BIOMASS REMOVAL: EFFECT ON SOIL NUTRIENTS AND PRODUCTIVITY.

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Abstract

Interest in renewable alternatives to fossil energy has increased. There is also a growing awareness of the impact of greenhouse gas emission on global climate change. Crop biomass can be used to make liquid fuels like ethanol. These cellulosic materials are also potential feedstock for controlled combustion substituting for natural gas or coal. There are a wide range of potential feedstocks, trees, perennial grasses and crop non-grain biomass (or residues.). Particularly in the Corn Belt, corn stover and other crop straws are likely feedstocks. Long-term and short-term economic and environmental consequences (positive and negative) must be considered. Management recommendations are emerging that based on minimizing soil erosion risks, maintaining soil carbon and nutrient management. The amount of biomass required to stay on the land to prevent loss of soil organic matter exceeds the amount needed to limit erosion. Biomass harvest removes 11 to 25 lb N, 1 to 4 lb P and 4 to 19 lbs K per ton of biomass removed depending on the crop. Soil tests and crop monitoring are recommended for both macro and micronutrients to avoid deficiencies.

Introduction

Interest in harvesting crop biomass and other cellulosic feedstocks has increased dramatically. Cellulosic feedstocks include woody perennials, herbaceous perennials and annuals. These feedstocks can be used to manufacture liquid fuel (e.g. ethanol) or utilized as a substitute for natural gas or coal in various thermochemical platforms. There are competing uses for crop biomass such animal feed and bedding, building material (Bainbridge, 1986; Simonsen, 1996), input for maintaining soil organic matter and erosion control (Wilhelm et al., 2007; Wilhelm et al., 2004). There are potential benefits and risks associated with harvesting the various feedstocks (Johnson et al., 2007b). It is hoped utilizing biomass can provide a renewable, domestic energy source thereby reducing energy dependency, reduce greenhouse gas emissions and providing an additional income stream to rural America (Johnson et al., 2007b; Perlack et al., 2005; Wilhelm et al., 2004). As is frequently the case, benefits need to balance against potential risks. Identifying risks facilitates strategies for avoiding or minimizing them. Potential risks associated with harvesting non-grain crop biomass include increased erosion, reduced soil organic matter, reduced soil fertility, which can lead to reduced soil productivity. This paper will briefly summarize some of the potential risks and offer mitigation strategies to protect the soil resource for sustained productivity.

Biomass Harvest considerations

Erosion control

The role of crop residue for erosion control has long been recognized. Surface residue reduces the risk of wind and water erosion. In general there are exponential decreases in erosion with increasing residue cover (Bilbro and Fryrear, 1994; Cogo et al., 1982; Gregory, 1982; Stocking, 1988). Removal of crop residue can decrease water infiltration (Blanco-Canqui and Lal, 2007) and increase water runoff (Erenstein, 2002; Lindstrom, 1986), contributing to water erosion. Harvesting crop biomass can also reduce soil aggregation, making the soil more prone to wind erosion (Malhi and Lemke, 2007; Malhi and Kutcher, 2007; Singh and Malhi, 2006). Erosion removes topsoil, which contains the highest concentration of organic matter and nutrients. A recent NRCS report estimate an Midwest region average of 12 lb/A N and 2 lb/A P are lost annually with surface erosion (ftp://ftp-fc.sc.egov.usda.gov/NHQ/nri/ceap/croplandreport/Part_2_Executive_Summary.pdf). Recognizing that excessive biomass harvest can exacerbates soil erosion, estimates of harvestable crop biomass limit harvest rates to reduce erosion and assume no tillage management (Graham et al., 2007; Nelson, 2002; Nelson et al., 2004; Perlack et al., 2005). Crop biomass should not be harvested from highly erodible land and prudence exercise to maintain adequate soil cover if biomass is harvested.

Recent measurements from a corn/soybean rotation in west central Minnesota found that any stover harvest reduced spring residue cover below 30% if chisel plowed. When the field was not tilled there surface residue coverage could still provide protection against erosion. The site has less than 2% slope.

