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Agronomic impacts of production scale harvesting of corn stover for cellulosic ethanol production in Central Iowa

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by

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DEDICATION

I dedicate this to all persons who have worked towards promoting sustainability through renewable energy and continue to do so.

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ACKNOWLEDGEMENTS

First, I would like to thank God for his many blessings, too numerous to count, that He has bestowed upon me which I try not to take for granted. Without you, nothing is possible. Thank you.

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ABSTRACT

This thesis investigates the impacts of corn stover harvest in Central Iowa with regards to nutrient removal, grain yield impacts and soil tilth. Focusing on phosphorus and potassium removal due to production of large, square bales of corn stover, 3.7 lb P_2O_5 and 18.7 lb K_2O per ton of corn stover were removed in 2011. P_2O_5 removal remained statistically the same in 2012, but K_2O decreased to 15.1 lb per ton of corn stover. Grain cart data showed no statistical difference in grain yield between harvest treatments, but yield monitor data showed a 3 - 17 bu/ac increase in 2012 and hand samples showed a 4 - 21 bu/ac increase in 2013. Corn stover residue levels decreased below 30% coverage when corn stover was harvested the previous fall and conventional tillage methods were used, but incorporating reduced tillage practices following corn stover harvest increased residue levels back up to 30% coverage. Corn emergence rates increased by at least 2,470 more plants per acre within the first three days of spiking, but final populations between harvest and nonharvest corn stover treatments were the same. Inorganic soil nitrogen in the form of ammonium and nitrate were not directly impacted by corn stover harvest, but it is hypothesized that weather patterns had a greater impact on nitrogen availability. Lastly, soil organic matter did not statistically change from 2011 to 2013 due to corn stover removal, even when analyzed within single soil types.

CHAPTER 1

OBJECTIVES

Objective 1: Quantify the average amount of phosphorus and potassium removal from baling corn stover on a production scale.

It is important to know how much phosphorus and potassium will be removed from harvesting corn stover in order to adequately replace them during fertilizer application. It is vital to observe values at the time the corn stover would be harvested and from actual corn stover bales themselves, because these values would be representative of what a cellulosic ethanol production facility would observe. This objective will show phosphorus and potassium removal rates as a result of production scale corn stover harvest.

Objective 2: Grain cart, yield monitor and hand sampling comparison of grain yield as a result of production scale corn stover removal.

Partial corn stover removal could have an impact on subsequent years' grain yields, and existing studies are limited to a single field or meter-by-meter research plots. There is a lack of evidence comparing grain yields across several fields with corn stover both being harvested and not harvested in each field. Furthermore, evaluating the grain yield could be done with grain carts, yield monitors or $1/1000^{th}$ of an acre samples, and it is important to confirm that each of these methods would come up with the same result (gain, loss or no change). Therefore, this objective will show a comparison of percent change in grain yield between corn stover removal treatments as measured by grain carts, yield monitors and plant bundles.

Objective 3: Assess soil properties after production scale corn stover removal.

Harvesting corn stover from fields could impact the soil health, but the extent of these impacts and how it affects plant growth are not fully documented. The impact corn stover harvesting will have on these soil properties will be important to know in order to maintain soil quality. This objective will quantify the difference in corn stover residue levels, corn emergence rates, soil nitrogen and soil organic matter as a result of production scale corn stover removal.

CHAPTER 2

LITERATURE REVIEW

In 2005, the Renewable Fuel Standard (RFS1) was implemented by the Environmental Protection Agency in order to mitigate greenhouse gas production into the atmosphere. It mandated that biofuel usage increase, and was later revised in 2006 under the RFS2. The RFS2 capped starch ethanol production at 15 billion gallons per year starting in 2015 and split biofuels into four categories: renewable fuel, advanced biofuel, biomass-based diesel, cellulosic biofuel. It also required that in order for a biofuel to be counted in a certain category, it couldn't just be produced by a particular feedstock; the life cycle analysis of the biofuel production had to decrease greenhouse gas production by a minimum percentage for each category. With all of this in mind, the RFS2 dictates that biofuel consumption should increase each year with a goal of 36 billion gallons by 2022 (Schnepf & Yacobucci, 2013).

To improve the sustainability of energy consumption and reduce the dependency on a limited supply of fossil fuels, renewable energies, energy conservation and biofuels all should be part of a diverse energy portfolio. Ethanol derived from corn starch is partially responsible for the increased price of corn (Koh & Ghazoul, 2008), and subsequently took over 41.8% U.S. corn grain production in 2010, reducing other industries share (Klopfenstein et al., 2013). Also, continuous intensive corn production could place a strain on water supplies (Schnepf & Yacobucci, 2013). Diesel biofuels have the tendency to become more viscous at lower temperatures and "gel" when compared to nonrenewable diesel, causing diesel engines to not work properly (Bozbas, 2008). Diesel in general though will gel at lower temperatures whereas ethanol or gasoline will not.

Cellulosic biofuels have market, logistical and production complications, because there is no large market in the United States for cellulosic feedstocks or industrial supply chains currently in practice (Awudu & Zhang, 2012). This becomes an issue, because, for instance, corn stover is less energy dense than corn grain and would require more fuel for transportation and more feedstock per gallon of ethanol produced (Pordesimo et al., 2005) (Wang et al., 2007). Overall, cellulosic ethanol production is higher than corn grain ethanol production due to higher processing costs (McAloon et al., 2000).

Nationally, most gasoline blends with ethanol only contain 10% ethanol, which essentially puts a limit on ethanol production (referred to as the "blend wall") of 13 billion gallons, which is less than the amount of ethanol mandated to be produced in 2013. Therefore, if higher blends of 15-20% were required, the blend wall would be expanded by 20-27 billion gallons of ethanol. However, the transportation industry is concerned about higher blends, because of its compatibility with engine components, and furthermore, infrastructure improvements would be needed as a result in many states for pumps, storage tanks, etc. (Schnepf & Yacobucci, 2013).

Infrastructure and fuel usage aside, these biofuels need to be produced on an industrial scale in a sustainable manner that can create a profit, and finding a suitable feedstock for biofuel production is essential. Focusing on cellulosic ethanol, McKendry (2002) states that there are five ideal characteristics for biomass that is intended for energy production:

1) high yield (maximum production of dry matter per hectare)
2) low energy input to produce
3) low cost
4) composition with the least contaminants

5) low nutrient requirements

The five points above are generic to all forms of biomass to be produced for energy production, but it is difficult to find all five characteristics in a single form of biomass. For example, most plant species have an energy content of 17-21 MJ/kg, but there are some that produce much higher and others that produce much lower (McKendry, 2002); corn stover has an energy content of 17.6 MJ/kg (dry) (Environmental Protection Agency, 2013). While there are many types of biomass, they can be categorized into four main groups (McKendry, 2002):

1) woody plants (willow trees, poplar trees, etc.)
2) herbaceous plants/grasses (switchgrass, miscanthus, corn stover, etc.)
3) aquatic plants (algae, etc.)
4) manures (hog manure, cattle manure, etc.)

Corn stover has been selected as a first generation feedstock for cellulosic ethanol production, because it is produced prolifically in the Midwest which is where the majority of ethanol production lies (Schnepf & Yacobucci, 2013). Currently, there is not a large demand for corn stover as livestock feed and bedding are the primary uses. DuPont is building a cellulosic ethanol plant in Nevada, IA that will annually produce approximately 30 million gallons of ethanol primarily from corn stover (Rosen, 2012). It will be collected in large square bales from farmers surrounding the plant. Single-pass baling and multi-pass baling were evaluated, but single-pass baling wouldn't allow for the corn stover to dry further which would lead to higher moisture contents. Higher moisture contents in bales lead to higher dry matter loss during storage (Sokhansanj et al., 2002). While multi-pass baling lets the corn stover dry a little more before it is baled, it incorporates higher ash content into each bale. Since the material is laid on the ground in multi-pass, as the baler passes it picks up more dirt and rocks from the ground that the single-pass can't pick up since it feeds directly from the combine into the baler (Ertl, 2013). DuPont has opted to do the multi-pass baling. Storage was also very important, but no single method has been selected thus far. Since corn stover can only be harvested in the fall, this means that the ethanol plant needs to meet its total feedstock requirement in a short window for the entire year (DuPont, 2012). The ethanol yield for DuPont's model was conservatively assumed to be 77 gallons of ethanol per dry ton of stover. Since this DuPont facility aims at producing 30 million gallons of ethanol annually, the feedstock cost would be about $20.2 million per year (at a cost of $51.82 per dry ton of corn stover). Once the material is at the ethanol plant, storage costs of the corn stover was estimated to be $7-13 per dry ton of corn stover with an average annual total of $3.9 million (average of $2.8 and $5.1 million) (Petrolia, 2008).

On an annual basis, 375,000 dry tons of corn stover will need to be collected within a 30-mile radius of Nevada, IA (Rosen, 2012). Nationally, 112 million dry tons of corn stover is estimated to be removed by 2020 (Perlack & Stokes, 2011). When removing this much corn stover from fields, it is important to maintain the quality of the soil and not remove too much corn stover. It is recommended that 2.27 ton/ac of corn stover remains on the field (Karlen et al., 2013), because it plays a vital role to help sustain the soil. Crop residues help increase soil organic matter, water infiltration, improves soil structure and decreases soil erosion and runoff. If corn stover harvest is coupled with conservation tillage, which is defined as leaving 30 percent or more residue coverage after planting by the United States Department of Agriculture (USDA), it could help improve those areas. By leaving the residue, it reduces the impact that raindrops have on the soil, absorbs some of the moisture and reduces water movement across the top of the soil. Reducing water movement is very important, because it increases water infiltration into the soil, especially if no-till or minimum tillage management practices are incorporated, which creates less run-off. Also, crop residues are very important to help maintain soil biota which are an integral part of agriculture (Rust & Williams, 2012).

There have been a variety of existing studies done to determine various agronomic impacts from corn stover harvest throughout the Midwest in research plots of meter-by-meter size, and a lot of them tested various harvest rates. A study in Ohio found soil macroaggregates (>4.75) decreased by 40% when 25% or more of the corn stover was removed, and that any harvest rates above 25% would be harmful to the soil organic carbon (SOC) levels and soil structure (Blanco-Canqui & Lal, 2009). The lack of soil structure at higher rates of corn stover removal can be linked to fungi, bacteria and other soil biota which produce biochemical residue, similar to glomalin from endomycorrhizae, that bind soil particles together like glue and form stable aggregates (Rust & Williams, 2012). A 32-year study was performed in Chazy, NY where 25 soil properties were measured, but only eight properties were adversely affected by corn stover harvest and were worsened with increased tillage practices. This study contained sixteen plots that were 6 x 15.2 meters on a Raynham silt loam. Organic matter decreased by 8%, soil bulk density increased by 5% and potassium concentrations decreased by 44% in plots where corn stover was removed when compared to the nonremoval counterparts. However, this long-term study removed all of the corn stover in the harvest treatments instead of partial removal (Moebius-Clune, et al., 2008). Grain yield impact is an important aspect that will be important for growers who would like to participate in stover harvest. Blanco-Canqui et al. (2009) reported no statistical differences in grain yield when 25% or less corn stover was removed. Some fields didn't even show a yield response at 50% removal. In 13-year long-term study in east central Minnesota, only 8 of the 13 years had a yield difference due to stover harvest, and were mostly only apparent during years that were drier than a 9-year average. However, all corn stover was removed again except for 15 cm of base stalk, fallen leaves and brace roots (Linden et al., 2000).

