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SUSTAINABLE CORN STOVER REMOVAL SYSTEMS FOR MUSHROOM SUBSTRATE PRODUCTION

A Thesis in

Agronomy

by

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ABSTRACT

Corn stover has been identified as a new potential feedstock for mushroom substrate production. Corn stover removal can increase soil erosion, deplete soil nutrients and reduce soil carbon if not managed appropriately. To mitigate corn stover removal in some situations, agronomists may need to add amendments like spent mushroom substrate (SMS) or mushroom compost (MC) to assist in to managing soil carbon levels. The objective of this study is to measure the effects of a 75% spring corn stover removal, using that stover as an ingredient for mushroom substrate and returning that SMS as an soil amendment to build soil health. The SMS resulted in an increase in soil C levels in the 0-5 cm soil profile by 81%, and 39% in the 0-25 cm soil profile. In the untreated check, where no stover was removed and no SMS added, soil C in the 0-5 cm soil profile declined by 14% and increased in the 0-25 cm soil profile by only 1.3% over the three year study. The combination of SMS addition and stover harvest also resulted in higher corn yields, lower slug populations, increased revenue, and decreased fertilizer inputs over the course of three a years of corn and three years of a hypothetical alfalfa rotation. Net returns were $4653 higher with the combination of stover harvest and SMS addition over the six years compared with the no stover harvest system. Spring and fall stover harvests were compared to evaluate the impact on the yield and nutrient composition of the stover. Spring harvested yields were reduced by 11% in the first year and 43% in the second year of the study compared to fall yields. Stover nutrient concentrations were generally unchanged, except for potassium, which declined from 7.4 to 3.0 g kg^{-1} or a 59.4% decrease from the fall to the spring. Based on this study, harvest in the spring can reduce nutrient removal and the associated costs and is a viable strategy to reduce the impacts of stover harvest. Overall, this study showed that the combination of partial stover harvest, SMS addition and spring stover harvest could improve returns associated with corn production while maintaining soil carbon levels.

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Chapter 1

Literature Review

Introduction

Corn (Zea mays L.) stover has been identified as a potential feedstock for the production of mushroom substrate and has been used successfully as a component of mushroom substrate (Obodai et al. 2003) and evaluated at the Penn State Mushroom Testing and Demonstration Facility (Beyer et al., 2010). The use of corn stover in commercial mushroom production has increased recently in Pennsylvania. Since mushroom production is a large industry in Pennsylvania, producing over 249 million kg of mushroom each year (NASS, 2012), there is considerable potential to develop a significant market for corn stover. Stover harvesting has already provided corn growers in some parts of the state an additional revenue source, but there could be consequences with the development of this resource. A key issue and concern is the potential impact of stover harvesting on the soil resource and the impact on the yield and profitability of crops following stover harvest. Strategies are needed to minimize these potential impacts.

Stover Harvest Impacts

Previous corn stover research has primarily focused on the worldwide demand for the identification of new liquid fuels sources. Biomass from corn stover is considered one of the largest potential feedstocks for the production of cellulosic ethanol (Graham et al., 2007). Corn stover is one of the largest single sources of biomass produced in the United States. Approximately 120 million dry tons are available. This has created a new focus on the impact of stover removal on the soil resource and productivity. The impact of removing corn stover on the yield of the succeeding corn crop has been variable. Several studies have shown that residue removal reduces yield of both grain and stover of subsequent crops (Wilhelm et al., 1986) and further reduces soil organic carbon (SOC) levels (Clapp et al., 2000; Maskina et al., 1993), but others show either no effect or increases in subsequent grain yields (Blanco-canqui and Lal, 2007; Barber, 1979; Karlen 1984).

Harvesting corn stover can have potential impacts on the soil resource. Stover removal can impact the soil residue cover and increase the potential for soil erosion. Sustainable harvest levels have been estimated based on the amount of crop residues that are needed to keep the soil loss at a tolerable limit (Graham et al., 2007; Perlack et al 2005). Wilhelm et al., (2007) concluded that in a no-till system, with continuous corn, approximate 0.56 Mg ha^{-1} of corn stover needs to be retained to control soil erosion on fields with 0-6% slope.

Other researchers have concluded that removing stover could have impacts on soil carbon or organic matter levels and that maintaining soil carbon levels is actually a more restrictive constraint on sustainable stover removal than either nutrient or erosion (Wilhelm et al., 2007). Soil organic carbon helps retain and recycle soil nutrients, improves soil structure, enhances water exchange characteristics and aeration and sustains microbial life within the soil. Wilhelm et al. (2007) estimated that when using no-till production systems, 5.1 Mg ha^{-1} residue needed to be retained on the soil surface to maintain soil carbon levels in a continuous corn system and 7.6 Mg ha^{-1} in a corn/soy bean rotation. Under tilled systems, recommended stover retention levels were much higher: 7.6 Mg ha^{-1} in continuous corn system. In regions like Pennsylvania with lower yielding corn, often grown in rotation, these guidelines could severely restrict corn stover removal.

Nutrient Removal

Removing corn stover can also remove nutrients that would otherwise be returned to the soil. In one Iowa State study (Sawyer and Mallarino, 2007), corn stover removal was estimated to be about 2.95

kg of P_2O_5 and 12.5 kg of K_2O per Mg (5.9 lbs of P_2O_5 and 25.0 lbs of K_2O per ton). For a 6.7 Mg ha^{-1} harvest, this would result in removal rates of 8.2 kg of P_2O_5 and 34 kg ha^{-1} of K_2O. At today's prices of $0.95 and $0.77 /lb respectively, this translates into a cost of about $83.98/hectare in nutrient removal. In some analyses, agronomists have also included a cost for the N removal in these cost estimates, but a recent study indicated that stover removal actually reduced the N response of subsequent crops (Coulter and Nafzinger, 2008) by reducing the immobilization of N by the stover.

Mitigation Strategies

Some of the negative effects of removing the corn stover can be mitigated by applying a compost, manure or for mushroom production, spent mushroom substrate (SMS). These applications could return the valuable nutrients and carbon that were removed during stover harvest. The use of SMS would help to recycle a by-product of the mushroom industry and could replace carbon removed from the system and recycle some of the nutrients removed in the stover. For corn, SMS application rates of 168 Mg ha^{-1} (75 tons/acre) are recommended for corn production (American Mushroom Institute, 2006). Wuest et al. (1995) applied SMS to corn as a sole nutrient source for three years at rates up to 90 kg m^{-2} (900 Mg ha^{-1}) and found it resulted in good yields and crop quality with minimal impacts on runoff.

Other researchers have assessed the potential for organic resources to offset stover removal. Fronning et al. (2008) added compost and manure in a series of five applications to supply a total 19.6 Mg ha^{-1} C (8.7 tons/acre) and 21.6 Mg ha^{-1} C (9.6 tons/acre) over a three year period to a corn/soybean rotation and removed the entire corn biomass with a silage harvest. At the end of the study, they reported that the 0-25 cm soil C in the compost and manure treatments was increased by 41 and 25%, respectively, while decreasing 3% in the unteated check. They concluded that soil C loss associated with stover removal could be overcome with compost or manure applications.

