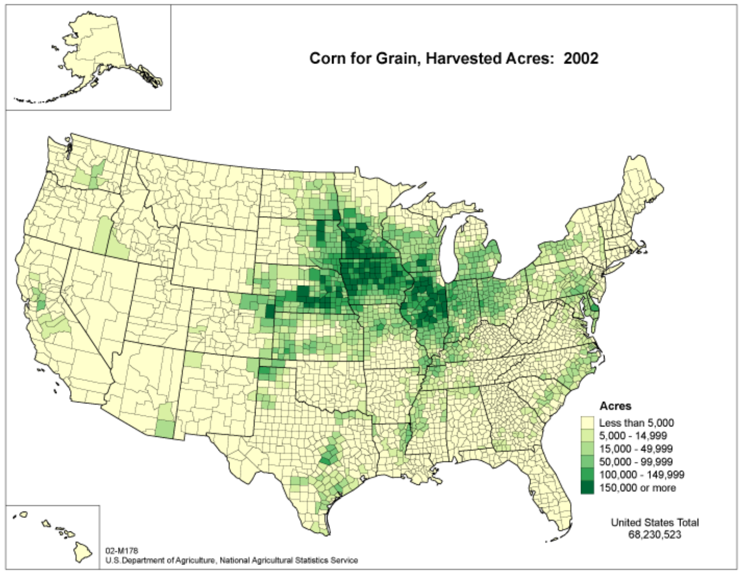

Figure 1. Distribution of corn production across the United States in 2002. (available from http://nass.usda.gov/fieldcrops)

Biomass production from corn has shown a steady increase since 1949 because of the continual increase in corn grain yield (Fig. 2). The assumption is that biomass removal from corn production would be the major source of cellulosic biomass used for energy production. The current estimate is that over 10,000 lbs/A would be produced on each acre of land and the assumption that this biomass would be harvested for energy production. The implications of biomass removal on soil productivity need to be considered as we begin to develop strategies for harvesting crop residue for energy.

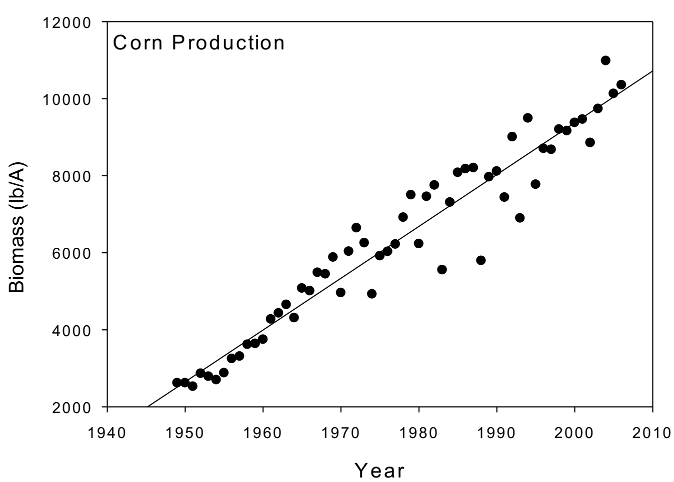

Figure 2. Annual increase in corn stover biomass production for United States corn production from 1949 through 2006. Biomass = -259555 + 134.46 Yr r^2 = 0.93 (http://nass.usda.gov/fieldcrops)

The long-term consequences on the soil resource and environmental quality need to be understood as new cropping practices are implemented. In this report several of these potential issues will be discussed in order to provide information to inform our decisions.

SOIL NUTRIENT REMOVAL

Although the analysis by Graham et al. (2007) considered the nutrient removal and potential costs of returning nutrients to the soil, their analysis didn't consider the implications of nutrient replacement on soil productivity. Biomass production removes large amounts of nutrients per acre and based on the corn production in 2006 there were 136 lb/A of nitrogen (N) removed in the grain and 115 lb/A of N removed in the corn stover. These amounts have continued and will continue to increase with the trend of increasing corn yields. Removal of nutrients in biomass shows there are large potential amounts removed from the soil in the corn stover (Table 1). Removal of these nutrients from the field will have a potential impact on the long term soil productivity because of the removal of these nutrients from the soil. To replenish these nutrient levels will require applications of nutrients and since many of these are relatively immobile, incorporation of the nutrients into the soil will be necessary. Replacement of these nutrients would occur within the upper portion of the soil profile and over long periods of time the lower soil profile may become depleted of these essential nutrients. Analysis of the distribution of soil nutrients within soil profiles that have had intensive biomass removal would be helpful to guide future studies. Another potential problem is that soil disturbance will be required for nutrient incorporation using tillage during times which the soil has a minimal residue cover which would increase the potential for soil erosion during times of intense rainfall. The implications of nutrient removal from the soil by biomass harvest will affect the nutrient resource in the soil and the effect on removal would be increased as even more corn is grown as a monoculture.