Existing studies that measure agronomic impacts are done in research plots and, generally, more residue is removed than would actually occur on an industrial scale. Studies with variation in soil types, location and entire fields following industrial scale production methods are missing. This study presents data that would be similar to values that growers in central Iowa would observe if they partially harvested corn stover from their fields. These data are very important, because it will give growers values to expect for grain yield impacts, residue cover, nutrient removal, emergence rates, soil nitrogen availability and soil organic matter.

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CHAPTER 3

ANALYSIS OF POTASSIUM AND PHOSPHORUS REMOVAL DURING CORN STOVER HARVEST

Abstract

Corn stover was harvested from Central Iowa corn fields for two consecutive years: 2011 and 2012. Core samples were collected from random samples of large square bales from 47 fields in 2011 and 116 fields in 2012 and analyzed for phosphorus and potassium by inductively coupled plasma atomic emission spectrometry. The average phosphate (P_2O_5) removal was 3.65 lb/ton dry stover in 2011 and 3.61 lb/ton dry stover in 2012. Potash (K_2O) removal rates were statistically different from 2011 to 2012 with concentrations of 18.73 lb/ton dry stover and 15.05 lb/ton dry stover, respectively.

Introduction

The revised renewable fuel standard (RFS2) mandates that biofuel consumption increase to 36 billion gallons per year by 2022. Cellulosic ethanol is one of the four categories of biofuels mandated, and corn stover has been selected as a first generation feedstock since it is already produced in large quantities in the Midwest as a byproduct of corn production (Schnepf & Yacobucci, 2013). 112 million dry tons of corn stover is estimated to be used by 2020 for cellulosic biofuel production (Perlack & Stokes, 2011). Current industrial uses of corn stover include livestock feed, bedding and limited use in industrial processes. To ensure the continued success of industrial harvest of corn stover and minimal effects on soil tilth, only a portion of total corn stover is removed. This protects soil organic matter, nutrient recycling and wind and water erosion. Recommendations for required corn stover residual vary based on geographic location and various environmental factors, but generally in the Midwest a minimum of 2.27 ton/ac is recommended to protect environmental sustainability (Karlen et al., 2013).

Therefore, with the increased interest for utilizing corn stover as a viable feedstock for cellulosic ethanol production in the Midwest, accurate estimates of nutrient removal during the industrial corn stover collection process is required to maintain soil fertility and support long term soil productivity. Phosphorus (P) and potassium (K) in particular are two main macronutrients that are managed on a seasonal basis. P is a mobile nutrient within plants that is important for plant growth and grain production, and K is a mobile nutrient within plants that aids in enzymatic activity and production of adenosine triphosphate (ATP). As corn plants mature, the majority of the nitrogen (N) and P translocate from the vegetative plant parts into the grain, but much of the K is left in the vegetative plant material. In fact, large amounts of K removal have already been observed due to corn silage harvesting for livestock feed (Ritchie et al., 1993). Sawyer and Mallarino (2012) reported there is about four times the concentration of P per ton of dry matter in the grain than the corn stover.

The concentration of P and K removal via corn stover harvesting after fall grain harvest has been investigated considerably in recent years. In 2004, Sheehan et al. estimated in a life-cycle model for Iowa that P and K removal would be 1.60 lb/ton and 15.2 lb/ton, respectively. Sheehan et al. (2004) averaged grain yields from 1995-1997, assumed a 1:1 ratio of corn residue to grain and used P and K concentrations for corn stover analyzed by the National Renewable Energy Laboratory (NREL) (2001) to estimate nutrient removal. The life-cycle model's results were supported with values of 1.57 lb-P/ton and 13.4 lb-K/ton by Hoskinson et al. (2007) after a one year study, and 1.4 lb-P/ton and 13.0 lb-K/ton by Karlen et al. (2013) after a four year study. However, higher values of K removal were reported in the Upper Midwest USA at 22.5 lb/ton, but P remained at 1.69 lb/ton (Avila-Segura et al., 2011). Iowa State University Extension has reported nutrient concentration removal rates of 2-4 lb P_2O_5 and 8-20 lb K_2O per ton of dry corn stover (Edwards, 2014). Also, rainfall can leach K from corn stover that is physiologically mature since it is in a soluble form, which could be one reason why the K concentrations reported in corn stover vary (Ertl, 2013) (Jeschke & Heggenstaller, 2012).

This study will analyze phosphorus and potassium removal resulting from corn stover harvesting at an industrial scale and is unique in both its intensity of measurement and diversity of local site locations.

Experimental Design

Following the corn grain harvest in the fall of 2011-2012, the corn stover was baled using large square balers on select fields. Bales were randomly selected across the entirety of the field to be sampled with a 2.5-inch diameter steel coring probe with boring teeth on one end, to a depth of 18 inches. The core was taken from one end of the bale across several layers (Figure 1).

Figure 1: Large square bale sampler with the 2.5-inch diameter coring probe drilling into the end of the corn stover bale

The average number of samples taken per field varied more in 2011, because a study was being done to determine the number of bales to be sampled to be representative of ash content for the entire field. In 2012, an average sample number of three bales per field were selected, because, based on the 2011 results, three bales per field gave an average standard deviation of 2.23% ± 2.5% for ash content (Schon, 2012). The number of fields and number of individual bales are shown in Table 1.

Table 1: A summarization of the sampling breadth each year

Year	Fields Sampled	Bales Sampled
2011	47	236
2012	116	395

The samples were dried by slightly modifying the ASABE Standard S358.2, Moisture Measurement – Forages (1988). After the samples were taken from the field, they were placed in an oven at 95^{o}C for 24 hours and then removed to record their "dry" weight. Once the sample had been dried, the ash content was obtained by the NREL's standard for determination of ash in biomass (Sluiter et al., 2005). Each sample was placed in a muffle furnace at 575^{o}C for approximately 8 hours.

Ash samples were then subsampled and digested in concentrated nitric acid. Digested samples were then analyzed for total phosphorus and potassium content via inductively coupled plasma (ICP) spectroscopy (Spectro-Ciros). This study reports nutrient values as phosphate (P_2O_5) and potash (K_2O), because these are the forms used for fertilizer recommendations. The nutrient concentrations were then calculated on a lb/ton of dry corn stover basis with the following equations:

Equation 1: Calculating phosphorus removal rate on an oxide basis

$$\frac{\text{lb } P_2O_5}{\text{ton of corn stover}} =$$

$$\text{ppm P } \times \text{\% Ash Content } \times \frac{2{,}000 \text{ lb}}{1 \text{ ton}} \times \frac{1\ P_2O_5}{0.4286 \text{ P}}$$

Equation 2: Calculating potassium removal on an oxide basis

$$\frac{\text{lb } K_2O}{\text{ton of corn stover}} =$$

$$\text{ppm K } \times \text{\% Ash Content } \times \frac{2{,}000 \text{ lb}}{1 \text{ ton}} \times \frac{1\ K_2O}{0.83 \text{ K}}$$

Lastly, it is important to note that these fields were randomly located throughout central Iowa and were managed independently by unique producers. Each producer followed their own management practices regarding tillage, fertilizer application, planting, field management (weeds, pests, disease, etc.) and grain harvest. Corn stover harvesting operations were managed and conducted by custom harvesting contractors. Also, each producer was able to participate or exclude themselves from the corn stover harvest trial, which resulted in new producers being introduced and existing ones being excluded from 2011 to 2012. All fields were located within a 50 mile radius of Ames, IA.

Statistical Analysis

Minitab 16 Statistical Software was used to perform statistical analyses for this experiment. A two-sample t-test was performed to determine if there was a statistical difference in P_2O_5 or K_2O concentrations compared across production fields between 2011 and 2012 values. A paired t-test was utilized to compare P_2O_5 or K_2O concentrations from only experimental fields that underwent corn stover harvest both in 2011 and 2012. Alpha (α) was equal to 0.05 for t-test analyses. A regression was then used to show an interaction between K_2O concentrations and rain accumulation 21 days prior to corn stover harvest for 2011 and 2012, and K_2O concentrations and harvest dates for 2011 and 2012. This was done to determine if increased rain accumulation or harvest date impacted K_2O concentrations.

Results

Inclusive of all corn stover samples taken, the results for P_2O_5 and K_2O removal per ton of corn stover (0% moisture and 0% ash) are shown in Figure 2 and Figure 3, respectively.

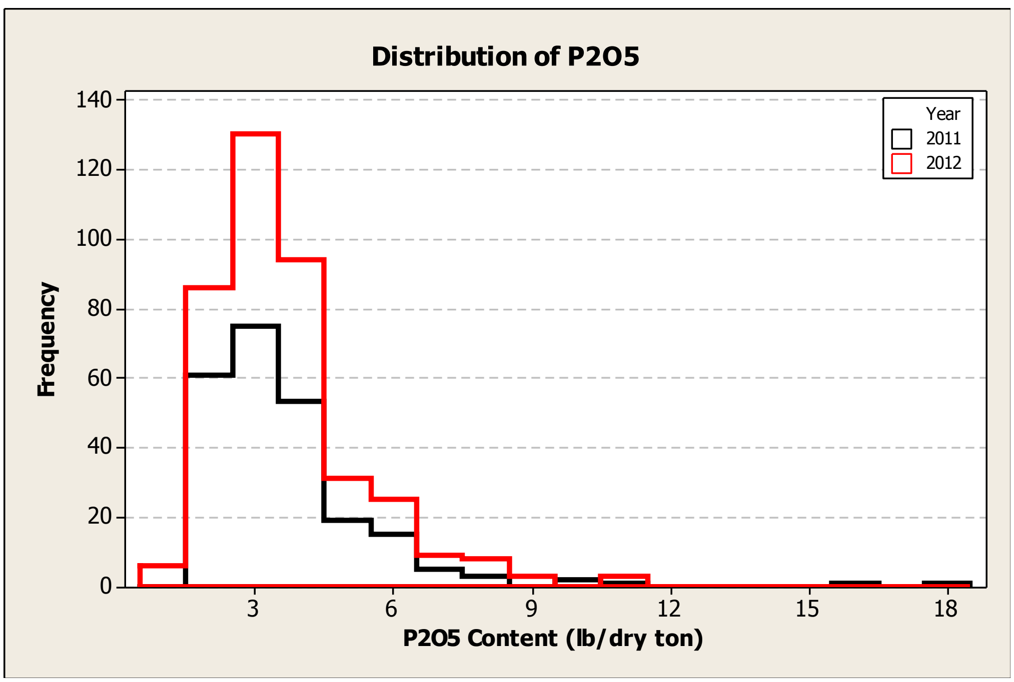

Figure 2: Histogram of all corn stover nutrient samples. The mean P_2O_5 removal for 2011 and 2012 are 3.65 and 3.61 lb/ton stover, respectively, with a p-value = 0.754

