The Effect of Tillage and Crop Rotation on Soybean and Soil Health

A Thesis

Presented to

The Faculty of the Graduate School

At the University of Missouri

In Partial Fulfillment

Of the Requirements for the Degree

Masters of Science

By

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May 2015

The undersigned, appointed by the dean of the Graduate School,

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THE EFFECT OF TILLAGE AND CROP ROTATION ON SOYBEAN AND SOIL HEALTH

Presented by Brandon Witte Nystrom

A candidate for the degree of

Masters of Science

And hereby certify that, in their opinion, it is worthy of acceptance.

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ACKNOWLEDGEMENTS

I am extremely blessed individual with an overwhelming amount to be thankful for in my life. My family and friends who support me are the backbone of my personal achievements. I thank God for the patience and perseverance to not only set goals, but to have the willpower to achieve them. Pursuing a graduate degree took a leap of faith and I am proud of myself for taking that leap.

First and foremost, I want to thank my grandparents who stirred my initial interests in agriculture during my youth. Farming is the greatest and most rewarding profession in the world. Their example of hard work and dedication to their land and family is exactly how I hope to lead my own life. Also, I wouldn’t be the man I am today without my parents. Their love and support is unwavering and I can’t even begin to explain to them my gratitude. While I don’t get to see all of my family on a regular basis, I can still feel their love from afar and know that they are there for me no matter what. Likewise, the support from my girlfriend Lauren, the members of my church and home town, and all of my friends both at home and away have kept me grounded and focused over the years. I would especially like to thank my advisor, Dr. Bill Wiebold, for his patience and guidance throughout my time in graduate school. He has been a tremendous mentor from whom I have learned a great deal. Additionally, I want to thank my committee members Dr. Felix Fritschi, Dr. Brent Myers and Dr. Randy Miles for all of their help and input with this project. And finally, I want to thank the entire crew at MU Variety Testing for their time and assistance.

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CHAPTER I

LITERATURE REVIEW

As the world population grows, the demand for more food, feed and fuel resources is drastically increasing. World population is expected to surpass the 9 billion mark by the year 2050 (United Nations, 2013) posing many questions on our ability to sustainably produce food on a limited amount of land. This has led to more efforts to increase crop production and yield. One of the most important crops in the US and Missouri, both in acreage and value, is soybean (Glycine max L.). Soybean is adapted to diverse climates and soil types. Its seed is roughly 20% oil and 40% protein (Wilcox, 1987), making it highly desirable for food, feed and biodiesel industries.

Since 1924 soybean acreage in the US has risen from roughly 647,497 to 30,958,451 hectares (USDA, 2014a). In 2013, soybean area in Missouri was an estimated 2,266,000 hectares, more than that of all other row crop species combined (USDA, 2014a). Yield in Missouri, on average, is estimated at 2,387.4 kg/ha^{-1} (USDA, 2014a). With the increase in soybean production and prices remaining relatively high, Missouri's soybean production grossed over $2.5 billion in 2013 (USDA, 2014a). The continual increase in demand and high prices are the main driving factors in soybean production. Due to the high value of this crop some farmers have implemented a continuous soybean cropping system. In 2006, only 6% of the total US soybean acreage was soybean followed by soybean (Wallender, 2013). However, in Missouri, for 2006 the practice of continuous soybean accounted for 34% of the total soybean acreage (USDA, 2014b). This is a substantial number especially when compared to neighboring states in 2006, such as Illinois, that had a continuous soybean portion of only 3.6% (USDA, 2014b). There has been a limited amount of research conducted on the long term effects of soybean management on plant production and soil characteristics. Most studies have focused on the short term advantages of soybean rotated with other grain crops. However, with the rising prices and increasing demand for soybean, further information on the impact from various soybean management systems is needed.