With considerable residue removal occurring early in the fall, much of the soil is exposed to rainfall during the winter. This effect could be mitigated by planting a cover crop or by harvesting the stover in the spring and selecting field sites that are less sloping and prone to erosion. Application of a solid manure or compost could also reduce erosion. There has been very limited work assessing the potential of or issues associated with spring stover harvest. In many areas of Pennsylvania and the northern Corn Belt, grain harvest occurs in mid-October to November and the potential to establish an adequate rye cover crop to provide soil protection is limited.

Key issues appear to be overlooked in some evaluations of stover removal. Corn yields have been increasing steadily during the past 30 years and since the harvest index has not changed appreciably (Duvick, 2005). Corn stover yields have increased as well. One consequence of this is that corn residue is becoming an increasing problem in no-till crop production. Assuming corn stover is approximately 50% of the total biomass of corn production, and that corn grain yields have increased in Pennsylvania according to USDA-NASS, from 5039 to 8967 kg ha^{-1} since 1980, then stover yields have increased by approximately 3580 kg ha^{-1} as well. As the stover yields have increased, they have resulted in more costs for managing stover in no-till production and a reluctance to adopt no-till crop production.

Sustainable Corn Stover Harvest System

Because of these concerns, strategies need to be developed that can justify the sustainability of stover removal, and lead to the development of a sustainable feedstock for the mushroom industry. Harvesting corn stover would result in an additional revenue stream for corn producers and a sustainable soil/crop production system. Other key aspects of the system should be to maintain or increase yields, reduce soil erosion, and maintain or increase soil productivity.

Developing a novel corn management system could help achieve develop a sustainable system for harvesting corn stover and utilizing SMS. One component of this system could be partial removal of the corn stover. Harvesting 75% of the available stover could leave enough residue on the field to reduce soil erosion and contribute to returning some carbon to the soil. Another component, at least on some fields, could include delaying the harvest of the stover until spring. This delay could also reduce erosion concerns and limit nutrient removal, since some nutrients could be leached from the residue during winter. Adler et al. (2006) reported that with switchgrass, the K concentration changed from an average of 3.38% in the fall to 0.63% in the spring. No-till production methods would also reduce erosion potential associated with stover removal. Adding SMS to supply nutrients and add carbon to the soil could be an additional and essential part of the system to reduce concerns over carbon depletion in the soil. Finally, another management strategy could be to rotate the field to an alfalfa grass hay crop after three years of corn. This strategy could also increase soil carbon, improve long term crop yields and utilize the excess nutrients applied with the SMS in this system (Angers, 1992).

Pest Issues

A system like this could also reduce some pest problems in no-till corn production. In some regions, such as the mid-Atlantic, slugs have become a severe problem in no-till corn production (Byers and Calvin, 1994). Corn fields with high residue will provide a favorable habitat for slugs and slug eggs. Slugs are not insects, they belong to the *phylum Mollusca*, class Gastropoda. Slugs usually feed on the lower parts of the plant when the corn is small, usually 2-8 inches in height, and can cause defoliation in corn. Damage appears as streaks, holes pierced and whiting and yellowing of the young corn leaves. The most severe feeding can cause splitting of the leaves. Significant color and growth differences in the corn can be attributed to the slug populations. Corn is most susceptible in late April through mid-June and is most prominent in cool and wet conditions. The most common slugs in the region are the gray garden slug (*Deroceras reticulatum*), marsh slug(*Deroceras laeve*), banded slug (*Arion fasciatus)* and the dusky slug (*Arion subfuscus*). One of the only control tactics for slugs is the broadcast of metaldehyde bait, marketed as Deadline, which can cost approximately $30/acre. Slug damage is often reduced under low residue conditions (Hammond et al., 1999) and removing corn stover in the spring may reduce slug populations and damage in no-till corn in our region.

Economic Considerations

Another benefit of this system could be improved economic returns. Crop producers would likely increase revenues from sale of stover and decrease fertilizer costs because of SMS applications. For example, in a hypothetical rotation of three years corn and three years alfalfa, the total fertilizer nutrient requirement for P_2O_5 would be 561 kg ha^{-1} and 1233 kg ha^{-1} K_2O. These estimates are based on yield goals of 11000 kg ha^{-1} corn each year and 6700 kg ha^{-1} of alfalfa the fourth (establishment) year and 13440 kg ha^{-1} of alfalfa the fifth and sixth year and nutrient uptake estimates in the Penn State Agronomy Guide (Beegle, 2011) An annual application of 17.9 Mg ha^{-1} DM of SMS/year for three years would supply 565 kg ha^{-1} P_2O_5 and 1317 kg ha^{-1} K_2O, which is roughly equivalent to the P and K needs of the corn and alfalfa during the entire six year rotation. The nitrogen contribution to corn from this SMS application would be about 45 kg ha^{-1} in the first year, 67 kg ha^{-1} in the second year and 70 kg ha^{-1} in the third year.

Little published information is available that can be used to assess the potential of stover harvest for mushroom substrate production and further research is needed to assess the potential impacts of this practice and to develop alternative systems to supply this material sustainably. The objective of this study was to evaluate the sustainability of a cropping system for the production of corn stover as a mushroom feedstock substrate using a combination of spring harvest, SMS additions, and crop rotation. In this evaluation, sustainability would include impacts on soil nutrients, soil carbon, crop production and the economic returns to the crop producer.

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Chapter 2

Impact of Corn Stover Removal and SMS Amendments on Cropping Systems

Introduction

Corn (Zea mays L.) stover has been identified as a potential feedstock for the production of mushroom substrate and has been used successfully as a component of mushroom substrate at the Penn State Mushroom Testing and Demonstration Facility (Beyer et al. 2010). The use of corn stover in commercial mushroom production has increased recently in Pennsylvania. Stover harvesting has provided corn growers in some parts of the state an additional revenue source. However, the impact of stover harvesting on the soil resource and the impact on the yield and profitability of crops following stover harvest has not been quantified.

Some of the negative effects of removing the corn stover like soil erosion, loss of soil carbon and loss of soil nutrients can be mitigated by applying compost, manure, or for mushroom production, spent mushroom substrate (SMS). These applications could return the valuable nutrients and carbon that were removed during stover harvest. The SMS application could also help improve the soil physical properties and improving water infiltration, reducing runoff and reducing erosion (Sparling et al. 2006). Fronning et al. (2008) added compost and manure in a series of five applications to supply a total 19.6 Mg ha^{-1} C (8.7 tons/acre) and 21.6 Mg ha^{-1} C (9.6 tons/acre) over a three year period to a corn/soybean rotation and removed the entire corn biomass with a silage harvest. At the end of the study, they reported that the 0-25 cm soil C in the compost and manure treatments was increased by 41 and 25%, respectively, while decreasing 3% in the unteated check. They concluded that soil C loss associated with stover removal could be overcome with compost or manure applications.