Table 1. Percentage soil cover measured 5/14/2008 for corn and soybean with different tillages and corn stover harvest rates (Johnson et al., unpublished data)

		Corn 2008	
Stover harvest rate	Chisel	No tillage since 2005	No tillage since 1995
	--------------% soil coverage-------------		
0	8.25 a[†]	58.88 a	65.50 a
50	5.75 ab	57.00 a	56.00 a
75	5.00 b	50.75 a	54.75 a
100	4.00 b	39.50 b	53.75 a
		Soybean 2008	
0	29.25 a	90.75 a	84.25 a
50	19.50 b	60.63 b	72.00 b
75	13.75 c	57.12 b	58.25 c
100	9.00 d	46.12 c	46.50 d

[†] Within a crop, different letters indicate significant differences $P \leq 0.05$ among harvest rates within tillage.

Soil organic matter

Many of the characteristics of an inherently fertile productive soil are attributed to soil organic matter (Doran, 2002). Soil organic matter is about 56% C (Stevenson, 1994), thus an increase in soil organic matter implies an increase in soil organic carbon as well. Mineralization of soil organic matter release C from the soil in the form of CO_2, a potent greenhouse gas. Until the

1960's, CO_2 originated from soil exceeded the amount of CO_2 entering the atmosphere from burning fossil fuels. The primary cause was land use change, in which great expanses of prairie and forest were transformed into annual crop agriculture (Houghton et al., 1983). Globally land use change is a significant contributor to atmospheric CO_2 (IPCC, 2000). Rebuilding soil organic matter removes CO_2 from the atmosphere (Cole et al., 1997). Conservation strategies such as reducing or eliminating tillage, utilization of cover crops or mulch crops, and incorporation of perennial into the rotation have duel benefits of reducing soil erosion and promoting carbon sequestration.

Is the amount of crop residue returned for minimizing soil erosion sufficient to maintain soil organic matter? The processes controlling soil organic matter are very different than the physical processes controlling soil erosion. Simplistically to increase soil organic matter the rate of input (humification) need to exceed the rate of output (decomposition) (Bayer et al., 2006). Theoretically, it should be possible to determine the residue inputs needed such that humification equals or exceeds decomposition. Once determined, this can be used to estimate how much biomass can be harvested in that system (Johnson et al., 2006a). Using this approach, Johnson et al., (2006b) estimated on average corn yield would need to exceed 150 bu acre^{-1} (10 Mg ha^{-1}) using no tillage or conservation tillage or continuous corn before any stover should be harvested. A higher yield was recommended in corn-soybean for corn-soybean rotation with moldboard plowing. Based on Johnson et al., (2006b) an annual harvest rate of 2 ton acre^{-1} (4.5 Mg ha^{-1}) from a continuous corn, no tillage field would need an average yield 210 bu acre^{-1} (13.2 Mg ha^{-1}) to maintain soil organic carbon. Wilhelm et al (2007) compared the recommended amount of stover retained on the land to maintain soil organic carbon, or limit water or wind erosion losses to T (tolerable annual soil loss). The amount of residue required to maintained soil organic carbon exceeded that needed to limit erosion by 4 to 50-fold. Managing to protect soil organic matter (carbon) should also protect against soil erosion loss.

Harvest and yield

Yield response to biomass harvest varies among locations (Table 2). In the NE study, the yield decrease partially was attributed to increased soil temperature and increased evapotranspiration leading to water stress (Wilhelm et al., 1986). Yield increases observed in Iowa (Kaspar et al., 1990) and WI (Swan et al., 1994) due to stover removal were the result of increased soil temperature allowing for improved seedling establishment in the cool environment. The impact of harvesting crop residue on yield is indirect interacting with soil microclimate, inadvertent increases in soil compaction or loss of soil fertility (Wilhelm et al., 2004).

Table. 2. Corn yield response to stover harvest.