Soil Erosion

Agricultural land is widely considered one of the most important resources in the world. Erosion of the land is a major worldwide issue that has resulted in the generation of many international conferences and soil protection agencies, such as the United States Natural Resources Conservation Service (NRCS). The loss of productive farm ground from erosion and decline of soil health can be used to trace the shift and movement of populations throughout history (Montgomery, 2007). Impacts from soil degradation on previous civilizations demonstrate the importance of maintaining our soils for a productive civilization. During the Dust Bowl of the 1930’s, an average of 176 metric tons of soil per hectare were removed on a large portion of the Great Plains (Hansen and Libecap, 2003). It was estimated that as many as 4,046,856 hectares had lost the upper 12.7 cm of topsoil (Hansen & Libecap, 2003). This is a prime example of how extreme weather and poor soil management over time can lead to ecological disaster and why our agricultural production systems should be managed to protect against it.

In 1982, the National Resource Inventory (NRI) exhibited that only 49% of all soil in the US had acceptable levels of protection against erosion. Nearly 23% of cropland (roughly 115 million hectares) suffered from erosion at two or more times the sustainable rate (USDA, 2007). In 1982, water erosion removed over 3 billion metric tons of soil, and wind erosion removed about 1.8 billion from US farmland (USDA, 2007). According to the NRCS, US wind and water erosion rates decreased 43% between 1982 and 2007. In that time frame, highly erodible cropland decreased from 50.6 million to 39.7 million hectares, a decrease of 36% (USDA, 2007). As of 2007, soil area eroding above the soil loss tolerance rates are down to around 28% of all crop ground (USDA, 2007). In Missouri, sheet and rill erosion decreased by 45% between 1982 and 2010 (USDA, 2010). A large portion of this decrease in soil erosion is attributed to the adoption of conservation tillage practices. Conservation tillage is defined as “any tillage/planting system which leaves at least 30 percent of the field surface covered with crop residue after planting has been completed” (McCarthy, 1993).

With soil erosion, soil particles are detached, transported and finally deposited at a new location. The underlying principle of soil erosion control therefore is to limit these factors from occurring. While there are many erosion control options including terraces, farming on the contour and strip cropping systems, the most commonly used method is the use of conservation tillage. This has become an important part of corn (*Zea mays*) and soybean production in the Midwest and Missouri. No-tillage (NT) is the most extreme form of conservation tillage in which crops are planted without the use of tillage implements. The residue left on the soil surface through NT is the main factor responsible for reducing erosion. Residue intercepts raindrops and decreases their energy, also reducing the dislodging and transportation of soil particles. Decreasing the impact from precipitation can therefore reduce compaction, increase infiltration and increase aggregate stability (USDA, 1996).

In a long term central Missouri study, erosion was found to be a significantly greater risk on tilled ground compared to conservation tillage (Burwell and Kramer, 1983). Soil loss is 4 to 5 times greater from fields planted with soybean versus corn after a large rain event (Alberts et al., 1985). Alberts et al. (1985) suggested that potential differences in soil physical properties, such as aggregate size and stability, between production systems may partially explain the differences seen in water and soil loss between cropping systems. Soybean also produces less residue than corn, and therefore, less soil coverage and protection against soil particle detachment and removal (Ghidey and Alberts, 1998; Alberts et al., 1985). Additionally, soybean residue decomposes faster than corn and wheat residue (Broder and Wagner, 1988), which can be partially attributed to accelerated microbial degradation of crops with a narrow C:N ratio (USDA, 2011). Continuous soybean reduces the total amount of ground coverage and protection compared with soybean in a corn rotation. This can be attributed to the large residue input from corn and the residues wide C:N compared to a legume species (USDA, 2011).

No-Tillage effects on soybean performance

There are few studies showing long term analysis of no-tillage soybean production side by side with conventional tillage methods. Experiments on short term benefits have mainly focused on nutrient and rotational effects in the Midwest. While these studies are good for analyzing changes in yield and soil properties, it is important to understand what long term effects no-tillage practices may have on the agricultural landscape. By analyzing the long term effects of no-tillage cropping in soybean we can gain a better understanding of this systems production capabilities.