Because of these concerns, strategies need to be developed that can justify the sustainability of stover removal, and leads to the development of a sustainable feedstock for the mushroom industry.

This would result in an additional revenue stream for corn producers and a sustainable soil/crop production system that maintains or increases yields, reduces soil erosion, and maintains or increases soil productivity.

Developing a novel corn management system could help achieve a sustainable system for harvesting corn stover and also utilizing SMS. One option in this system could be partial removal of the corn stover to leave enough residue on the field to reduce soil erosion and contribute to returning some carbon to the soil. Another option, at least on some fields, could include delaying the harvest of the stover until spring. This could also reduce erosion concerns and limit nutrient removal, since some nutrients could be leached from the residue during winter. Adler et al., (2006) reported that with switchgrass, the K concentration changed from an average of 3.38% in the fall to 0.63% in the spring. Adding spent compost to supply nutrients and add carbon to the soil could be an additional and essential part of the system to reduce concerns over carbon depletion in the soil. Finally, another management strategy could be to rotate the field to an alfalfa grass hay crop after three years of corn. This could also increase soil carbon, improve long-term crop yields, and utilize the excess nutrients applied with the SMS in this system.

A system that removes corn stover could also reduce some pest problems such as slugs in no-till corn production, which have become a severe problem in no-till corn production in the mid-Atlantic region. Cornfields with high residue provide a favorable habitat for slugs and slug eggs (Beyers et al. 1994). One of the only control tactics for slugs is the broadcast of a metaldehyde bait, marketed as Deadline, which can cost approximately $74/ha. Slug damage is often reduced under low residue conditions (Hammond et al. 1999) and removing corn stover in the spring may reduce slug damage in no-till corn in our region.

Another benefit of this system could be improved economic returns. Crop producers would likely increase revenues from sale of stover and decrease fertilizer costs because of SMS applications. For example, in a hypothetical rotation of three years corn and three years alfalfa, the total fertilizer nutrient requirement for P_2O_5 and K_2O would be 561 kg ha^{-1} and 1233 kg ha^{-1} respectively. These estimates are based on yield goals of 11.0 Mg ha^{-1} corn each year and 6.73 Mg ha^{-1} of alfalfa the fourth (establishment) year and 13.4 Mg ha^{-1} of alfalfa the fifth and sixth year and nutrient uptake estimates in the (Beegle, 2011). An annual application of 8.8 Mg DM of SMS/year for three years would supply 561 kg ha^{-1} of P_2O_5 and 1317 kg ha^{-1} of K_2O (504 pounds/acre P_2O_5 and 1176 pounds K_2O pounds/acre), which is roughly equivalent to the P and K needs of the corn and alfalfa during the entire six-year rotation. The nitrogen contribution from the SMS would be about 45, 67, and 78 kg N ha^{-1} in the first, second and third year respectively (40, 60 and 70 pounds pounds/acre).

The objective of this study is to evaluate a cropping system that includes 75% corn stover removal in the spring, no-till corn production, and a SMS application prior to corn planting compared to a more conventional corn production system with and without corn stover removal.

Materials and Methods

A field study was established in spring 2009 and continued for three years on the Russell Larson Research Farm near State College, Pa on a Hagerstown silt loam soil in a field that had been in corn the year previously. Crop residue from the prior year was removed from the stover removal treatments to simulate the removal of residue prior to the establishment of the test. Individual plot size was 3 meters by 45.7 meters and the experimental design was a randomized complete block with three treatments and four replicates. Spent mushroom compost produced from the Penn State Mushroom Testing and Demonstration Facility was analyzed by the Agricultural Analysis Services Laboratory to assess the carbon and nutrient profile of the compost (Table 2-1).

The SMS used in this study consisted of a “prewet” mix of 1075 kg of corn stover, 317 kg of switchgrass straw, 68 kg of dried poultry manure, 1229 kg of straw-bedded horse manure and 1630 liters of water (the prewet is a static pile that is mixed four days prior to the actual build to allow the switchgrass straw time to soften up). In addition to the prewet ingredients, other subsequent ingredients included 181 kg of gypsum, 136 kg additional pounds of poultry manure, the prewet pile, 3411 liters of water and approximately 4444 kg of additional horse manure for a total wet weight of 11836 kg. On the day of the compost construction or "build," the compost was placed in an aerated bunker and fresh air was supplied to the compost. On day 3, the compost was mixed, 227 kg of dried distillers grain and additional water was added to the pile. The compost was then placed back in the aerated bunker. On day 6, the compost was mixed again and additional water was added to the compost to achieve approximately 75% moisture. During each year of the study, the compost was applied at a rate of about 18 Mg ha^{-1} of dry matter per acre (56 Mg ha^{-1} on an as-is basis) using a small-scale manure spreader.

Treatments consisted of three treatments managed in a no-till system that involved stover harvest and SMS applications, which include 1) SH/SMS - 75% stover harvest in the spring followed by an SMS application prior to planting, 2) SH/NPK - 75% stover harvest in the spring followed with an application of NPK (commercial fertilizers) and 3) NSH/ NPK - No stover harvest followed with an application of NPK. SMS application rates of 18 Mg ha^{-1} DM was based on the potential removal of the P and K during a six-year rotation of three years of corn followed by three years of alfalfa hay. NPK rates were also based on the amount of nutrients removed in the grain and stover.

Fertilizer additions to each treatment were managed to provide optimum levels of nutrients and account for nutrients removed in the harvested stover. In the NPK/stover treatment for example, 63 and 73 kg ha^{-1} of P_2O_5 and K_2O, respectively (56 lbs./acre P_2O_5 and 65 K_2O lbs./acre) were applied prior to planting. In NPK treatment, where stover was not removed, 56 kg ha^{-1} of P_2O_5 and K_2O were applied respectively (50 lbs./acre K_2O and 50 lbs./acre P_2O_5) were applied prior to planting (Table 2-2).

Corn was planted in late April or early May, (Table 2-2) with a Monosem (Edwardsville, KS) 4-row no-till corn planter at a seeding rate of 74100 plants per hectare. The hybrid used was Dekalb DKC 59-64, a 109 day Relative Maturity hybrid with resistance to the European corn borer (*Ostrinia nubilalis* (Hübner), Western corn rootworm (*Diabrotica virgifera virgifera)* and glyphosate.

Prior to harvest, individual plots were sampled to assess the total biomass and the harvest index (grain/total biomass ratio) of the crop. Plant tissues samples were taken prior to harvest. All plots were harvested with a research combine and yields adjusted to 15.5% moisture.

Corn stover was harvested in early spring with a Hesston StakHand (Agco, Duluth, GA) harvester equipped with load cells from each plot (Table 2-2). Residue samples were collected following a spring stover harvest and crop residue coverage were estimated using digital photography interpreted with SamplePoint software (Booth et al. 2006). Statistical analysis was performed using the PROC GLM procedures in SAS version 9.2 (Cary, NC).