State	Yr	Residue	Grain Yield response	Citation[†]
IN	6	0, 1X and 2X remaining	None	1.
IA	3	0, 66% 90% removed	None	2.
NE	4	0, 0.5, 1.0 to 1.5X	Decrease	3.
NE	11	0, 0.5, 1.0 to 1.5X	Decrease	4.
IA	2	Removed over row	Increase	5.
WI	7	Bare, 1X, 2X	Bare decreased (5/7) 2X decreased (6/7)	6.
MN	13	0,1X	None or decrease	7.
MN	29	Grain vs silage	None	8.
CN	30	Grain vs silage	decreased (3/4)	9.
OH	2.5	O, 50, 75, 100% removed	None or decreased	10.

[†] 1. Barber, (1979); 2. Karlen et al (1984); 3. Wilhelm et al., (1986); 4. Powers et al., (1986); Kaspar et al, (1990); 6. Swan et al., (1994); 7. Linden et al., (2000); 8. Wilts et al., (2004); 9. Hooker et al., (2005); 10. Blanco-Canqui and Lal, (2007)

Nutrient removal and biomass harvest

Calculating the amount of a given nutrient removed by residue harvest is straight forward if the concentration and harvest rate are known. Table 3, summarizes macronutrient concentration for several crop residues.

Table 3. Macronutrient concentration of potential biomass crops.

Feedstock	N	P	K	citations[†]
	-----------------%	-------------------		
Corn stover	0.76	0.11	1.17	2, 5, 6, 7, 9, 10
Corn cob	0.57	NR[‡]	NR	5, 11, 12
Soybean straw	1.27	0.19	0.20	2, 3, 6, 7, 10
Wheat straw	0.68	0.07	0.97	1, 2, 3, 4, 8

[†] 1. (Jawson and Elliott, 1986); 2. (Lindstrom, 1986); 3. (Franzluebbers et al., 1995); 4. (Cookson et al., 1998); 5. (Burgess et al., 2002); 6. (Fageria, 2004); 7. (Al-Kaisi et al., 2005); 8. (Tirol-Padre et al., 2005); 9. (Hoskinson et al., 2007) 10. (Johnson et al., 2007a) 11. (Yu et al., 2008) 12. (Halvorson and Johnson, 2009)

[‡] NR, not reported.

The amount of nutrient removed per ton of feedstock can then be calculated (Table 4). The amount removed per acres can subsequently calculated by harvest rate. If two tons of stover were harvested per acre the total removal would be 34.4 lbs N, 4.4 lbs P and 46.8 lbs K. Crop response to removing these nutrients will vary by inherent soil fertility and prior fertilizer management. Additional nutrient inputs would be anticipated especially with repeated harvests. Soil test should be conducted to determine if and when additional inputs are required. The escalating input costs and offset risk of displaced nutrient dictate inputs be applied judicially. Removal of biomass will also remove other macro (Ca and Mg) and micronutrients (Cu, Fe, Mn and Zn), which in the long term may need to be supplemented. Producers harvesting biomass should be alert to signs of micronutrient deficiencies.

Table 4. Amount of macronutrient removed per ton of feedstock harvested.

Feedstock	N	P	K
		lbs	
Corn stover	15.2	2.2	23.4
Corn cob	11.4	NA[†]	NA
Soybean straw	25.4	3.8	4.0
Wheat straw	13.6	1.4	19.4

[†] NA, not available

Summary

As harvesting biomass as bioenergy feedstock increases management practices need consider potential productivity issue, nutrient management and protecting the soil and water resource. Resolving the interconnected and complex problems of energy and global warming will require a multi-faceted solution. Long-term and short-term economic and environmental consequences (positive and negative) must be considered. Management recommendations are emerging that consider minimizing soil erosion risks, maintaining soil carbon and nutrient management. The amount of biomass required on the field increases with increased soil tillage intensity. The amount of nutrient removed with biomass is a function of concentration and harvest rate. Limiting harvest rate to maintain soil organic matter also reduces the amount of nutrients removed.

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