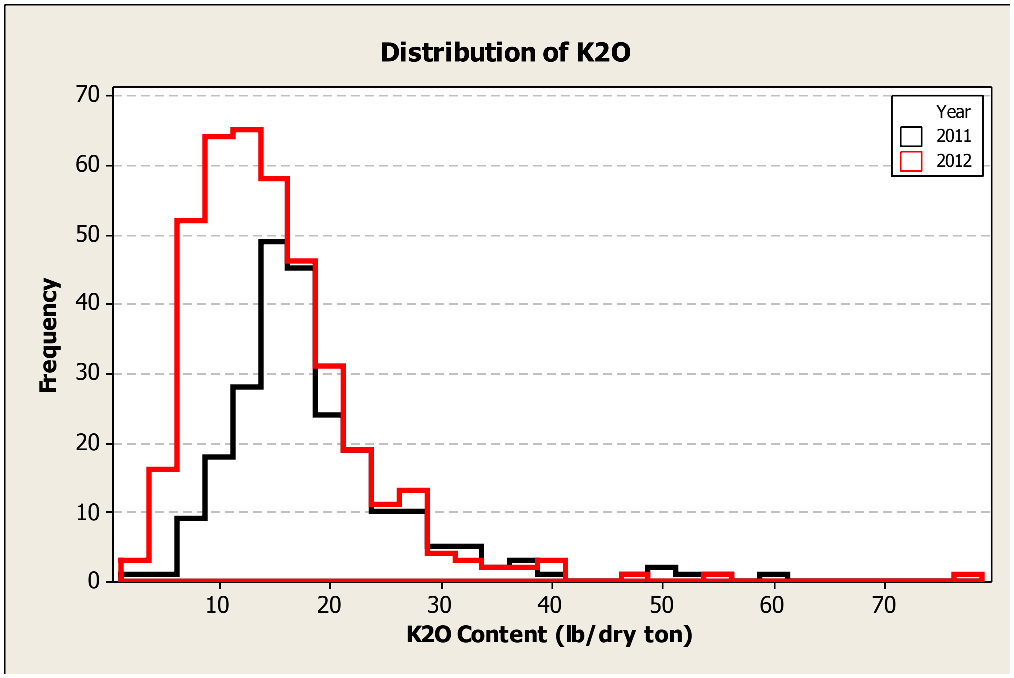

Figure 3: Histogram of all corn stover nutrient samples. The mean K_2O removal for 2011 and 2012 are 18.73 and 15.05 lb/ton stover, respectively, with a p-value < 0.001

The mean P_2O_5 concentrations in 2011 and 2012 are not statistically different with values of 3.65 and 3.61 lb/ton dry stover respectively, but the mean K_2O concentrations are. K_2O concentrations were 18.73 lb/ton dry stover in 2011 and 15.05 lb/ton dry stover in 2012. However, the inclusion of additional fields in 2012 could have had an impact on the nutrient concentrations due to natural variation in the fields. Therefore, a two-sample t-test for dissimilar fields (Table 2) and a paired t-test for similar fields (Table 3) from 2011-2012 was performed to see if there was still a significant difference in K_2O but not P_2O_5. Both tests show that there still was no difference in P_2O_5 concentration removal, but K_2O concentration removal did still show a difference with a p-value of <0.001 for dissimilar fields and 0.033 for similar fields, meaning that the trend in nutrient concentrations are not a result of sampling additional fields in 2012.

Table 2: Two-sample t-test results for nutrient concentration differences for dissimilar fields

Nutrient	Difference (lb/ton dry stover)	P-value
P_2O_5	0.167	0.373
K_2O	4.034	<0.001

Table 3: Paired t-test results for nutrient concentration differences for similar fields

Nutrient	Difference (lb/ton dry stover)	P-value
P_2O_5	-0.088	0.763
K_2O	3.72	0.033

K_2O concentrations were then compared against rain events that occurred 21 days prior to each corn stover harvest date, since potassium is a mobile nutrient in the plant and is able to leach from the corn stover after rain events. Scatterplots of 2011 and 2012 K_2O concentrations (Figure 4, Figure 5) both have no statistical interaction between rain accumulation and K_2O concentrations with a R^2 values of 2.6% and 1.0% for 2011 and 2012 respectively. K_2O concentrations over the course of the harvest season (beginning September 1st through November) also showed no statistical correlation as can be seen in Figure 6 and Figure 7 with R^2 values of 2.0% for 2011 and 3.6% for 2012.