Soil Carbon and Nutrient Assessment

Prior to the initiation of the study, and following the grain harvest in the third year, soils were sampled using a hand soil probe that is 5.08 cm in diameter at 0-5 cm and 5-25 cm depths to assess total N and C and also P, K, Ca, Mg, pH and Zn. A composite sample from the ten locations in each plot was analyzed. Soil samples were weighed before being sifted through a 4-mm screen to remove rock fragments and other debris. The Mehlich 3 (ICP) (Wolfand Beegle, 1995) was performed to test for P, K, Ca, Mg and the Mehlich buffer (Mehlich, 1976) test was used to determine pH. Total C was assessed by combustion (Nelson and Sommers, 1996) and the total N was also be analyzed by combustion (Bremner, 1996). At the conclusion of the study, soils were sampled again to assess changes in carbon and other nutrient levels. Field estimates of bulk densities (Grossman and Reinsch, 2002) were also assessed before and after the study following harvest in the third year (Table 2-2).

Plant Tissue Analysis

In each plot, corn tissue was collected from a two-meter row section prior to the mechanical corn harvest in the fall. Plants were counted, ears were removed, and the stalks were separated from the ear up (tops) and ear down (bottoms). Plant tissue analysis was performed on tops (with cob), bottoms, and shelled corn (both machine and hand harvest) to estimate nutrient uptake. Each sample was analyzed for N, P, K, Ca, Mg, S, Fe, Cu, Al, and Zn by the Penn State Agricultural Analytical Service laboratory. The Total N and C were analyzed using the combustion method (Horneck and Miller 1998). The P, K, Ca, Mg, S, Fe, Cu, Al, and Zn were analyzed using the Acid Digestion Hot Block method (Huang and Schulte, 1985).

Slug Sampling and Damage Assessment

Three slug traps were randomly placed in each plot ten days prior to planting and be monitored every ten days (Table 2-2). Each trap was constructed from white Owens Corning rolled roof shingles. These slug traps provide a relative measure of slug activity (Byers at al., 1989). Each trap was placed with the white side up between the previous year's corn rows with the residue removed to help develop a cool wet environment favorable to slugs. Counts were conducted by turning the shingle over and counting all species of slugs on the bottom of the shingle as well as the area underneath the shingle. Counts were taken from ten days prior to planting until approximately 30 days post planting. Corn plant height measurements at the V-6 stage were taken to document to help assess any lack of vigor associated with slug damage (Table 2-2).

Economic Impact of Stover Removal and Cropping system

Enterprise budgets were developed for the estimated six-year rotations for each of the three treatments. The budgets reflected current costs and returns similar to those in the Farm Management Enterprise Budget in the Penn State Agronomy Guide (Harper, 2011). The price of round baled corn stover directly out of the field was estimated at approximately \$89 Mg^{-1} (\$100/ton). The price of harvesting and round baling stover was estimated from the Pennsylvania Custom Machinery Harvest Rates (http://www.nass.usda.gov/Statistics_by_State/Pennsylvania/Publications/Machinery_Custom_Rates/custom10.pdf). The compost cost included the purchase price from the mushroom grower, which is approximately $75 per 26.9 Mg or about $2.79 Mg^{-1}. Additional trucking and application costs were included. Nutrient cost estimates for fertilization of the corn and alfalfa included both the cost of nutrients and the cost of application. Net returns to land and management were calculated for each of the three treatments over the six-year timeframe to determine their potential impact.

Results and Discussion

Weather

Total precipitation for the months of April through October was variable and ranged from 59.9 cm to 92.5 cm compared to an average of 69 cm (Table 2-3). Conditions were especially dry in June and July of 2011, when there was a 5-week period with no precipitation and higher than normal temperatures, which resulted in poor corn pollination and greatly reduced corn yields. Air temperatures over the three years for April through October were close to normal in many months, except for the warm July in 2011 and the cool June temperatures in 2009 and 2011 (Table 2-4).

Population and Corn Growth

Corn populations were generally similar in the first two years but in the third year the SMS treatment had significantly higher plant populations than the other two treatments (Table 2-5). This could have been due to a better seed environment due to the enhanced organic matter at the soil surface. Conditions at planting during 2011 were marginal with some sidewall compaction occurring throughout the plot. In addition, the excessive stover accumulation in the NSH/NPK treatment may have contributed to lower emergence. The SMS treatment tended to have the tallest corn at both the V6 and the R4 stage (Table 2-5). The SH/SMS treatment was taller than the SH/NPK treatment at R4 each year. This could have been due to an alleviation of water stress from the SMS either through enhanced water holding capacity or a mulching effect from the SMS. In 2010 when the weather was wet and cool the SH/NPK was 23 cm taller than the NSH/NPK treatment at the V6 stage presumably due to less slug injury. These results indicate that in some years, a stover harvest can improve early season stands and corn growth and that SMS application can enhance mid-season corn growth under some conditions.

Yield

Grain yields in two of the three years were highest in the SH/SMS treatment yield also tended to be higher in 2011, but drought caused yields to be lower and more variability than in other years for both the grain and stover (Table 2-6). Over the three years the SH/SMS treatment resulted in a 6.3% increase corn yield over the SH/NPK treatment and a 9.9% increase over the NSH/ NPK treatment. In addition, the SH/NPK had higher yields than the NSH/NPK two of the three years. These data are in contrast to some reports (Wilhelm *et al.*, 2007) that suggest lower yields where stover harvests had occurred but in this study there appeared to be more effect of the residue on corn yields, perhaps related to emergence and slug issues.

Concentration and Uptake

The phosphorus concentration in the corn stover averaged 0.06% P or 1.38 g P_2O_5 ha^{-1} or 1.38 kg P_2O_5 Mg^{-1}. Averaged over all treatments P_2O_5 uptake was 5.2 kg ha^{-1}. The Potassium concentration averaged 0.15% K or 1.8 g kg^{-1} or 1.8 kg K_2O Mg^{-1} (Table 2-7). Averaged over all treatments for three years the removal rate in the corn stover was 6.8 kg K_2O ha^{-1}. These removal rates were lower than these reported by Sawyer and Mallarino, 2007 who estimated removal rate of 2.95 kg P_2O_5 Mg^{-1} and 12.5 kg K_2O ha^{-1}. The much lower K_2O removal rates are likely due to the spring harvest of the stover. In a related study, Houser (2012) reported that K concentrations were reduced by 60% in the spring relative to the fall. In this study, there may have been even more leaching of K.

Crop producers would likely increase revenues from sale of stover and decrease fertilizer costs because of SMS applications. For example, in a hypothetical rotation of three years corn and three years alfalfa, the total fertilizer nutrient requirement for P_2O_5 would be 561 kg ha^{-1} and 1233 kg ha^{-1} K_2O. These estimates are based on yield goals of 11000 kg ha^{-1} corn each year and 6700 kg ha^{-1} of alfalfa the fourth (establishment) year and 13440 kg ha^{-1} of alfalfa the fifth and sixth year and nutrient uptake estimates in the Penn State Agronomy Guide (Beegle, 2011) An annual application of 17.9 Mg ha^{-1} /ha DM of SMS/year for three years would supply 565 kg ha^{-1} P_2O_5 and 1317 kg ha^{-1} K_2O, which is roughly equivalent to the estimated P and K needs of the corn and alfalfa during the entire six year rotation. The nitrogen contribution to corn from this SMS application would be about 45 kg ha^{-1} in the first year, 67 kg ha^{-1} in the second year and 70 kg ha^{-1} in the third year.