Removal of nutrients in grain will continue to be the primary removal of N from the soil; however, this removal would occur in any use of grain. The export of nutrients in the grain is not considered in this analysis.

Table 1. Amount of nutrients removed in 2006 corn stover production across the United States.

Nutrient	Corn (lb/A)
N	115.00
P_2O_5	40.00
K_2O	167.00
Ca	30.00
Mg	23.00
S	16.00
Cu	0.06
Mn	1.72
Zn	0.34

BIOMASS REMOVAL ON CROP PRODUCTION

An analysis of the impact of biomass removal begins with the potential impact on crop production through the soil resource. Wilhelm et al. (1986) showed that removal of 1 lb of biomass reduced subsequent grain production by 0.13 lb and stover production by 0.29 lb. The long-term consequences of biomass removal on crop productivity should be considered in biomass removal studies. An aspect of biomass removal could be to reverse the increasing trend shown in Fig. 2 of annual increases because of the cumulative impact of biomass removal on the soil-plant interactions. This reduction was caused by the changes in the SOC, nutrient availability, soil water, and general soil condition. Wilhelm et al. (2004) summarized the current state of knowledge about the impacts of biomass removal on crop yields for a number of crops and showed that soil organic matter was one of the primary factors affected by management of crop residues. These differences were dependent upon the initial organic matter content in the soil profile. Another parameter affected by residue removal was the impact on soil compaction. The changes in soil management and harvesting methods could potentially increase the number of harvest trips across a field and could cause compaction. Voorhees et al. (1989) showed that wheel-induced compaction could impact water runoff and soil erosion and concluded that more harvest trips with the potential for more wheel-tracked areas would increase the potential for runoff. Young and Voorhees (1982) had shown that 50% of the runoff was from the wheel-tracked areas even though these areas only covered 25% of the soil surface. The changes in the soil by biomass removal through harvesting methods may produce erosion and runoff problems especially on highly erodible soils.

BIOMASS REMOVAL ON SOIL ORGANIC MATTER

Changes in the SOC levels will be one of the first noticeable changes to occur within the soil. Soil organic matter provides a valuable asset to the soil in terms of soil structure, water holding capacity, and energy source for microbial activity. Dick et al. (1998) found that tillage and rotation were more important than residue removal for changing carbon sequestration in the soil profile. This was confirmed in a study by Cambardella and Gale (2000) that showed SOC is derived from the root system more than the above ground biomass. The placement of crop residue on the surface helps to moderate the soil microclimate in the upper layers of the soil that maintains the soil biological activity and this effect can not be ignored in evaluations of residue removal because SOC changes are related to soil biological activity. One component of the soil profile that may be affected most dramatically by crop residue removal is a potential increase in crusting which would cause problems in stand establishment, infiltration of water, and gas exchange.

A consequence of reducing the SOC levels is to decrease the water holding capacity of the soil as shown by Hudson (1994). He showed that the water availability in different soils was directly affected by the organic matter content and that the field capacity value of the soil increased rapidly as organic matter increased (Fig. 3). Soil water availability impacts on crop production are critical to efficient crop production and account for the majority of the yield variation within fields and among years across the United States. The impact of modifying the soil water availability can not be dismissed in the current climate regime where rainfall events will become even more variable.

Wilhelm et al. (2004, 2007) summarized a number of studies and found that the amount of residue required to maintain SOC levels ranged from 900 to 15,000 lb/A/yr. Johnson et al. (2006) evaluated the potential impacts of biomass production on SOC from corn, wheat, sorghum, and soybean and concluded that approximately 9000 lb/A/yr of biomass could be removed without any impact on SOC levels in soils. This value is in the range proposed by Wilhelm et al. (2004) and assumes that the soil is maintained in a conservation tillage system with limited soil disturbance. The balance between maintaining SOC and preventing erosion will have to be considered in all analyses of biomass removal.