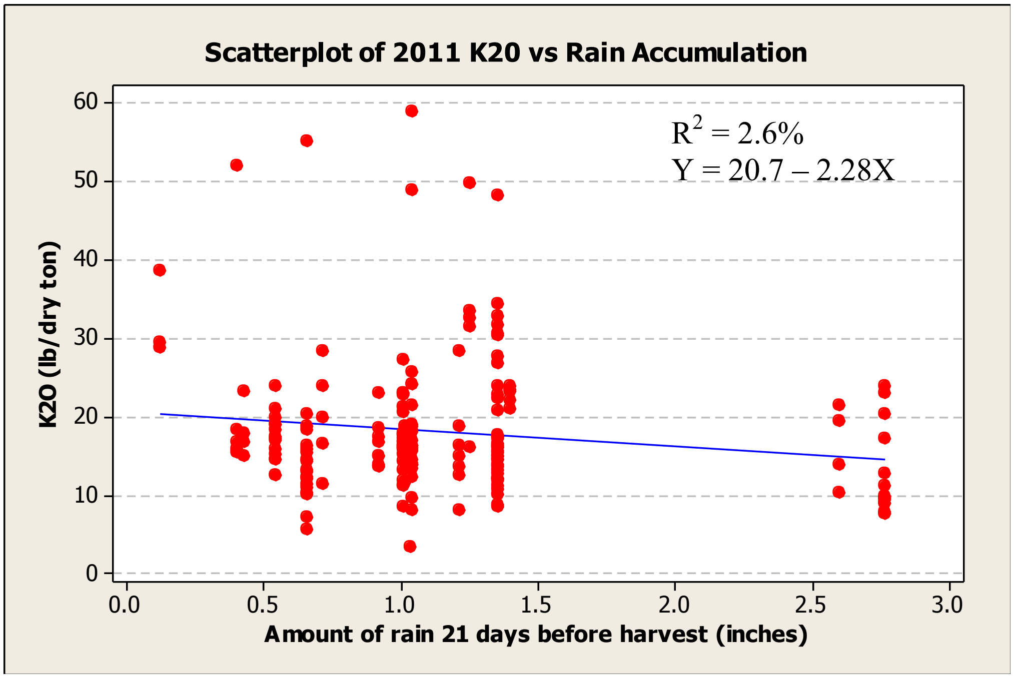

Figure 4: 2011 potash concentrations after rain accumulation

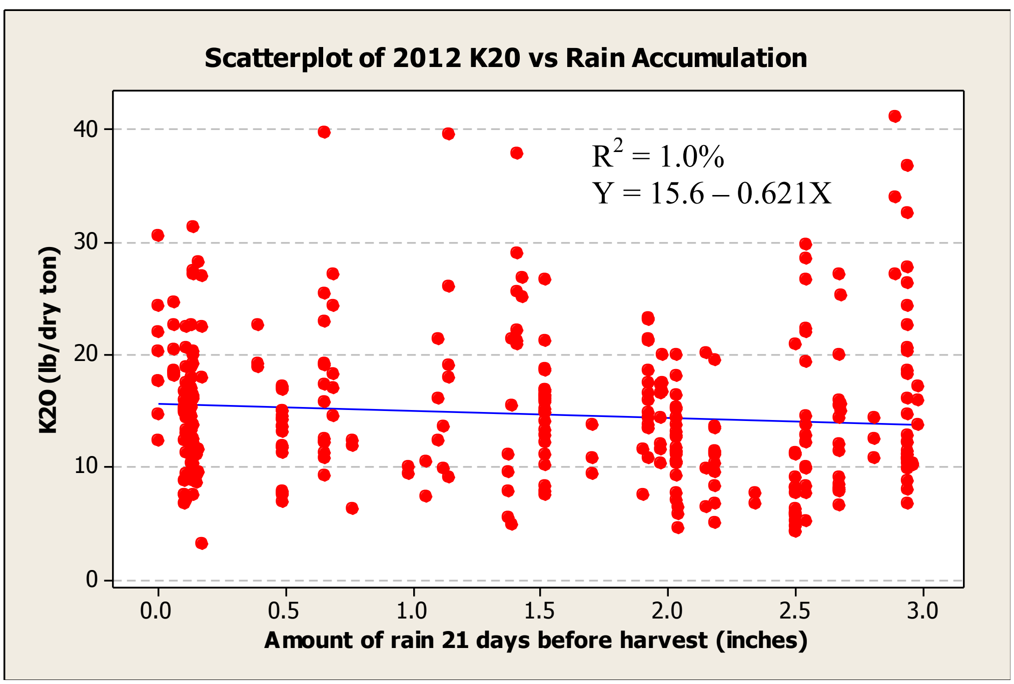

Figure 5: 2012 potash concentrations after rain accumulation

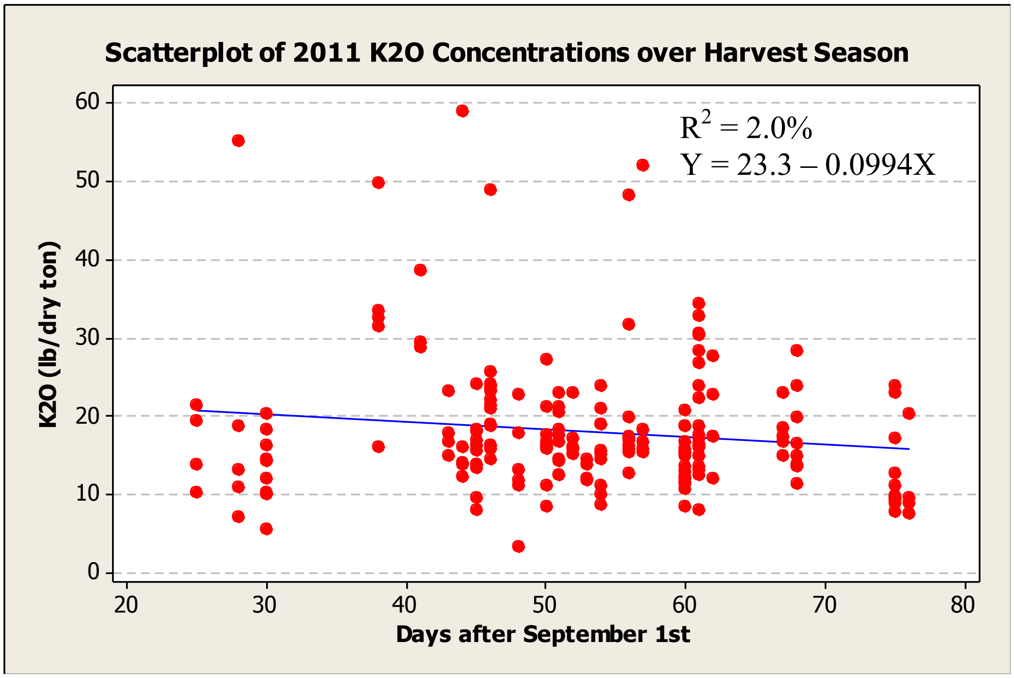

Figure 6: 2011 potash concentration as harvest season progressed

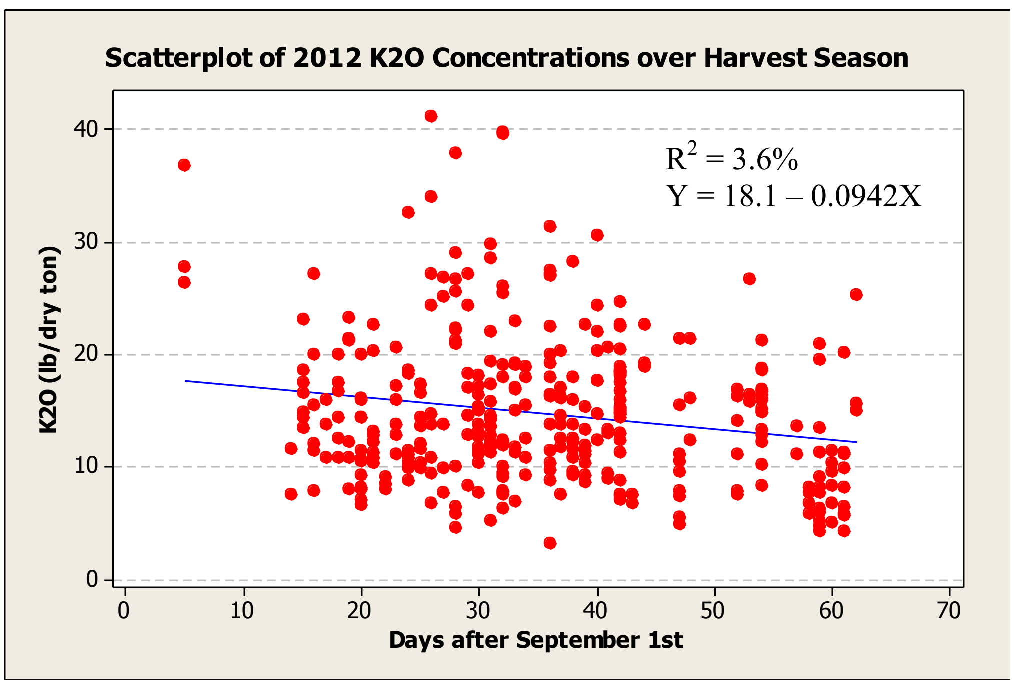

Figure 7: 2012 potash concentrations as harvest season progressed

Conclusion

A production scale harvest of corn stover revealed the average removal rate of P_2O_5 in 2011 and 2012 were not statistically different with values of 3.65 and 3.61 lb- P_2O_5/ton dry stover, respectively. K_2O was statistically different with average removal rates of 18.73 lb- K_2O/ton dry stover in 2011 and 15.05 lb- K_2O/ton dry stover in 2012. These nutrient concentrations are within the range reported by the Iowa State University Extension and Outreach of 2-4 lb P_2O_5 and 8-20 lb K_2O per ton of dry stover (Edwards, 2014), and are similar to the concentrations observed by Hoskinson et al. (2007) and Karlen et al. (2013). These nutrient values would be more representative to what an ethanol plant would expect to have in its feedstock if it used industrially produced, large square corn stover bales that have a mixture of corn vegetative parts. Also, rain and harvest date were not statistically correlated to K_2O concentration per ton of dry stover in either 2011 or 2012 due to the low R^2 values.

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CHAPTER 4

GRAIN CART, YIELD MONITOR AND HAND SAMPLING COMPARISON OF GRAIN YIELD AS A RESULT OF PRODUCTION SCALE CORN STOVER REMOVAL

Abstract

Analyzing the impacts of harvesting corn stover on grain yield is important for growers in their decision making process of whether or not to participate in harvesting corn stover from their fields. Corn stover removal's impact on grain yield was measured in this study through three separate types of measurements: grain cart, yield monitor, hand sampling. Harvesting corn stover had a neutral or positive impact on grain yields. Total available corn stover was also measured from hand sampling of individual plants. 2013 showed a statistical increase in available stover when corn stover was harvested the previous year, but 2012 did not. Lastly, a stover harvest index (SHI) was calculated for both 2012 and 2013 and indicates that a SHI should be calculated each year rather than relying on a standard SHI.

Introduction

Before increased corn stover harvesting for cellulosic ethanol production occurs in the Midwest, the yield impact from harvesting corn stover needs to be investigated on a production scale, because a change in grain yield could affect a grower's contribution of corn stover to a cellulosic ethanol plant. Currently, yield monitors are the primary method used for recording grain yields because of its ability to tie yield data to spatial maps. The resulting yield maps can help growers compare the performance of different hybrids, discern good and poor locations in fields and analyze differences based on experimental treatment. It is a very useful tool as long as it's calibrated correctly. Since it measures grain yield by having grain impact a metal plate which has an impact sensor associated with it, the impact sensor needs to be calibrated beyond the factory settings. Low, medium and high yields are calibrated at the beginning of the season, but even if it's only calibrated once, it will have an error of 1-10% throughout the season. Therefore, it is important to calibrate them throughout the season, but this doesn't frequently happen in practice. Another method of measuring grain yield is by outfitting a grain cart with electronic scales. This way entire harvested areas can be weighed and compared (after taking into account the grain's moisture content and area it was harvested from), however, variations within that harvested area cannot be analyzed or compared since the resulting data would be part of a "bulk" yield (Nielsen, 2010).

In a normal year with adequate rainfall, it has been observed that there is no significant yield difference (<2%) in grain by harvesting corn stover (Wortmann, 2012). However, if the weather was dry during the growing season, it was observed that corn stover removal had a negative impact on grain yield 8 out of 13 years in east central Minnesota (Linden et al., 2000). Another study conducted in Iowa did not show any statistical difference as a result of stover harvest treatment (50% removal and 90% removal), although there were variations from year to year (Karlen et al., 2013). Many of these studies related any grain yield change to environmental factors rather than actual removal of corn stover.

Experimental Design

For all three of the grain yielding methods below, each of them took place in experimental fields that were set up similar to Appendix. Corn stover was harvested the previous fall in alternating strips of 48 rows, and grain yield measurements were conducted within each strip. Growers calibrated their own grain carts and yield monitors as they normally would. This is true for 2012 and 2013 yield data. 2012 grain samples were dried at 95^{o}C in 2012 for 72 hours, because there was limited number of ovens and many samples of grain and corn stover. This allowed for grain and corn stover to be dried in the same oven to maximize the space that was available.

Grain Cart Yield

Experimental field producers provided grain carts (Figure 8) which recorded all of the grain from each strip, as designated in Appendix. Each time the combine hopper was full, he would dump into a grain wagon, the weight was recorded and the combine would return to its strip. Grain from one strip was never mixed with grain from a different strip while combining. Each time a strip was completed the combine would empty its hopper and begin a new strip. Two moisture samples were taken randomly within each strip from the combine. Grain moisture in 2012 was calculated by drying the grain in an oven at 95^{o}C for 72 hours. In 2013 a Grain Analysis Computer 2500-UGMA (DICKEY-john) was used to record determine grain moisture.

Figure 8: Grain cart measuring grain yield off of one experimental field strip

Yield Monitor Data Collection

Experimental field producers also used yield monitors to record spatial grain yields. Each yield monitor was calibrated by the grower of each experimental field as they normally would. This meant that some growers calibrated their monitors only once at the beginning of the harvest season, and others more than once. Therefore, the amount of time between a calibration and when an experimental field's grain was harvested varied from field to field. The spatial data were then imported into Ag Leader's SMS Advanced software and analyzed by each strip. Corn grain yield values below 50 bu/ac were excluded to eliminate any boundary effects or nonproductive areas, and grain yield values above 250 bu/ac were also excluded to eliminate any extreme high values.

Plant Bundle Data

While grain cart and yield monitor data were being recorded, whole corn plants, representing 1/1000th of an acre (17.5 feet) (Figure 9), were harvested near each location shown in Appendix. Plant samples were cut within six inches of the ground and were always harvested at least eight rows from a strip's border. Once the whole plants were cut, they were wrapped in netting (Figure 10) to provide adequate ventilation while losing minimal biomass.

In order to determine the weight of the corn stover and grain, the 2012 wrapped plant bundles were placed in drying rooms at 150^{o}F until a constant mass was observed. The grain was shelled, separated from the corn stover, weighed and a sample of the grain was placed in an oven at 95^{o}C for 72 hours.

Figure 9: Measuring 17.5 feet for a plant bundle

Figure 10: The wrapper used to put netting around a plant bundle

2013 plant bundles were separated between corn stover and corn grain first. The grain was then put through an ALMACO automatic ear sheller (ALMACO Inc.; Nevada, IA), weighed and a sample was taken to be analyzed by a Grain Analysis Computer 2500-UGMA (DICKEY-john) for moisture content. The corn stover was then shredded and a sample was taken and dried in an oven at 95°C for 24 hours.

Statistical Analysis

Minitab 16 Statistical Software was used to perform statistical analyses for this experiment. Paired t-tests were used to compare grain yield values between harvest and no harvest treatments of corn stover within each experimental field for grain cart, yield monitor and plant bundle data in 2012 and 2013. Corn stover yields were also analyzed using a paired t-test between harvest and no harvest treatments of corn stover within each experimental field. The stover harvest index (SHI) for 2012 and 2013 were also analyzed using paired t-tests, and the 2012 SHI was compared against the 2013 SHI with a paired t-test. All t-test used an alpha (α) equal to 0.05.

Results

In order to compare the different experimental fields against each other, grain yields were calculated on a bushel per acre basis, and a percent difference in grain yield was then calculated for each field. A positive percent different signifies a greater yield where corn stover was harvested and vice-versa. Also, the grain yields were analyzed at 15% moisture content and 56 pounds of corn per bushel. The stover harvest index (SHI) is a ratio, by mass, of corn grain to corn grain plus corn stover. The mass values to calculate the SHI came from the plant bundles that were cut within 6 inches of ground level, and both corn and corn stover weights for this value were analyzed at 0% moisture and 0% ash content. Therefore, a value above 0.5 indicates that there was more grain than corn stover, by weight.

In the strips that had corn stover removed, grain cart data showed five out of seven fields with an average increase in corn grain yield in 2012 and five out of six fields had an average increase in 2013. A paired t-test showed no statistical increase in corn grain yield from grain cart data in 2012 or 2013. Yield monitor data from 2012 and 2013 showed a positive percent difference in every field measured except one in 2013, but only 2012 had a statistical increase in grain yield (3 - 17 bu/ac) where corn stover was harvested. Plant bundle data in 2012 showed no statistical difference in 2012, but there was a 4 - 12 bu/ac increase in 2013. Taking all three of the grain data collection methods into consideration, the statistical effect on grain yield from harvesting corn stover is either positive or no effect. All of the paired t-test results are shown in

Table 4 and Table 5. Grain and stover data by field are recorded from 2012 – 2013 in Table 6 and Table 7.

Table 4: 2012 paired t-test results of grain and stover harvest

	Treatment	95% C.I. of Yield Difference	P-value
Grain Cart	Harvest	-2 to 8 bu/ac	0.235
	No Harvest		
Yield Monitor	Harvest	3 to 17 bu/ac	0.013
	No Harvest		
Plant Bundles	Harvest	-15 to 6 bu/ac	0.331
	No Harvest		
Corn Stover	Harvest	-0.4 to 0.1 ton/ac	0.274
	No Harvest		

Table 5: 2013 paired t-test results of grain and stover harvest

	Treatment	95% C.I. of Yield Difference	P-value
Grain Cart	Harvest	-1 to 9 bu/ac	0.119
	No Harvest		
Yield Monitor	Harvest	-4 to 12 bu/ac	0.256
	No Harvest		
Plant Bundles	Harvest	4 to 12 bu/ac	0.014
	No Harvest		
Corn Stover	Harvest	0.2 to 0.4 ton/ac	0.002
	No Harvest		

Total available corn stover was also calculated and analyzed across the two treatments and both years. In 2012, the average available corn stover was 3.8 and 4.0 tons per acre for harvest and nonharvest treatments with no statistical difference. 2013 did show a statistical difference with 0.28 ton/ac more of dry stover in the harvest treatments with a p-value of 0.002. The average available corn stover was 3.3 tons/acre in harvest treatments and only 3.1 tons per acre in nonharvest treatments. The average SHI for 2012 and 2013 were 0.50 and 0.56, respectively, with no statistical difference between treatments (2012 p-value = 0.167, 2012 p-value = 0.704). However, between years, the 2012 SHI was not statistically the same as the 2013 SHI with a p-value < 0.001.