A summary of phosphorus inputs and outputs over the three years of the study showed that the NSH treatment was close to being in balance with a balance of -2 kg ha^{-1} P (Table 2-8). This confirms the nutrient recommendations used for this study. The SH/NPK treatment had a positive P balance of 34 kg P ha^{-1}. This was likely due to an overestimate of the stover removal, since additional P of 41 kg ha^{-1} was added to compensate for stover uptake and this only totaled 6 kg ha^{-1}. The balance for the SH/SMS treatment was 255 kg P ha^{-1} which was slightly more than anticipated.

The balance for potassium revealed a positive balance of 54 kg ha^{-1} for the NSH/NPK treatment, indicating that that the fertilizer recommendation slightly overestimated removal rates (Table 2-8). The potassium balance for the SH/NPK treatment had a large positive balance of 153 kg ha^{-1}, mostly due to an overestimate of the potential stover removal and the associated fertilizer application. The potassium balance for the SH/SMS treatment was also higher than anticipated due to the lower stover removal. The lower yields in the third year of the study also likely contributed to the higher nutrient balances. The original fertilizer recommendations for corn were based on average yields of 11 Mg ha^{-1} and over the three years, yields averaged 9.2 Mg ha^{-1}. Based on these nutrient balances, compost rates could be adjusted downward for future recommendation, without likely impacting corn yields or the fertilizer requirements for the succeeding crops.

Soil Carbon Accumulation or Depletion

With the addition of SMS, the total C increased greatly in the surface 0-5 cm from 19.9 to 36.2 g ha^{-1} or an 81% increase. At these lower SMS application rates than industry guidelines (American Mushroom Institute. 2006), which are based on N, SMS more than offset the C impacts from removal of the stover. In the 0-25 cm soil profile the total C was increased 39.2% which was similar the net carbon impact found by Fronning et al. (2008) who reported a 41% increase from compost additions prior to stover and grain corn removal over a three year period. In the SH/NPK treatment, soil C in the 0-5 cm declined 14%, which was also similar to what Fronning et al. (2008) found.In the 0-25 cm depth the soil C remained nearly constant in the SH/NPK treatment compared to a 12.4% increase in the NSH/NPK (control). This may have been a result of the fall soil test in 2011 compared to the spring soil test in 2009 (Table 2-9). Given the carbon accumulations noted with the SMS rates in this study, along with the P accumulations, it might be worthwhile to consider lower SMS rate either initially or after an initial rotation such as the one in this study has enhanced soil quality variables. Eventually, only enough SMS would need to be added to maintain soil carbon levels associated with the stover removal and these would likely be much lower than those used in this study.

Soil Cover

Over the three years of the trial, the NSH/NPK averaged a 98% soil cover rating compared to 82% for the other two treatments after a spring corn stover harvest (Table 2-10). With 82%, ground cover after removing corn stover there would be adequate cover to minimize either rain or wind erosion until the next crop is planted. This suggests that the spring harvest strategy used as part of this system could contribute to the overall sustainability of corn stover harvesting. Berruto et al (2010) reported that spring harvested corn stover provides a dry, easy to store material, so this approach could have some other advantages.

Bulk Density

Treatment effects on bulk density were most apparent in the 0-5 cm soil depth, as the SH/SMS treatment had lower bulk density than the NSH/NPK in the 0-5 cm soil profile and therefore improved soil quality (Table 2-11). This was probably due to the addition of the SMS, which provided a great deal of organic matter to the soil surface. Stewart et al. (1998) also reported that SMS applications over a two-year period reduced bulk density in a vegetable trial and this resulted in reduced crusting, improved aggregate stability, increased infiltration rates and reduced diurnal temperature changes. There were no differences in bulk density between treatments in either the 5-25 cm and the 0-25 cm soil profiles. These results suggest that incorporating surface SMS applications as part of a stover harvest strategy cannot only mitigate the impacts of stover removal, but it could improve soil properties such as bulk density and the subsequent yield potential of the soil. Based on the results of this study, the SMS/SH treatment could be considered as a method to remediate soils with low soil carbon and water holding capacity.

Slugs

There were differences among the treatments when observing the slug counts (Table 2-12). There were also visual differences (yellowing and piercing) and height differences among the treatments and corn plant measurements at the V-6 stage. In 2010 when the weather was wet and cool the SH/NPK was 23 cm taller than the NSH/NPK treatment at the V6 stage presumably due to less slug injury. It was expected that the NSH/NPK treatment would yield higher slug counts due to the increased residue but it was surprising that the SH/SMS treatments were so low. This could have been due to some inhibitory effect of the SMS on slugs.

Cropping System Economics

A list of the inputs and field operations for each of the treatments is shown in Table 2-13. After evaluating the 3 year study and the additional 3 years of hypothetical alfalfa rotation the SH/SMS resulted in the highest net return of $15746/ha (Table 2-14). This higher net return was due to a combination of several factors including higher corn yields, additional stover revenue, lower P and K inputs for the corn crop and lower P and K inputs for subsequent rotational hay crop. This resulted in a higher net profit for the system. The net returns were increased by 30% over the SH/NPK and a 42% over the NSH/NPK. The positive economic returns are a function of the cost of the SMS and the associated transportation costs. In this analysis, we assumed an 80 km hauling distance and compost at $125/Mg but a longer hauling distance or more expensive compost could reduce returns considerably. One option to reduce hauling costs could be to consider backhauling SMS arrangements when delivering stover to the mushroom compost facility. Another option would be to evaluate lower compost rates, which would decrease the compost and transportation costs but might not influence the yield and nutrient application costs to the corn and the subsequent alfalfa since it appears that both the carbon and nutrient accumulations were higher than anticipated with the rates used in this study.

Conclusions

This study documents the potential of a cropping system that included 75% stover removal in the spring, and a SMS application prior to no-till corn planting. When compared to a conventional corn production system with stover removal, this system resulted in less potential for soil erosion, higher corn yields, and increased soil carbon and nutrient levels at the end of a three year rotation. The system also provided sufficient P and K to potentially avoid the need for supplemental P and K fertilizers during the hay phase of the rotation (Table 2-15). This study demonstrates that with careful management and recycling of carbon and nutrients with SMS corn stover removal can be a sustainable practice in Pennsylvania. This study provides guidance for producers who would like to harvest corn stover for additional revenue and still be able to maintain long-term productivity, while minimizing runoff and erosion. Based on this study, SMS as a soil amendment can increase grain yields, increase soil carbon, maintain considerable soil cover and can create significant return on investment. Future research should focus on lower SMS application rates, which would be needed to maintain soil carbon levels under a stover harvesting strategy. This study also has demonstrated the potential benefits of delaying stover harvests until spring and the potentially lower potassium removal rates. Future research should focus on confirming these removal rates and documenting the decline in stover potassium over time during the fall and winter.