A large portion of soybean crop production research done in the Midwest is in rotation with corn and sometimes wheat *(Triticum aestivum L.)*. In some instances, interactions between various climatic, soil and treatment conditions are less profound (Al-Kaisi and Yin, 2005) than in others (Wilhelm and Wortmann, 2004). This indicates that interactions are complex and that many factors can have an effect on productivity. While this is a complex issue, a large amount of focus in research is based on yield because of its direct impact to producers. One of the longest studies on NT soybean production in a corn-soybean rotation was conducted in central Iowa by Karlen et al., (2013). The study ran for 32 years and examined both yield and a variety of soil fertility characteristics. The average soybean yield for each phase increased as the study progressed and showed no major differences among tillage treatment yields. In fact, taking into account the estimated costs of each system, no-tillage had the greatest return on investment (Karlen et al., 2013). This was true for all three cropping systems (continuous corn, rotated corn, rotated soybean) used in this experiment. The authors concluded that the implementation of a long term NT soybean system with adequate soil management and rotation can be successful on a glacial till soil (Karlen et al., 2013).

Despite few NT studies longer than 20 years, a similar trend to Karlen et al. (2013) was observed in West et al. (1996). This study took place over a 20-year period in north central Indiana on a Chalmers silty clay loam using four tillage systems in a corn/soybean rotation. There was an initial decrease in yield of 5% in NT soybean plots when switching from tilled. But, the differences between tilled and no-tillage treatments decreased as the study progressed. During the last 10 years of the experiment, yields from both tilled and NT were essentially equal (West et al., 1996). A 20-year study conducted in Ohio by Dick and Van Doren (1985) showed no reduction in overall yield on two of the three soil types for NT soybean. Similarly, Wilhelm and Wortmann (2004) showed no significant effect of NT on soybean yield compared to tillage over 16 years in Nebraska. It can be concluded from these results that it is possible to successfully implement long term NT soybean production on certain soil types without a major yield reduction.

There are several important factors that play a role on the successful adoption of NT in soybean management. One of the most critical factors in NT soybean production is the specific soil conditions and its ability to properly drain. Studies on well drained soils have shown soybean can perform just as well if not better in NT than tilled (Hussain et al., 1999a). Similar studies on poorly drained soils (Dick and Van Doren, 1985a; West et al., 1996; Yin and Al-Kaisi, 2004) have shown that NT soybean doesn't fare nearly as well compared to those under tillage. It's apparent that a soils ability to drain may have a direct correlation to its ability to successfully produce soybean with NT.

A major concern with poor soil drainage in reducing NT soybean yield is an increase in the amount of root diseases and soil borne pathogens. These diseases can build up in the soil overtime when crops are produced in continuous cropping systems (Abawi and Widmer, 2000). Some of the more common fungal borne soybean diseases that favor cool and poorly drained soils include *Pythium*, *Phytophthora*, and *Fusarium* (Sweets et al., 2008). The life cycle of *Phytophthora* is a good example of how poorly drained soils can promote pathogen growth. When a soil is saturated for a prolonged time, zoospores are released from *Phytophthora* sporangia and facilitate around seed and plant parts before infection (Schmitthenner, 1985). These favorable conditions may be promoted by a NT system. Understanding the condition in which these diseases occur is a crucial step in managing for NT soybean, especially in variable soil types.

Crop rotations and the use of resistant cultivars are two methods that are widely recommended when managing for diseases control in NT. However, there are other important management decisions that can affect the yield gaps between NT and tillage systems. One of these options is the adoption of biotechnology and herbicide tolerant soybean. A 16-year study in Italy showed an overall significant yield decrease (an average of 16%) in NT plots compared to conventional tillage plots (Mazzoncini et al., 2008). A major reason behind this significant decrease in yield with NT was attributed to the immense weed pressure. This caused a 51% yield reduction compared to the conventional tillage plots. The authors concluded this difference in yield could have been narrowed through the use of biotechnology and the post application of herbicides if it weren't for a ban on GMO soybean in Italy (Mazzoncini et al., 2008).

In the United States, the rise in use of biotechnology has gone hand in hand with the increase in number of NT acres (Fernandez-Cornejo, 2014). Since the first cultivation of herbicide tolerant (HT) crops in the late 1990's, the percentage of GMO soybean acreage planted in the US has risen from 17% in 1997 to 94% of the 2014 spring crop (Fernandez-Cornejo, 2014). On the worldwide scale there has been roughly a 4 billion acre increase in biotech crop production since 1996 (James, 2013). There are many benefits seen from the adoption of biotech soybean including an increase in grower options for weed control (Gianessi, 1999), decreases in production costs and reduction of soil erosion through the use of conservation tillage practices (Bullock and Nitsi, 2001; Qaim and Traxler, 2005). The application of biotechnology in soybean is therefore an extremely useful tool for farmers to manage their fields and practice NT.