2012 and 2013 grain and stover yield data was not combined for statistical analysis and was analyzed separately, because the growing conditions were quite different for each year. 2012 was a hot, dry year and Story County was classified as “Abnormally Dry” starting in May and progressed to “Severe – Extreme Drought” conditions starting in July and continuing through September. The 2013 growing season started as “Abnormally Dry – Severe Drought” in early April, but received an average of 6.44 inches of rain in April and 11.64 inches of rain in May. In fact, April – May received 11.5 inches of rain more in 2013 than 2012. This caused many areas in and surrounding Story County, IA to be saturated with rain and some to flood. 2013 drought conditions disappeared by the beginning of May, but by August and September some areas were classified as “Abnormally Dry – Severe Drought”. Drought conditions were according to the U.S. Drought Monitor Map Archive (2014) which is jointly produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture and the National Oceanic and Atmospheric Administration.

Table 6: 2012 comparison of grain yielding methods. Grain yields are shown at 15% moisture and 56 lb/bu. SHI = stover harvest index

Field ID	Treatment	Grain Cart Data (bu/ac)	% Difference	Yield Monitor Data (bu/ac)	% Difference	Bundles Grain Data (bu/ac)	% Difference	Stover Yield (ton/ac)	SHI
6	Harvest	-	-	103	5.4	-	-	-	-
	No Harvest	-		98		-		-	-
12	Harvest	80	12.4	-	-	-	-	-	-
	No Harvest	73		-		-		-	-
65	Harvest	154	3.3	171	12.1	162	1.8	5.2	0.45
	No Harvest	150		153		163		5.2	0.47
91	Harvest	156	-0.5	-	-	146	-4.8	3.6	0.53
	No Harvest	157		-		154		3.6	0.54
98	Harvest	163	8.8	169	5.4	144	4.3	4.9	0.45
	No Harvest	151		161		138		4.8	0.45
128	Harvest	136	1.4	136	3.7	124	7.0	3.2	0.42
	No Harvest	134		133		127		3.5	0.50
144	Harvest	133	-4.3	139	7.9	123	5.7	3.1	0.52
	No Harvest	139		131		121		3.1	0.52
146	Harvest	156	1.8	177	12.5	143	-13.5	3.7	0.52
	No Harvest	154		159		165		4.3	0.53

Table 7: 2013 comparison of grain yielding methods. Grain yields are shown at 15% moisture and 56 lb/bu. SHI = stover harvest index

Field ID	Treatment	Grain Cart Data (bu/ac)	% Difference	Yield Monitor Data (bu/ac)	% Difference	Bundles Grain Data (bu/ac)	% Difference	Stover Yield (ton/ac)	SHI
6	Harvest	159	6.4	182	5.8	152	11.7	3.4	0.56
	No Harvest	149		172		136		3.1	0.55
12	Harvest	-	-	-	-	-	-	-	-
	No Harvest	-		-		-		-	-
91	Harvest	134	4.2	-	-	138	9.3	3.2	0.55
	No Harvest	131		-		119		2.8	0.54
98	Harvest	149	-2.0	164	0.8	161	6.8	3.4	0.57
	No Harvest	153		163		151		3.1	0.58
128	Harvest	146	3.9	157	3.8	155	6.8	3.2	0.57
	No Harvest	141		151		140		3.0	0.56
144	Harvest	120	0.8	141	-4.1	-	-	-	-
	No Harvest	119		147		-		-	-
146	Harvest	156	6.6	130	7.5	157	1.9	3.5	0.55
	No Harvest	147		122		155		3.3	0.56

Conclusion

Harvesting corn stover in the fall had a statistical neutral or positive effect on grain yield the following fall. Since there was no statistical negative response, measuring the impacts of grain yield with one of the three methods would not impact a grower's decision to participate in a corn stover harvesting program, assuming he/she would not enroll in the program only if there was a negative response. This is important, because existing studies have not compared the different methods for evaluating grain yield after corn stover harvest. Therefore, growers in central Iowa would expect to see a similar response if they decided to utilize one or more of these three grain yielding methods in order to help them evaluate grain yielding impacts.

It is not possible to say whether or not the stover harvest in 2011 and 2012 lead to the difference in available stover in 2013, but more data would need to be collected over a longer period of time to see if there would be a continued trend of more corn stover available year after year due to corn stover harvest, or if this result is just a single occurrence and a result of other environmental factors. Also, the stover harvest index (SHI) was not statistically different between treatments during 2012 or 2013, but there was a statistical difference between years when the experimental fields from each year were grouped together. This suggests that the SHI would not be consistent from year to year and should be calculated on an annual basis. This is important for cellulosic ethanol producers, because they would want to estimate how much feedstock would be available in the form of corn stover after grain harvest.

Comparing the three methods, hand sampling plant bundles are representative of that small area within a zone, but, according to yield monitor data, grain yield could vary greatly within each zone (shown in Appendix). If more samples were taken randomly within each zone, some variation of grain yield could be accounted for to a certain degree, but it would still not account for all of the variability. Of the three methods, the plant bundles were the most labor intensive and time consuming to collect and process, and it also posed the greatest safety concern since John Deere Gator Utility Vehicles were used throughout the fields to collect plant samples with machetes while maintaining a safe distance ahead or behind a combine.

Grain cart data worked very well to collect all of grain that the combine actually harvested, and the grain samples collected for moisture content were representative of various areas harvested within each strip (shown in Appendix). However, area measurements were needed to be determined in order to calculate the grain yield in bu/ac, and the calculation would then give an average grain yield for the entire strip. No low or high areas of grain yield within a strip could be seen because of this. For this study it was okay, because grain yields were averaged across strips anyway for statistical analysis, and it was not the purpose of this study to specifically analyze certain field characteristics within each strip. This method was not very labor intensive and is well suited for large scale grain harvest when the desired result is an average grain yield across an area.

Yield monitor data was relatively easy to collect as well, but the yield monitors need to be calibrated correctly (and should be done periodically throughout the harvest season for best results). Using yield monitor data to determine an average grain yield across a large area did not fully utilize the potential of yield monitor data, because grain carts performed well to collect this type of data. Yield monitors, when properly calibrated, provide a better spatial representation of grain yield and could be used to calculate differences in grain yield between specific characteristics within a field (i.e. soil types, slope, etc.).

With all of this in mind, it is not recommended that hand sampling plant bundles be used for a large scale analysis, but could be used for smaller research plots that are meter-by-meter in size. Yield monitor data is not as accurate for total grain harvest when compared to grain cart data, but yield monitor data would be able to provide a more in-depth analysis when conducting a spatial analysis. Grain carts would be recommended for large research trials when wanting to compare bulk grain yield across different treatments.

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CHAPTER 5

CORN STOVER HARVEST IMPACTS ON SOILT TILTH

Abstract

The agronomic impacts of corn stover harvesting in Central Iowa are a major concern for soil tilth. In this chapter, various datasets were collected at various stages of corn production as a result of corn stover harvest. In eight agronomic fields, average corn stover residue decreased by 50.2% and 52.7% in 2012 and 2013, respectively. The average residue cover in experimental fields with corn stover harvest was 15% in 2012 and 16% in 2013, but reduced tillage could increase residue coverage. Corn stover harvest had a positive impact on corn emergence for the experimental fields with 2,470 more corn plants per acre by the third day after emergence where corn stover was removed, but the final populations were the same. Late spring soil sampling for ammonium (NH_4-N) and nitrate (N_3-N) were no different where corn stover was or wasn't harvested, and this was further evident by plant analysis of total nitrogen. Results showed soil organic matter remained unchanged due to corn stover harvesting, but soil organic matter as a whole (disregarding corn stover removal) fluctuated naturally or due to measurement error. Overall, this 3-year study showed no adverse impacts to soil tilth, for the characteristics measured, as a result of corn stover harvest.

Introduction

A direct impact of harvesting corn stover is the amount of corn residue left behind. Generally, there is a 1:1 ratio (by mass) between corn stover and corn grain produced in a field (corn stover includes the stalk, leaves, husk and cob) before stover harvest. Corn stover is very important to the soil because it returns nutrients to the soil, provides cover from soil erosion (wind or rain), increases the water holding capacity of the soil when incorporated and promotes microbial growth (DeJong-Hughes & Coulter, 2009). If too much is removed, it could have a negative impact on the soil. One of the impacts, returning nutrients to the soil, is of concern from a conservation standpoint but also from an economic standpoint. Potassium (K) and phosphorus (P) are among two of the macronutrients that have many questions related to how much is removed, because fertilizer applications need to take into consideration corn stover removal if it is to succeed. P is needed especially during early growth stages and is important in storing and transferring energy produced by photosynthesis. K is needed because it helps with the movement of water, nutrients and carbohydrates within the plant itself (McCauley et al., 2009). While both are important to corn production, it has been reported than an additional 17% of P is needed to be replaced but an additional 93% of K is needed to be replaced (assuming 180 bu/ac yield and 2 ton/ac corn stover harvest rate). This higher increase in K removal is important to know when making fertilizer recommendations (Sawyer, 2007).

When 25% or more of corn stover was removed in Ohio, soil macroaggregates decreased by at least 40% and it was determined that any harvest rate above 25% would also decrease soil organic carbon, harming the soil structure (Blanco-Canqui & Lal, 2009). Another study found that removing all of the corn stover decreased soil organic matter by 8% during its 32-years (Moebius-Clune, et al., 2008). A lack of soil structure from higher corn stover removal rates can also be linked to a lack of glomalin-like residues produced by fungi, bacteria and other soil biota (Rust & Williams, 2012). Additionally, soil bulk density has been found to increase as well when all of the corn stover was removed (Moebius-Clune et al., 2008). In South Dakota for a 4-year study with a corn/soybean rotation, corn residue was removed at three different intensities (none, some, all), and a steady decrease in soil organic matter and particulate organic matter was recorded when residue removal took place. Soil aggregates sizes decreased as well (Hammerbeck et al., 2012).

Overall, corn stover harvest has negatively impacted several areas; most consistently soil organic matter over long periods of time and at higher rates of residue removal, but the retention of corn residue can increase the risk of having poor stand counts. The removal of this residue could lead to greater adoption of no-till management practices and hinder plant emergence by blocking sunlight to heat the soil (Swan et al., 1996).

Experimental Design

General Field Layout

In this study, there were two types of fields: experimental and production. The experimental fields were located within a 30-mile radius of Iowa State University's BioCentury Research Farm. Individual experimental fields had a research plot that consisted of the majority of the field, but did not include end rows. Each plot varied in size from 18.8 – 78.9 acres and had six strips, except for field 91 which had nine strips, alternating in treatment of stover harvest: no harvest or harvest. Every strip was 48-rows wide to accommodate for each grower's planting and harvesting equipment, but a field's research plot length depended on each field's size. Every strip was separated into four zones, and within these zones measurements were taken. A general layout of an experimental field can be seen in Appendix.

Production fields were located within a 40-mile radius of Iowa State University's BioCentury Research Farm. These fields had corn stover harvested from the entire field, and only residue measurements were taken at randomly selected locations.