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Chapter 3

Differences between Fall and Spring Corn Stover Harvest

Introduction

Corn stover has been identified as a potential feedstock for the production of mushroom substrate (Beyer et al., 2010) and the use of corn stover in commercial mushroom production has increased recently in Pennsylvania and the mid-Atlantic region. Since mushroom production is a large industry in Pennsylvania, producing over 249 million kg of mushroom each year (NASS, 2012), there is considerable potential to develop a significant market for corn stover. Other uses of corn stover such as dairy bedding and potentially bioenergy are causing an increased use of this resource. Soils in this region are particularly vulnerable to stover removal because of slope, low organic matter and lower corn yield potential than in the Midwest US. A key concern is the potential impact of stover harvesting on the soil resource in carbon retention, nutrient removal and soil erosion. Strategies are needed to minimize these potential impacts.

One tactic for mitigating the impacts on soil erosion and nutrient removal could be the use of spring versus fall harvest. Overwinter weathering of the stover is likely to reduce the nutrient content, especially for potassium as has been reported in other crops. Adler et al., (2006) reported that with switchgrass, the K concentration changed from an average of 3.38% in the fall to 0.63% in the spring. Another potential benefit of spring harvested corn stover is higher dry matter content. Shinners et al., (2007) reported that harvesting dry stover in the fall below 20% moisture could be difficult. Spring stover removal can also reduce populations of slugs, which can be a significant pest in corn in some regions. Slug damage is often reduced under low residue conditions (Hammond et al., 1999) and removing corn stover in the spring may reduce slug damage in no-till corn.

Sustainable stover harvest levels have been estimated based on the amount of crop residues that are needed to keep the soil loss at a tolerable limit (Graham et al., 2007; Perlack et al 2005). Wilhelm et al., 2007 reported that in a no-till system, with continuous corn, approximate 0.56 Mg ha^{-1} of corn stover needs to be retained to control soil erosion on fields with 0-6% slope. With a partial spring stover harvest and no-till corn production, soil erosion potential could be reduced to allow stover harvest on a soil with slopes common in our region.

The objective of this study is to document the difference in yield and nutrient composition between fall and spring harvested corn stover. Spring harvested corn stover can mitigate potential for soil erosion, increased corn yields, and nutrient levels in the soil.

Field Research

A field study was established in 2009 and conducted for two years until 2011 on the Penn State Russell Larson Research Farm near State College on Hagerstown silt loam soil (Fine, mixed, semiactive, mesic Typic Hapludalfs) in a field previously cropped to corn each year. The study consisted of two treatments managed in a no-till system where corn had been harvested for grain: 1) fall harvested corn stover and 2) spring harvested corn stover. In the first year, the field was planted to the Pioneer hybrid 35K01 at 30,000 seeds per acre and fall harvest occurred on 12 November 2009 and the spring harvest on 19 March 2010. In the second year, the field was planted to the DeKalb hybrid 59-35 at 30,000 seeds per acre and fall harvest occurred on 19 November 2010 and the spring harvest on 11 May 2011. Individual plot size was 3.0 m by 30.5 m and was a randomized complete block with six replicates. Corn stover was harvested with a Hesston (Agco) (Duluth, GA) StakHand harvester, equipped with load cells. The goal was to harvest as much of the stover as possible, and with this machine ,was nearly a 100% removal. Residue samples were collected following the fall harvest and in the spring harvest to assess the nutrient content of the stover. Statistical analysis were performed using PROC GLM procedures in SAS version 9.2 (Cary, NC).

Stover Yield

Stover yields were significantly lower in the spring harvest compared to the fall. Averaged over both years, the spring harvest yield averaged 6003 kg ha^{-1} or 73% of the fall yield which was 8274 kg ha^{-1} (Table 3-1). The response to spring harvest varied considerably between the two seasons. In the spring, 2010 harvest yields averaged 7133 kg ha^{-1} compared to 7970 kg ha^{-1} for the fall 2009 harvest for a recovery of 89 %. In spring 2011, the spring stover yield was 4873 kg ha^{-1} compared to 8578 kg ha^{-1} obtained in the fall or 57 % of the fall yield. Lazotte and Savoie (2010) in Quebec estimated stover yield at two sites in spring and fall environments and found only small DM losses over winter and reported 97% of the stover was still present in the spring. They harvested approximately 50% of the available stover in the spring and spring yields averaged 94% of the fall harvest yields. Fernandez (2011) reported a Wisconsin study that showed the percent residue remaining in April from the previous corn crop during three years was 88, 92, and 79%. Our lower spring yields in the second year of our study were likely due to an open winter with little snow, which increased over winter losses. Based on our study, spring stover yields likely vary relative to the fall depending on weather conditions that influence losses and spring recovery and in our environment might range from 57% to 89%. If harvest goals for some sites are in range of 4000 kg ha^{-1} or less, then our study confirms that these levels will often be available for harvest in the spring.

Stover Nutrient Concentrations

Fall stover nutrient concentrations averaged 7.3 N, 0.58 P and 7.4 g kg^{-1} K. Stover nutrient concentrations in the spring compared to fall varied among the nutrients (Table 3-2). Nitrogen concentrations between spring and fall stover were not significantly different in either year, although they tended to be lower, averaging 0.9 g kg^{-1} N, lower in the spring than in the fall. Carbon levels were similar in both the spring and the fall. Phosphorous levels in the spring stover were slightly lower than the fall values in 2009 and similar to the fall concentration in 2010. Averaged over both years, potassium levels declined from 7.4 g kg^{-1} in the fall to 3.0 g kg^{-1} in the spring, which indicates that 59.4% of the potassium was able to leach back into the soil. The reduction in potassium concentration in the spring compared to fall harvested stover was similar in the two years of the study: 59.5% in 2009 and 60.9% in 2010. This is contrast to the 81% reduction in tissue potassium reported by Adler et al 2006 in switchgrass and the lower reduction in corn potassium could be related to the larger size of the corn crop residue.

Stover Nutrient Uptake

Nutrient removal from corn stover harvest is often expressed in pounds of fertilizer nutrients/ton of dry matter in English units. For this study, the fall harvested corn stover these concentrations are equivalent to 13.0 lbs. N/ton, 2.6 lbs. P_2O_5/ton and 18.0 lbs. K_2O/ton. These are slightly lower than those reported by Saywer et al. 2007, in Iowa, who reported 5.9 lbs./ton P_2O_5 and 25.0 lbs. K_2O/ton but are similar to those reported by Gould (2007), in Michigan who reported 13.6 lbs. N/ton, 3.6 lbs./ton P_2O_5 and 19.7 lbs. K_2O/ton.