Continuous versus rotated soybean

The continuous corn yield penalty (CCYP) has been well studied (Gentry et al., 2013), yet isn't fully understood. However, many studies agree that continuous corn production leads to an overall decrease in yield when compared to corn in rotation

(Crookston et al., 1991; Meese et al., 1991; Porter et al., 1997). Continuous soybean production also leads to a decrease in yield (Wilhelm and Wortmann, 2004; Karlen et al., 2013). Although the effects of continuous soybean production on yield are well established, the reasons for these effects are unclear. Understanding the importance of rotation and its usefulness will help us determine how it can be properly implemented into a long term cropping sequence.

One issue already discussed is the amount and type of residue from the previous year's crop. Corn leaves substantially more residue than soybean (Lal, 2005) and is broken down at a slower rate (USDA, 2011). This may influence soil reactions and explain some of the benefits seen in the following year's crop yield. Due to the increase in residue from a rotation with corn, a corn/soybean rotation can increase the relative amount of microbial biomass carbon and increase nitrogen availability (Moore et al., 2000). This is an area of study that doesn't receive a lot of attention, but can play a vital role in why we see the effects of rotation in the Midwest. Soybean in rotation is unique, in that they can provide a readily available source of nitrogen, anywhere from 22-308 kg/N per hectare to the following year's crop (Killpack & Buchholz, 1993). Most crops, such as corn, cannot fix nitrogen and therefore can benefit when grown after soybean or other leguminous crops (Baldock et al., Meese et al., 1991; Vanotti and Bundy, 1995; Carpenter-Boggs et al., 2000). Due to the potential benefits, rotation plays a key role in increasing soybean NT acreage and therefore more information is needed.

In 2010, 84% of corn and 94% of soybean was grown in a rotation cropping system in the US (Wallender, 2013).The large amount of acreage in rotation illustrates a pressing need for information on the long term effects of this system on both plant development and the soil. As with tillage studies, long term rotation experiments are less frequent than short term projects. Many of the studies that have focused on rotation also include different tillage sequences. A 20-year study on a silty clay loam in Indiana concluded that soybean in rotation with corn, under various tilled and NT systems, showed a yield advantage compared to continuous cropping over the course of the study (West et al., 1996). This agrees with another 20-year study, where soybean was rotated with either grain sorghum (*Sorghum bicolor*) or wheat (*Triticum aestivum* L.), and showed a near 15% overall yield advantage when compared to continuous soybean (Kelley et al., 2003). Despite few studies that focus on soybean rotations for more than a few years, these experiments show positive long term benefits of rotation.

Differences in soil types and environment, as with tillage, have been shown to influence the effectiveness of rotation on grain production from year to year (Dick and Van Doren, 1985b; Crookston et al., 1991; Porter et al., 1997). Sometimes the effect may be greater at a location one year and less in another year. Porter et al. (1997) found that rotated corn and soybean compared to continuous cropping in low yielding environments had double the yield advantage when compared to high yielding locations. This correlates to previous reports that continuous crop production on poorly drained soils leads to a decrease in yield (Dick and Van Doren, 1985b), and is likely a result of increased disease pressure and unfavorable growing conditions. Understanding how different environments may affect a cropping sequence can help producers develop a plan to best manage their fields.