Residue Counts

The amount of residue left on a field was measured at a 45 degree angle to the corn rows using the line transect method (Figure 11) as outlined in the National Agronomy Manual – 503.51 (Natural Resources Conservation Service, 2011). For the experimental fields, a residue count was once taken at every location. For the production fields, a minimum of six measurements were taken randomly per field. Residue count measurements were taken after spring tillage and planting occurred, except for in 2013 when measurements on experimental fields were taken both before and after spring tillage and planting.

Figure 11: Example of 32% crop residue (left) and 8% crop residue (right)

Emergence Counts

Corn plant emergence was measured only in experimental fields by laying a fiberglass pole on the ground between two corn rows that represented 1/1000th of an acre (17.5 feet). In 2013, four stand counts were taken for three consecutive days starting when corn plants were spiking through the soil, and the fourth measurement was taken approximately 30 days after spiking. Stand counts were taken at each sub-location as shown in Appendix and only in one row. Once the fiberglass pole was laid down and the first measurement taken, 8 inch flags were placed at each end of the fiberglass pole so each subsequent measurement could be taken at that exact spot. Any corn plant that spiked above ground level was counted.

Late Spring Soil Sampling

Late spring soil samples were taken in 2012 and 2013 in accordance with Iowa State University's Extension document PM-1714 (1997). 2012 samples were taken at every location, and 2013 samples were taken at every sub-location shown in Appendix. The samples were then analyzed for nitrate (NO_3-N) and ammonium (NH_4-N) at Iowa State University's Soil and Plant Analysis Laboratory via colorimetric testing using the Lachat Flow Injection Analyzer (Hach).

Late Spring Plant Tissue Sampling

Late spring plant samples were taken in 2013 at the same time of the late spring soil samples. Five plant samples were randomly harvested at ground level (Figure 12) around each sub-location shown in Appendix, dried at 80^{o}C until the samples maintained a constant mass and ground to pass through a 1 mm screen. The samples were then submitted for total nitrogen analysis at Iowa State University's Soil and Plant Analysis Laboratory and analyzed according to the Soil and Plant Analysis Council, Inc (1998).

Figure 12: Plant sample for late spring total nitrogen analysis

Soil Organic Matter

Soil organic matter was measured in the fall of 2011 after grain harvest and the fall of 2013 after grain harvest. Both samples sets were collected using a Wintex 1000 automatic soil sampler and in accordance with Iowa State University's Extension soil sampling document PM-287 (2003). 2011 samples were taken randomly within each zone as shown in Appendix, and 2013 samples were taken randomly within soil types contained in each strip as shown in Appendix. Both samples were sent to the Minnesota Valley Testing Laboratories (MVTL) Inc. for organic matter analysis via loss on ignition method listed in North Central Regional (NCR) Regional Research Publication No. 221 (NCR, 1998).

Statistical Analysis

Minitab 16 Statistical Software was used to perform statistical analyses for this experiment, except for the plant emergence values in which Statistical Analysis System (SAS) was used for a mixed effects linear model. A paired t-test was used to compare residue levels across harvest treatments in experimental fields, and a two-sample t-test was used to compare residue levels across harvest treatments in production fields. Plant emergence was analyzed using a mixed effects linear model to account for the repeated measures nature of the data. A random effect is included for each location that was sampled repeatedly over time. Late spring soil sampling and late spring plant samples were analyzed using paired t-tests across harvest treatments. Soil organic matter (by field and soil type) was analyzed using a mixed effects linear model as well. All t-tests used an alpha (α) equal to 0.05.

Results

Residue Counts

Harvesting corn stover had a statistical difference in the percent residue coverage in experimental fields in 2012 and 2013, and production fields in 2012 under conventional tillage practices. No production fields were measured that had no corn stover removal in 2013. Experimental fields in 2012 saw an average reduction of 13 residue percentage points from an average of 28 in nonharvested areas to 15 in harvested areas; production fields saw an average reduction of 11 residue percentage points from an average of 26 in nonharvested areas to 15 in harvested areas. 2013 experimental fields also saw a decrease in percent residue coverage with a 16 reduction of residue percentage points from an average of 32% in nonharvested areas to 16% in harvested areas. The average residue coverage for production fields with corn stover harvested was 20%. This data is summarized in Table 8.

Table 8: Average percent residue cover by year exclusively for fields with conventional tillage. The differences and p-values are representative of the means with the same superscript

Year	Treatment	Mean (%)	Difference (%)	p-Value
2012	Experimental Harvest	15[a]	-13 [a]	0.005 [a]
	Experimental No Harvest	28 [a]		
	Production Harvest	15[b]	-11 [b]	< 0.001 [b]
	Production No Harvest	26 [b]		
2013	Experimental Harvest	16[c]	-16 [c]	< 0.001 [c]
	Experimental No Harvest	32 [c]		
	Production Harvest	20		

Besides harvesting corn stover as a way of managing residue cover, tillage is another affective method by incorporating the corn stover into the soil itself. However, the type of tillage can play a significant role in the amount of residue even after corn stover removal. Figure 13 displays several comparisons of varying tillage impacts.

First, pre-spring tillage values were obtained from experimental fields (gray) and are labeled “Before Tillage”. The average harvest residue coverage was 22% and no harvest was

42%. Then after spring tillage and planting were completed by each grower, post-spring tillage values were measured in experimental fields and are labeled "Conventional". The interval bars show that spring tillage had a statistical impact by reducing the amount of residue cover in both areas of corn stover harvest and no harvest.

Second, production fields where corn stover was harvested were measured after spring tillage and planting, but were differentiated by tillage type. As is evident by the average residue counts in Figure 13, residue levels of corn stover harvested fields with reduced tillage (37% residue coverage), strip tillage (43% residue coverage) or no tillage (57% residue coverage) can achieve residue levels similar to fields that had no corn stover removed and conventional tillage. Production fields with conventional tillage had an average residue count of 20%.

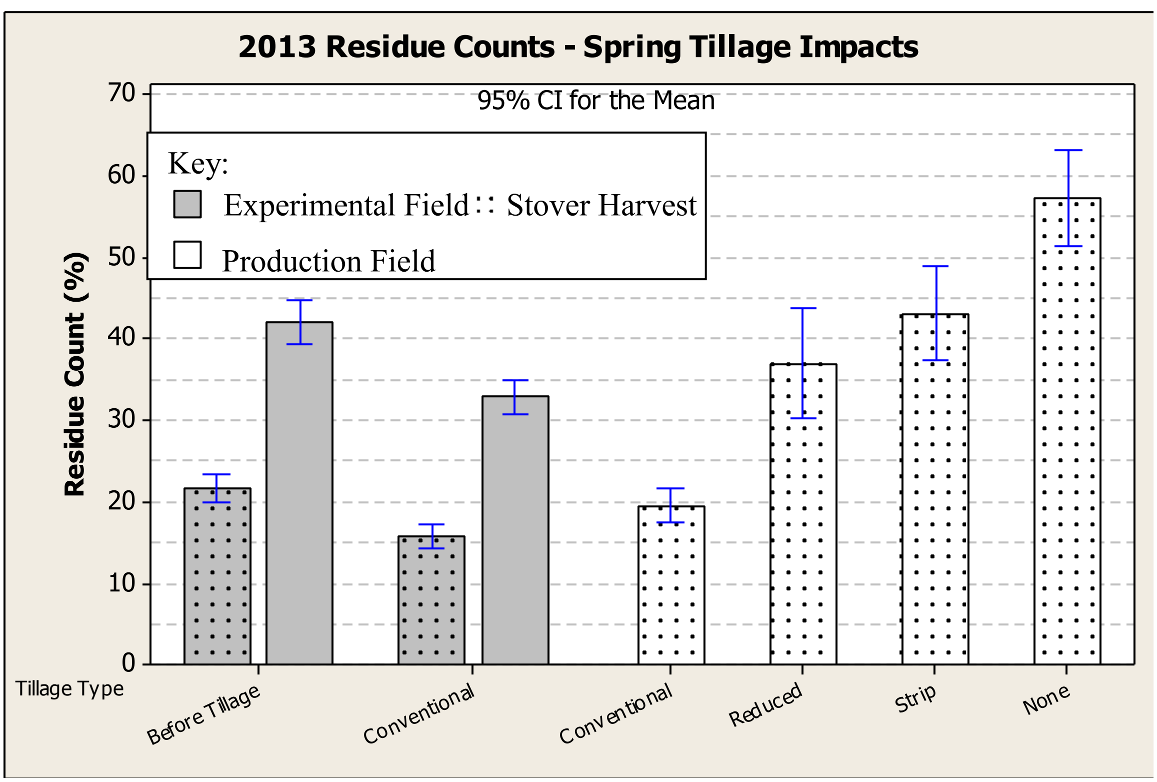

Figure 13: 2013 residue counts by tillage method

Emergence Counts

Emergence was measured for three consecutive days starting with when corn plants were spiking through the soil and approximately one month later. A repeated measures model was setup using statistical software called Statistical Analysis Software (SAS). This model took the four sets of emergence values observed in the field and estimated population values at 10 and 15 days after the initial stand count.

Combining all of the agronomic fields' data together, it shows that corn stover removal has a positive impact on emergence for the first three days of observed stand counts. A statistical increase of 2,670, 2,570 and 2,470 plants per acre was found for the first three days (Table 9). Following this, the model extrapolated that at ten days there would still be a statistical increase of 1,700 plants per acre, but this statistical difference was nonexistent by day fifteen. Returning to the empirical data, there was no observed statistical difference at the final population stand count one month after the initial count. Analyzing each experimental field on an individual basis, Figure 14 shows percent difference in emergence count between harvest treatments with a positive value signifying more plants in stover harvested strips. Five out of the six fields observed showed more plants where corn stover was harvested on the first count, declining to the second and third counts. On the final stand count, there was no statistical difference.