Spring harvested corn stover had concentrations of 6.4 g kg^{-1} N, 0.53 g kg^{-1} P and 3.0 g kg^{-1} K are equivalent to 12.0 lbs./ ton N, 2.5 lbs./ton P_2O_5 and 7.2 lbs. /ton K_2O. Nutrient removal can influence subsequent fertilizer costs, especially if the K levels are reduced substantially in the spring as they are in this study. Coulter and Nafziger (2008) reported that N fertilizer costs are not increase with stover removal due to reduced potential immobilization from stover decomposition. Considering the costs of nutrient removal for P and K at \$0.70/P_2O_5 and \$0.58/lb K_2O, these results in a nutrient cost removal per ton of \$12.26 in the fall and \$5.92 in the spring. Thus, delaying harvest until spring can reduce nutrient removal substantially. At an approximate stover value of \$100/ton, the nutrient removal represents 12% of the revenue in the fall and 6% in the spring.

Conclusions

Based on this research, a spring stover harvest can be a tool to mitigate impacts of stover removal. Spring harvested stover yield can vary depending on the environment but in this study 73% of the fall stover was remaining in the spring. Other studies have shown higher levels of stover remaining in the spring. Since sustainable stover harvest strategies often recommend a partial stover harvest there should be adequate residue to harvest in the spring in most cases. A spring harvest strategy allows field to remain covered and reduce potential for soil erosion and runoff. Harvesting in the spring can also reduce nutrient removal, especially potash, and reduced fertilizer replacement costs by $6.34 per ton of corn stover. Other studies have shown that spring-harvested stover can result in a drier product and reduce the incidence of slug injury on subsequent crops. As corn producers consider stover harvest as a means to increase revenue or manage residue, they should consider delaying harvest until late winter or early spring in some situations to minimize nutrient removal. Corn producer should also consider an obtaining an analysis of stover removed since in some cases the nutrient content may be lower than commonly quoted Midwestern figures as occurred with the fall harvested stover in this study.

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Appendix Tables

Table 2-1: Compost and nutrients analysis, application rates, and dry matter (DM).

Date	27 April 2009	21 April 2010	May 12 2011
	------------------------------------	Mg ha^{-1} ------------------------------------	
Rate	55.3	55.1	57.8
	----------------------------------g kg^{-1} on "as is" basis------------------------		
DM	326	325	310
C	105	128	104
N	6.4	10	6.4
P_2O_5	3.5	3.5	3.0
K_2O	8.0	10.4	5.8
M	674	675	690
S	326	325	310
C/N	163	128	163

Table 2-2: Important dates throughout the research trial that include soil sampling, fertilizer application, ground cover assessments, planting, herbicide application, and harvest.

	2009	2010	2011
Soil sampling	3 March		12 December
Spring stover harvest	4 April	19 March	11 May
Applied compost	27 April	21 April	12 May
Applied P/ K	27 April	25 March	11 May
Planted corn	29 April	30 April	12 May
Placed slug traps	29 April	30 April	12 May
herbicide/ N	30 April	5 May	13 May
Ground cover pictures	4 April	25 March	12 May
Side dressed	8 June	8 June	8 June
Post herbicide	8 June	15 June	20 June
Corn height (V 6)	7 June	6 June	27 June
Corn height (R 4)	6 August	20 August	27 August
Disease Ratings	6 August	20 August	27 August
Hand harvest	9 November	3 November	17 November
Corn harvest	13 November	3 November	18 November

Table 2-3: Monthly precipitation during the growing seasons for the duration of the trial.

	Precipitation			
Month	2009	2010	2011	Normal
	---cm--			
April	7.47	3.20	15.85	8.98
May	11.13	9.60	14.15	9.46
June	11.86	6.27	6.86	10.10
July	10.82	8.51	4.98	9.92
August	6.86	12.17	15.04	10.63
September	8.74	8.00	23.50	11.37
October	15.62	12.19	12.12	8.61
Total	72.49	59.94	92.48	69.08

Table 2-4: Average monthly air temperatures for 2009, 2010, and 2011 at the Penn State Agronomy Farm near State College at Rock Springs, Pa.

	Mean Temperature				
Month	2009	2010	2011	Mean	Normal
	°C				
April	8.7	12.0	10.7	10.5	9.0
May	13.7	16.3	15.8	15.2	15.1
June	15.2	21.0	15.1	17.1	19.7
July	20.0	22.9	23.9	22.3	22.1
August	21.9	21.8	20.7	21.5	21.0
September	16.4	16.9	17.8	17.0	17.0
October	8.4	10.5	10.7	9.9	10.9

Table 2-5: Corn population and corn growth for the three treatments during the three-year trial

Treatment†	2009			2010			2011		
	population	V6	R4	population	V6	R4	population	V6	R4
	Plants ha^{-1}	cm	cm	Plants ha^{-1}	cm	cm	Plants ha^{-1}	cm	cm
SH/ SMS	70112	110	279	78712	108	248	70514	116	236
SH/ NPK	69888	105	260	75433	107	234	63954	101	207
NSH/NPK	68992	103	274	78712	84	247	57723	102	215
LSD (.05)	ns	ns	7	ns	10	7	11711	10	11

† Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.
‡ not significant at P>0.05.

Table 2-6: Corn and stover yields as influenced by stover harvest and SMS application in Central PA in 2009, 2010, and 2011.

Treatment†	2009	2010	2011	Mean
		Grain Yields (kg ha^{-1})		
SH/ SMS	12218	11396	5407	9674
SH/ NPK	11415	10907	4986	9103
NSH/NPK	10788	10512	5112	8804
LSD (.05)	652	378	ns	351
		Stover Yields (kg ha^{-1})		
SH/ SMS	4048	5162	2505	3905
SH/ NPK	3877	4918	1996	3597
NSH/NPK				
LSD (.05)	ns	ns	ns	ns

† Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.

‡ not significant at P>0.05.

Table 2-7: Stover nutrient concentration as influenced SH/SMS and SH/NPK harvest in 2009, 2010 and 2011 in Central PA.

Treatment[†]	2009				2010				2011				Mean			
	N	C	P	K	N	C	P	K	N	C	P	K	N	C	P	K
	----g kg^{-1}----															
SH/ SMS	6.8	422	0.60	1.5	7.1	435	0.52	1.9	7.2	454	0.70	0.95	7.0	432	0.60	1.4
SH/ NPK	6.0	415	0.50	1.3	6.6	425	0.56	1.9	7.3	457	0.65	0.98	6.6	438	0.58	1.4
NSH/NPK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	6.4	418	0.55	1.4	6.9	430	0.55	1.9	7.2	456	0.68	0.96	6.8	435	0.59	1.4
LSD (.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

† Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.

‡ not significant at P>0.05.

Table 2-8: Total Phosphorus and Potassium balance of inputs and outputs.

	Input			Output			Balance
Treatment†	Fertilizer	Compost	Total (P)	Stover	Grain	Total (P)	Total
SH/ SMS	19	247	265	6.9	83	90	255
SH/ NPK	114	0	114	6.0	74	80	34
NSH/NPK	73	0	73		75	75	-2
Treatment†	Fertilizer	Compost	Total (K)	Stover	Grain	Total (K)	Total
SH/ SMS	36	1124	1159	18	96	114	1045
SH/ NPK	257	0	257	17	87	104	153
NSH/NPK	140	0	140		85	86	54

†Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.