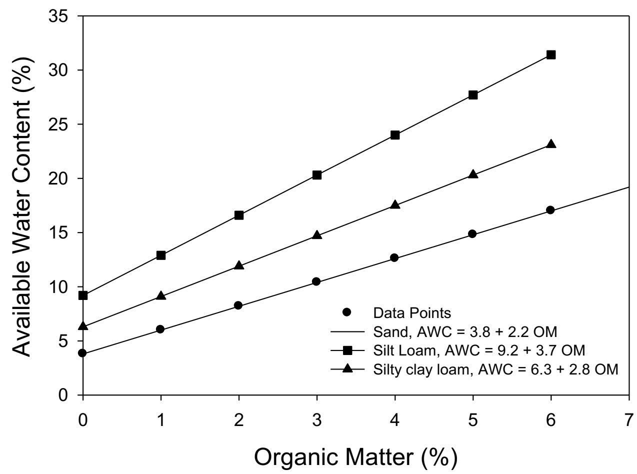

Figure 3. Changes in available soil water content as a function of changes in soil organic matter for different soils. (Derived from Hudson, 1994).

CONCLUSIONS

There are complex interactions between residue production, residue removal, and the impact on subsequent crop production and SOC content. The implications for biomass removal on soil productivity can not be ignored as we begin to look for alternative sources of energy. Although several analyses have shown that biomass can be removed from the soil without problems, there are constraints on the agricultural practices to achieve these goals. The assumption of conservation tillage with minimum disturbance of the soil is one of the major changes in management that will have to be adopted. To achieve this goal of reduced tillage disturbance while replacing soil nutrients removed with the crop residue will require development of practices to incorporate nutrients with minimal soil disturbance. The effect of changing the SOC on soil water availability and potential impacts on soil crusting are two major factors in soil productivity that need to be thoroughly evaluated. The potential change from a crop rotation system of corn-soybean to monoculture corn in the upper Midwest could further increase the potential consequences of any removal of biomass from the soil surface. The soil resource and the productivity of that resource needs to be protected and analyses should be conducted that consider the interplay of crop production systems, energy generation, soil productivity, and environmental quality as multiple endpoints in comprehensive studies of agricultural systems. The stability of agricultural productivity requires a soil resource that can supply the maximum amount of nutrients, water, and an optimum soil environment in terms of gas exchange and as we develop any new practices we should consider all of these factors as part of our assessment.

REFERENCES

Cambardella, C.A. and W.J. Gale. 2000. Carbon dynamics of surface residue- and root-derived organic matter under simulated no-till. Soil Sci. Soc. Am. J. 64:190-195.

Dick, W.A., R.L. Blevins, W.W. Fyre, S.E. Peters, D.R. Christenson, F.J. Pierce, and M.L. Vitosh. 1998. Impacts of agricultural management practices on C sequestration in forest-derived soils of the eastern Corn Belt. Soil Tillage Res. 47:235-244.

Graham, R.L., R. Nelson, J. Sheehan, R.D. Perlack, and L.L. Wright. 2007. Current and potential U.S. corn stover supplies. Agron. J. 99:1-11.

Hudson, B.D. 1994. Soil organic matter and available water capacity. J. Soil and Water Conserv. 49:189-194.

Johnson, J.M.F., R.R. Allmaras, and D.C. Reicosky. 2006. Estimating source carbon from crop residues, root and rhizodeposits using the national grain-yield database. Agron. J. 98:622-636.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.L. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. ORNL/TM-2005/66 http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf)

Voorhees, WB., J.F. Johnson, G.W. Randall, and W.W. Nelson. 1989. Corn growth and yield as affected by surface and subsoil compaction. Agron. J. 81:294-303.

Wilhelm, W.W., J.W. Doran, and J.F. Power. 1986. Corn and soybean yield response to crop residue management under no-tillage production. Agron. J. 78:184-189.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B.Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: A literature review. Agron. J. 96:1-17.

Wilhelm, W.A., J.M.F. Johnson, D.L. Karlen, and D.T. Lightle. 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. Agron. J. 99:1665-1667.

Young, R.A. and W.B. Voorhees. 1982. Soil erosion and runoff from planting to canopy development as influence by tractor wheel-traffic. Trans. ASAE. 25:708-712.