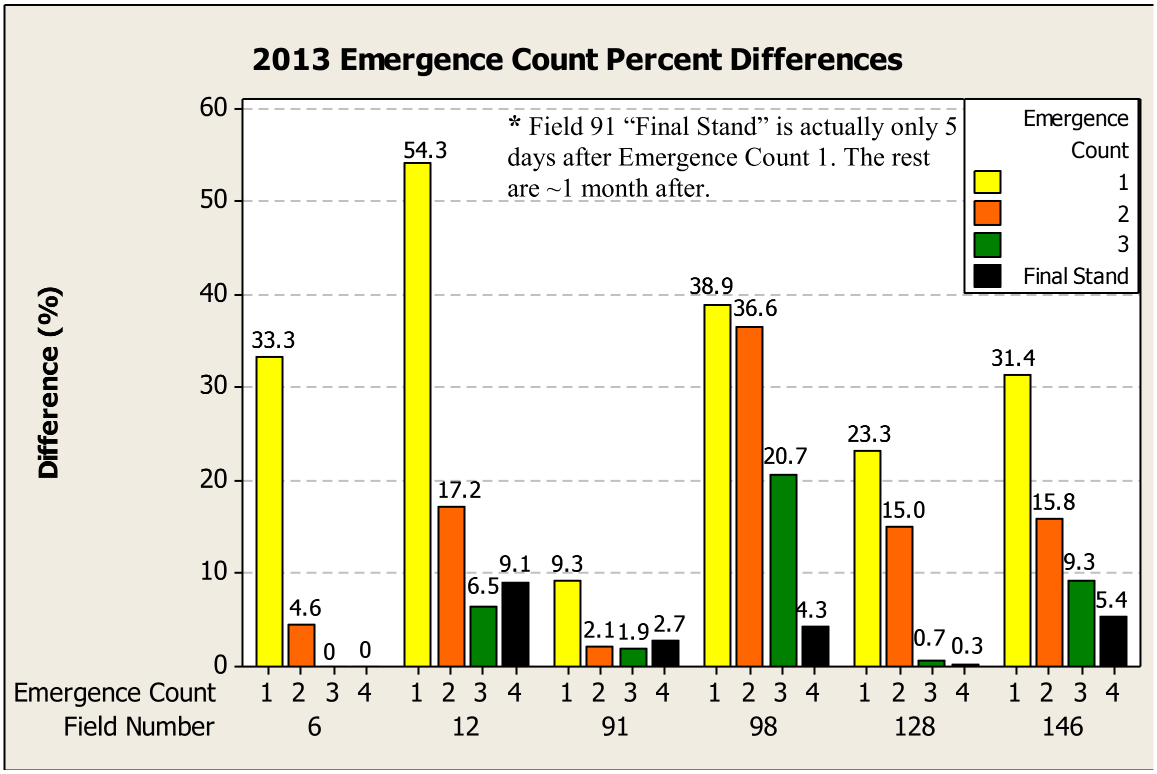

Figure 14: 2013 percent difference of plant emergence for six experimental fields where a positive value means more plants in areas where corn stover was removed

Table 9: Emergence rate of corn plants for areas with and without corn stover harvest

Day	Treatment	Mean (plants/acre)	Difference (plants/acre)	p-Value
1	Harvest	21,030	2,670	< 0.001
	No Harvest	18,360		
2	Harvest	23,720	2,570	< 0.001
	No Harvest	21,150		
3	Harvest	26,230	2,470	< 0.001
	No Harvest	23,760		
Final Stand	Harvest	29,800	140	0.91
	No Harvest	29,760		

Late Spring Soil Sampling

Soil samples were collected at the peak growing time for corn plants (6 to 12 inches tall from ground level to the center of the whorl) to make sure adequate amounts of nitrogen was available. Soils with nitrate levels of 25 ppm and above are considered adequate for the rapid uptake of nitrogen that is about to take place by the corn plants. Anything less than this critical nitrogen value, it is recommended that additional nitrogen be applied according to Iowa State University Extension's PM-1714.

In 2012, there was no statistical difference in concentrations of ammonium or nitrate, and the respective concentrations were 9 and 27 ppm for harvested areas and 8 and 26 ppm for nonharvested areas. However, 2013 results were almost the exact opposite in terms of ammonium and nitrate concentrations. For harvested areas, ammonium concentrations were 25 ppm and nitrate concentrations were 14 ppm. Nonharvested areas showed similar values of 26 ppm for ammonium and 12 ppm for nitrate. Nitrate values for 2012 were sufficient in both treatments, but both treatments were below the critical nitrate value of 25 ppm. These data are summarized in Table 10.

Table 10: Inorganic nitrogen content in late spring soil samples for areas with and without corn stover harvest

Year	Treatment	Nutrient	Mean (ppm)	p-Value
2012	Harvest	NH_4-N	9	0.315
	No Harvest	NH_4-N	8	
	Harvest	NO_3-N	27	0.686
	No Harvest	NO_3-N	26	
2013	Harvest	NH_4-N	25	0.926
	No Harvest	NH_4-N	26	
	Harvest	NO_3-N	14	0.082
	No Harvest	NO_3-N	12	

It is important to note that although ammonium and nitrate values vary greatly from 2012 to 2013; this is not entirely uncommon as they are both sensitive to temperature and soil moisture. Growing conditions were different in the spring of both years. 2012 only had 9.2 inches of rain between March and June 1st, whereas 2013 19.8 inches of rain. Also, 2012 had an average temperature of at least 52°F beginning in March which is warmer than the 38°F average of the previous three years in March. 2013's average temperature in March was 45°F and didn't have a monthly average at or above 52°F until May. Therefore, the warm, dry spring of 2012 could have increased microbial activity in the soil by converting ammonium to nitrate, and very little of the nitrate would have been leached due to the lack of rain. 2013's cooler weather and increased rain might have decreased soil microbial activity and oxygen availability which would have reduced the conversion of ammonium to nitrate; any nitrate in the soil would have been easily leached away with the rain also. Overall, the data suggest that ammonium and nitrate concentrations in late spring have other environmental factors, like rainfall and temperature, which could have had a greater impact rather than whether or not corn stover was removed.

Late Spring Plant Tissue Sampling

Plant tissue sampling was also conducted in 2013 to see if corn plants in both treatments were receiving adequate amounts of nitrogen. A two-sample t-test revealed that there was no significant difference between harvest treatments with a mean of 3.82 and 3.75 % nitrogen for harvest and nonharvest, respectively, meaning that corn stover harvest did not adversely or advantageously impact plants' ability to uptake nitrogen. Figure 15 shows the variation between different fields and percent total nitrogen, but there was never a significant difference within the same field. A paired t-test revealed a p-value of 0.175 when the harvest treatments were compared, but the null hypothesis that both means are equal could not be rejected.

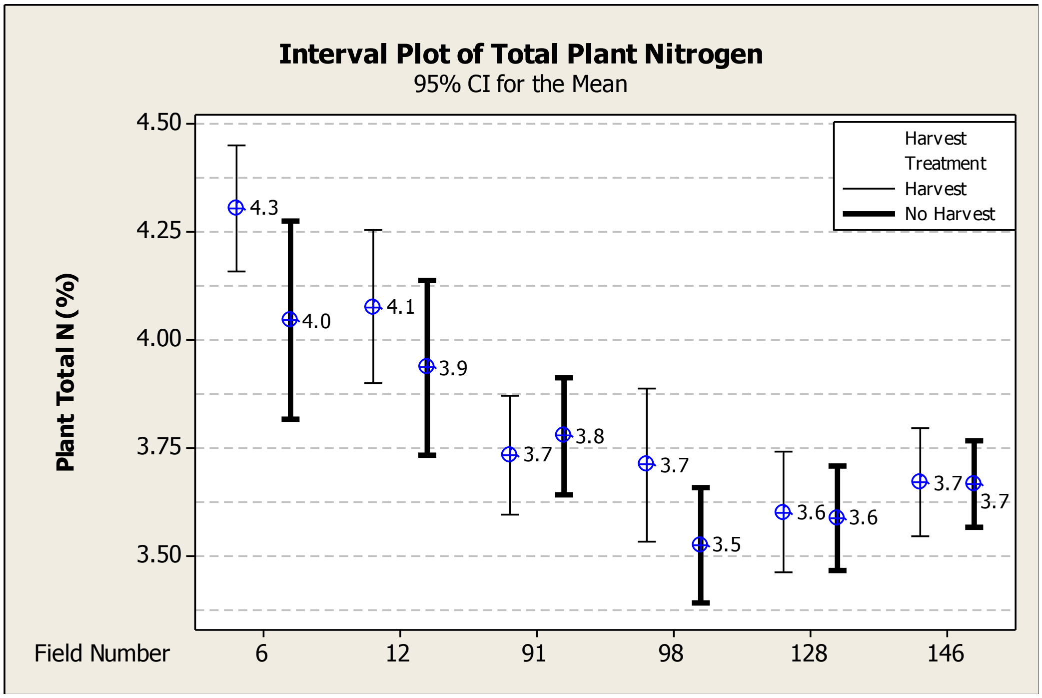

Figure 15: An interval plot showing percent total nitrogen in corn plant tissue at the time of late spring soil sampling

Soil Organic Matter

For the experimental fields, an initial baseline of soil organic matter was established in 2011 and was compared against 2013 soil organic matter values in Figure 16 and Figure 17. By pairing the harvest treatments across 2011 and 2013, it is evident that there is no statistical increase or decrease in mean soil organic matter values after two years of corn stover harvest for any of the fields. Also, there is no statistical difference within a single year between harvest treatments.

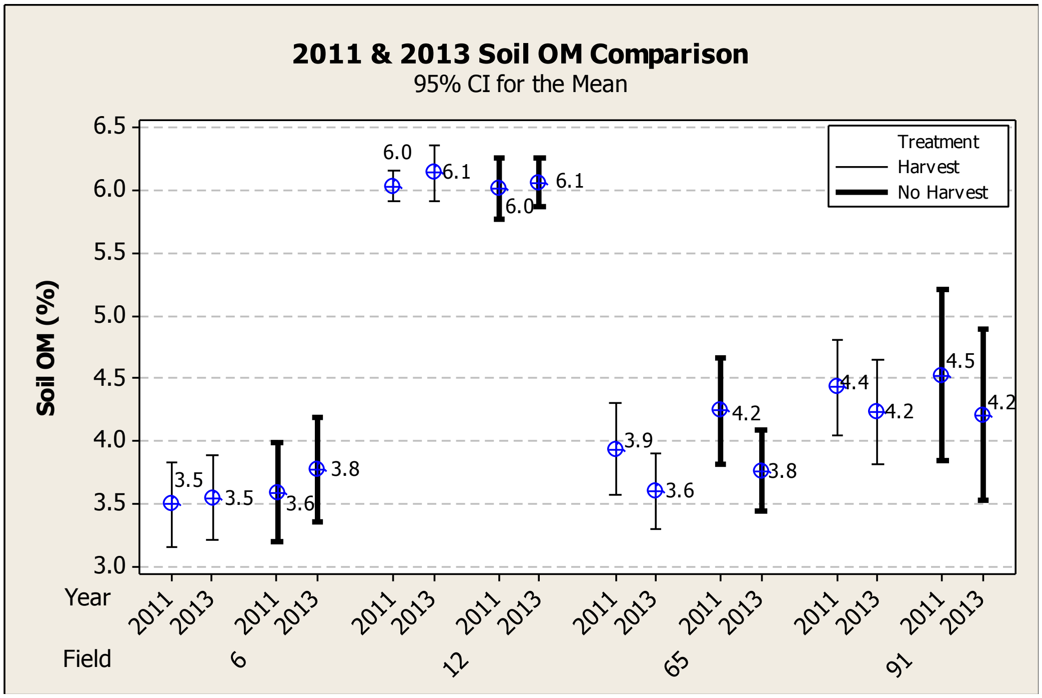

Figure 16: A comparison of soil organic matter after two years of corn stover harvest

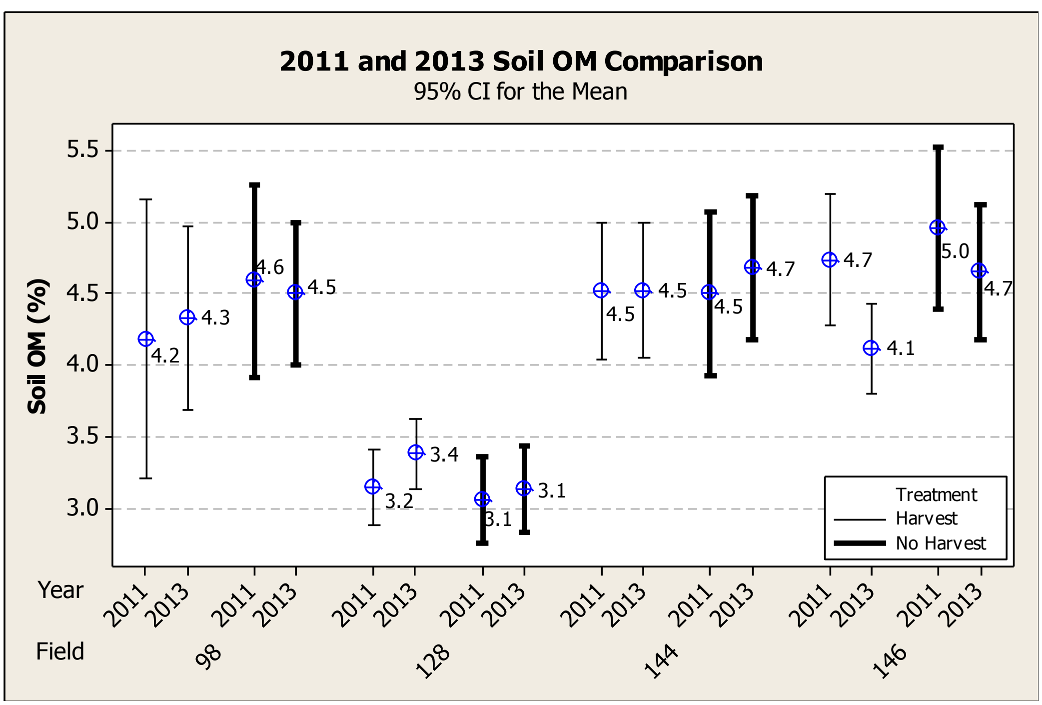

Figure 17: A comparison of soil organic matter after two years of corn stover harvest

Going one step further and comparing soil organic matter values by soil type, as in Table 11, there is still no evidence in a statistical change of soil organic matter content. The four soil types have different means, but the treatments within the soil types are not statistically different.