Table 2-9: Impact of the stover harvest treatments on soil bulk density in the 0-5, 5-25, and 0-25 cm profiles.

	0-5 cm			5-25 cm			0-25 cm		
Treatment	2009	2011	Change	2009	2011	Change	2009	2011	Change
	-----g cm^{-3}------		%	--------g cm^{-3}------		%	------g cm^{-3}------		%
SH/ SMS	1.12	.97	-13.3	1.08	1.19	12.1	1.09	1.15	6.2
SH/ NPK	1.16	1.06	-8.6	1.06	1.14	8.1	1.08	1.13	5.0
NSH/NPK	1.13	1.10	-2.6	1.09	1.18	9.8	1.09	1.16	6.8
LSD (.05)	ns	.11	5.6	ns	ns	ns	ns	ns	ns

† Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.
‡ not significant at P>0.05.

Table 2-10**:** Soil cover after spring stover harvest with a 75% removal rate.

Treatment†	2009	2010	2011	Mean
	--% cover--------------------------------------			
SH/ SMS	78	86	81	82
SH/ NPK	80	83	81	81
NSH/NPK	99	97	98	98
Overall average	86	89	87	87
LSD (.05)	7	8	4	5

†Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.

Table 2-11: Impact of stover harvest means for carbon in the 0-5, 5-25, and 0-25 cm profiles

	0-5 cm			5-25 cm			0-25 cm		
Treatment†	2009	2011	Change	2009	2011	Change	2009	2011	Change
	-------g kg^{-1}-----		%	-------g kg^{-1}------		%	-------g kg^{-1}-----		%
SH/ SMS	19.9	36.18	81.6	11.9	14.3	21.0	13.5	18.7	39.2
SH/ NPK	20.9	17.93	-14.0	12.0	14.1	8.3	13.8	14.0	1.3
NSH/NPK	18.5	20.43	10.2	12.4	12.9	13.3	13.6	15.3	12.4
LSD (.05)	ns	4.8	19.3	ns	0.99	ns	ns	1.51	12.8

† Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and phosphorous: NSH, no stover harvest.

‡ not significant at P>0.05.

Table 2-12: Total seasonal slug observations, as impacted by stover management and compost applications, treatments in 2010 and 2011.

Treatment†	2010††	2011††
	-----------------slug trap $^{-1}$	-----------------------
SH/ SMS	1.3	1.5
SH/ NPK	4.0	8.3
NSH/NPK	12.8	13.0
LSD (.05)	7.3	3.7

†Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.

†† Slug trap size was .09 m^2 .

Table 2-13: Commodity inputs and outputs used in the economic analysis of the stover harvest treatments.

	SH/SMS†	SH/NPK†	NSH/NPK†
Outputs			
Corn Yield (Mg/ha)	29.0	27.3	26.4
Stover Yield (Mg/ha)	11.7	10.8	0.0
Inputs			
SMS (Mg-DM/ha)	53.8	0	0
Corn N input (kg/ha)	297	504	504
Corn P input (kg/ha)	0	219	168
Corn K input (kg/ha)	0	420	168
Alfalfa P input (kg/ha)	0	265	265
Alfalfa K input (kg/ha)	0	840	840

† Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.

SMS: Spent Mushroom Substrate

P and K inputs expressed as P_2O_5 and K_2O

Table 2-14: Expenditures, revenue, and net return on investment for the all treatments throughout the three years of both corn and hypothetical alfalfa production.

Treatment†	SH/SMS		SH/NPK		NSH/NPK	
	Expenditure	Revenue	Expenditure	Revenue	Expenditure	Revenue
	---$ ha^{-1}---					
Corn Revenue		8005	0	7538	0	7279
Corn Stover		1284	0	1186	0	0
Alfalfa Production		9263	0	9263	0	9263
Corn production (P)	0		459		343	
Corn production (K)	0		482		215	
Corn production (N)	329		457		457	
Seed, Herbicide	1356		1356		1356	
Compost	185		0		0	
Planting/spraying	459		459		459	
Loading/applying compost	49		0		0	
Trucking of compost	247		0		0	
Harvesting crop	86		86		86	
Harvesting stover	94		94		94	
Alfalfa Production (P)	0		1037		1037	
Alfalfa Production (K)	0		1400		1400	
Totals	2806	18552	5832	17987	5449	16542
Net	15746		12155		11093	

†Abbreviations: SH, Stover harvest: SMS, Spent mushroom substrate: NPK refers to traditional fertilizers Nitrogen, Potassium, and Phosphorous: NSH, no stover harvest.

Assumptions: corn revenue @ $.275/ kg, corn stover $89/ Mg, alfalfa $223/Mg, corn production (P_20_5) $2 .09/kg (0,73,56 kg/ha), corn production (K_2O) $1.19/kg (0,140,56 kg/ha)corn production (N) $1.19/kg (112,168,168 kg/ha), hybrid seed @$ 253/ha, herbicide @$ 88.92/ha, compost @ $ 185/ha, planting @ $ 62/ha, spraying @ $64/ha, loading/applying compost @ $49/ha, trucking of compost 80 km @$ 1.25, harvesting corn crop $86/ha, harvesting stover @ $94/ha.

Table 2-15: P_20_5 and K_20 crop needs for the theoretical six-year rotation for SH/SMS treatment and total applied (kg ha^{-1}).

	1st Year Corn	2nd Year Corn	3rd Year Corn	1st Year Alfalfa	2nd Year Alfalfa	3rd Year Alfalfa	6 year Total	Total P and K
P_2O_5	99	99	99	50	108	108	561	564
K_2O	131	131	131	168	336	336	1317	1317

Table 3-1: Stover yield and nutrient removal as influenced by fall or spring harvest in 2009 and 2010.

	2009					2010					Mean				
Treatment	YD†	N	C	P	K	YD†	N	C	P	K	YD†	N	C	P	K
	---kg ha^{-1}---														
Fall	7970	73	3486	6.0	67	8578	47	3937	3.4	55	8274	60	3711	4.7	61
Spring	7133	58	3037	4.6	24	4873	22	2271	1.9	12	6003	40	2654	3.3	18
LSD (.05)	467	12	162	0.9	10	1012	9.1	599	.62	11	740	11	516	.71	12

†Abbreviations: YD, Yield.

Table 3-2: Stover nutrient concentration as influenced by fall or spring harvest in 2009 and 2010.

	2009				2010				Mean			
Treatment	N	C	P	K	N	C	P	K	N	C	P	K
	---g kg^{-1}---											
Fall	9.1	437	0.75	8.4	5.5	459	0.4	6.4	7.3	448	0.58	7.4
Spring	8.2	426	0.65	3.4	4.6	466	0.4	2.5	6.4	446	0.53	3.0
LSD (.05)	ns	ns	0.08	1.2	ns	ns	ns	1.1	ns	ns	ns	1.0