Table 11: 2013 soil organic matter values by the four most predominant soil types in the experimental fields

Soil Type	Treatment	Mean (%)	p-Value
Clarion	Harvest	3.7	0.759
	No Harvest	3.8	
Canisteo	Harvest	5.5	0.748
	No Harvest	5.6	
Harps	Harvest	6.1	0.347
	No Harvest	6.6	
Webster	Harvest	5.4	0.971
	No Harvest	5.7	

Conclusion

Harvesting corn stover reduces the amount of residue coverage by about half when conventional tillage methods are utilized, but reduced tillage methods could maintain the USDA's 30% minimum residue coverage to help prevent soil erosion and return adequate nutrients into the soil. The reduction in corn stover residue does have positive impact on corn emergence rates. This could be occurring because, albedo effects are decreased allowing the sun's energy is able to warm the soil more quickly, and emerging plants have less resistance to push up through when there is less stover.

Corn plants are also getting the amount of nitrogen that they normally would without harvesting corn stover, but the availability of nitrogen can be greatly impacted by the weather due to biological activity. As long as the nitrogen is available (NO_3-N), both harvest and no harvest treatments are able to uptake similar amounts. Soil organic matter also has not decreased over two years, but it might over a longer period of time. However, as was evident in residue coverage, reduced tillage could play an important part of maintaining soil organic matter since the stover would not be incorporated into the soil as much and would remain as organic matter.

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CHAPTER 6

GENERAL CONCLUSION

Overall, this 3-year study showed adverse impacts can be avoided and some benefits can be seen, for the characteristics measured, as a result of corn stover harvest. Nevertheless, harvesting corn stover can have negative effects if the correct management practices are not followed or if fields are inadequate for corn stover harvest even when coupled with good management practices. Application of additional nutrients will not be a large issue, because only potassium needs to be applied in significantly larger amounts than currently practiced in Central Iowa with grain harvest. The majority of phosphorus and nitrogen are already removed via corn grain harvest, and minimal amounts remain behind in the corn stover.

There is enough corn stover material to be harvested for production scale levels of corn stover harvest in Central Iowa, but the rate at which it is removed may have to be adapted from year to year in order to maintain soil quality standards. For example, if a drought were to occur and grain yields were greatly reduced, corn stover yields would be greatly reduced as well and lower rates of stover harvest may need to occur in order to preserve soil residue coverage to prevent erosion, return potassium to the soil and incorporate organic matter into the soil. Without adequate amounts of organic matter, biological activity would decrease over time and thus decrease crop production of any kind. However, fortunately organic matter did not seem to be impacted after two years of corn stover harvest, but if residue levels are not maintained, it could lead to decreased organic matter over time. This is why reduced tillage methods to keep residue on top of the soil would be beneficial instead of incorporating it all into the soil. Increased residue would provide some protection from erosion, soil aggregates and organic matter for soil stability and soil biota.

The agriculture industry on a whole would also benefit from the neutral to positive effects that corn stover has on subsequent corn grain harvests. By doing this, more growers would be willing to harvest corn stover, thereby producing more feedstock for the cellulosic ethanol plants, without reducing the supply of corn grain. Cellulosic ethanol may start taking some of the ethanol market share, thereby slightly reducing the demand for grain and the price for food and livestock producers. The method by which fields are compared for grain advantage wouldn't matter in most fields, but each would have their own use. A yield monitor would allow growers to select poor performing parts of their field to be excluded from stover harvest, whereas a plant bundles would allow cellulosic ethanol plants to estimate that year's feedstock supply by utilizing the stover harvest index (SHI).

Corn stover harvest can be done without adversely impacting the areas reported in this 3-year study and can be beneficial if proper management techniques are used. Partial corn stover removal resulted in decreased residue levels that were below the USDA's 30% recommended coverage when conventional tillage was used, but by incorporating reduced tillage methods, this could help increase and maintain the 30% recommendation following corn stover harvest. While final plant populations were similar, corn stover removal could help corn plants have a greater emergence rate and giving them an earlier start. Grain yields did not statistically decrease as a result of corn stover harvest, but either provided a benefit or remained neutral. This is good, because it will not deter most growers then from participating in a corn stover harvest program. However, while P_2O_5 removal per ton of dry stover remains at 3.6 lb, K_2O removal is more year dependent, as was seen in this study, with concentrations of 18.7 lb/ton dry stover in 2011 and 15.1 lb/ton dry stover in 2012. Ammonium and nitrate concentrations are also likely to fluctuate from year to year depending on environmental conditions like temperature and soil moisture. However, there is no clear interaction between ammonium or nitrate concentrations and corn stover removal. Corn plants were receiving similar concentrations of nitrogen regardless of harvest treatment and did not show a deficiency.

In the end though, it will be up to individual growers to utilize good management practices if they decide to harvest corn stover, and up to the cellulosic ethanol plants to follow through and make sure that the feedstock is being harvested in a responsible manner, not only for environmental concerns, but for continued performance on those fields providing the corn stover themselves.

Future work could be done to see if K_2O removal by production scale harvesting of corn stover is statistically different every year and to investigate if a smaller range of concentrations are observed compared to the 8-20 lb/dry ton reported by Iowa State University Extension (Edwards, 2014). Grain yield data could be analyzed spatially with well calibrated yield monitors to compare various field characteristics, like slope and soil type, to further determine if any yield differences exist within these areas. Also, a long-term study could be performed to determine if any changes in soil organic matter occur due to production scale harvesting of corn stover with regular soil sampling. This could be done with various crop rotations and tillage practices; annually recording the amount of corn stover remaining (on a ton/ac basis) and residue coverage (%) would also be of value to determine which has a greater impact on subsequent years' soil organic matter content.

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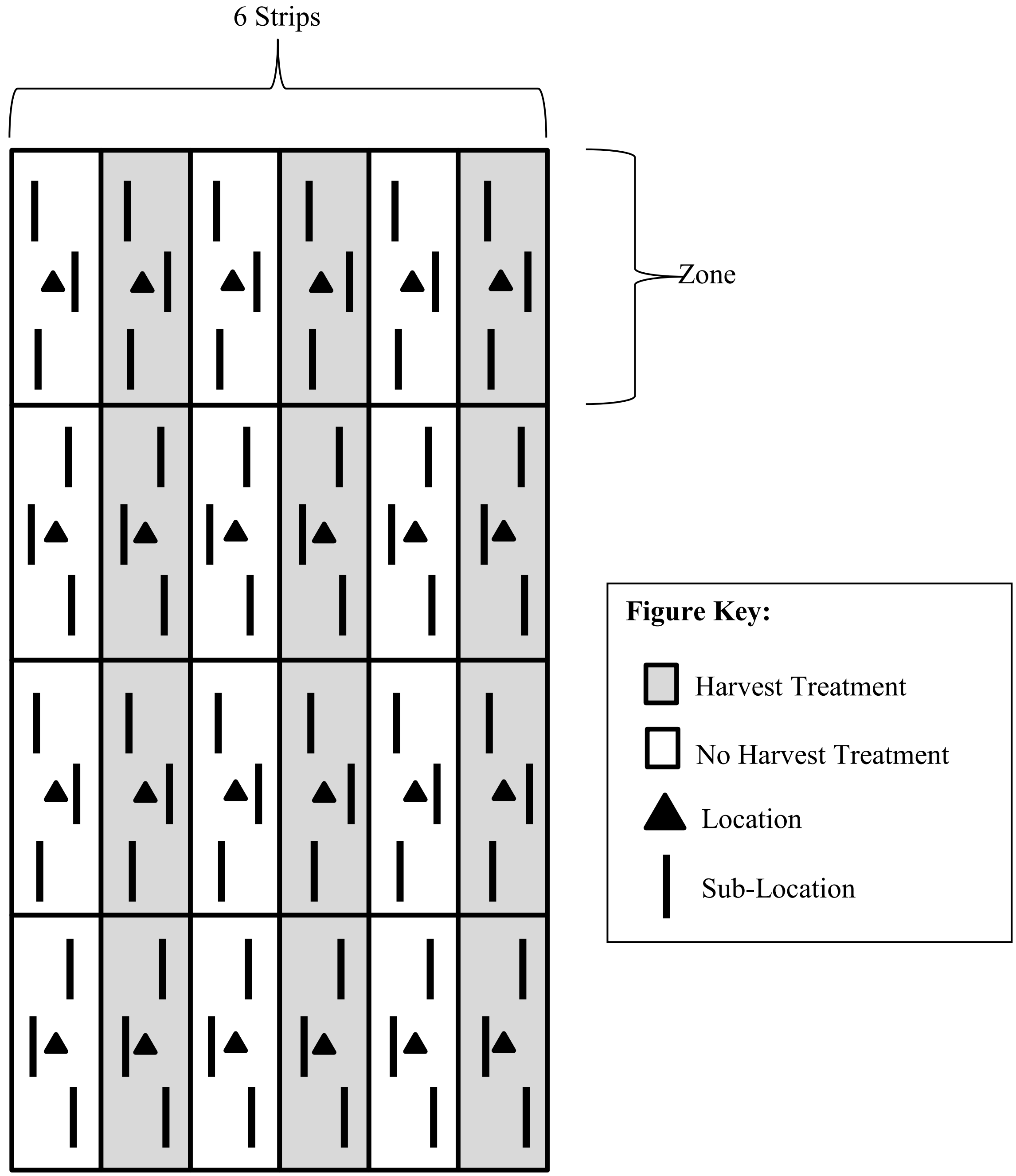
APPENDIX

GENERAL EXPERIMENTAL FIELD LAYOUT



This diagram reflects the general layout of experimental fields. There are alternating strips of harvest treatments. Each strip is 48 rows wide and the length if field dependent. The locations signify where residue measurements, hand samples for grain and stover yield estimation and 2012 late spring soil samples were taken. Emergence rates and 2013 late spring soil sampling were taken at each sub-location.