Increases in soybean yield from rotation have been documented in shorter studies under similar Midwest conditions, as well (Peterson and Varvel, 1989; Crookston et al., 1991; Meese et al., 1991; Porter et al., 1997). Aside from differences in soil mapping units, there are other environmental factors that can help determine why the effects from rotation occur. Rotations can alter the microbial biomass of a soil, and therefore change its productivity. *Mycorrhizal* fungi and their relationships with legumes facilitating nitrogen fixation have garnered a lot of attention. One experiment, studying the effect of dormant spores in monoculture corn and soybean, suggests that the rapidly multiplying *Mycorrhizal* fungi in continuous cropping systems may be disadvantageous (Johnson et al., 1992). The authors came to this theory after evaluating how the fastest growing mycorrhizal species are selected for in a monoculture, while populations of more beneficial species decrease over time (Johnson et al., 1992). These results are consistent with other work (Ellis et al., 1992) that showed an increase in colonization of beneficial *Mychorrhizae* with the absence of soybean the previous year. Based on these results, crop rotation seemingly benefits soil microbial biomass.

Soy Management and Soil Characteristics

Soybean management affects productivity and soil characteristics. Over the years there has been a wide range of reported differences in soybean yield as a response to soil type and levels of drainage (Porter et al., 1997; Yin and Al-Kaisi, 2004).

Many studies have shown positive soil health characteristics associated with NT crop production (Ismail et al., 1994; Lal et al., 1994; Hussain et al., 1999b) and crop rotation (Havlin et al., 1990; Kelley et al., 2003). Most of the results from previous work have shown a strong influence from soil type and soil quality. Soybean production on poorly drained soil has been shown to decrease yield (Dick and Van Doren, 1985b; West et al., 1996). This is an indication of the importance for producers, especially on marginal land, to accept practices that help improve soil quality factors. The variance in data shows there is evidence that many environmental, soil and management factors are responsible for successful soybean development.

One of the most widely used measurements to describe soil quality is soil organic matter (SOM). SOM is the very small portion of the soil profile that originates from living organisms and provides nutrient sources for plant growth and development. Types of SOM can be either active or passive. Passive organic matter is difficult for microbes in the soil to use, while active organic matter degrades relatively quickly (Hoorman & Islam, 2010). Often, SOM is further described by focusing on the elemental carbon, soil organic carbon (SOC) (Weil et al., 2003). The active portion of SOM (active carbon) consists of living microorganisms and freshly produced non-living residue (Hoorman & Islam, 2010). Due to the easy decomposition of active carbon and its value to the soil (Hoorman & Islam, 2010), it is a good indicator of soil quality and more specific to the soil environment than SOM. Total SOC, which is part active carbon, has shown a positive response in long term no-tillage/minimally disturbed soils in the upper soil layer (Lal et al., 1994; Havlin et al., 1990). This increase in SOC with reduced tillage is not uniform, however, moving farther down in the soil profile (Doran, 1980; West and Post, 2002). Many questions on soil health indicators in response to tillage are yet to be determined.

As the public and scientific concern over global greenhouse gas emissions continues to garner attention, so does the role that agriculture plays in the discussion. In 2012, agriculture was responsible for roughly 10% of total greenhouse gas emissions in the United States (EPA, 2012). Sources of N_2O, CH_4 and CO_2 from agriculture include livestock production systems and manure management, rice production, soil management and the burning of fossil fuels (EPA, 2012). Soil sequesters the earth's largest source of carbon, roughly double the size of the atmospheric level (Lal and Kimble, 1997). These soils are responsible for around 20% of all CO_2 released into the atmosphere, through the processes of soil respiration (Rasogi et. al, 2002). Despite limited data, there is a lot of speculation that soil management practices can have a positive influence on decreasing the amount of CO_2 released into our atmosphere, which could contribute to the lowering of greenhouse gas emissions. In several instances, conservation tillage practices have been found to reduce CO_2 emissions when compared to conventional tillage (Al-Kaisi and Yin, 2005b; Bauer et al., 2006). The actual production and release of soil CO_2 is determined by the respiration from soil biotic factors (Rasogi et. al, 2002). These biotic factors include plant roots and soil animal and microbial activities (Rasogi et. al, 2002).

As stated, there is evidence to suggest NT practices decrease the amount of CO_2 emissions when compared to conventional tillage methods (Reicosky et al., 1995; Bauer et al., 2006; La Scala et al., 2006). When soils are disturbed by tillage, materials are quickly decomposed and C is more readily mineralized (Lal and Kimble, 1997). This contributes to lowering soil C levels and quick release of CO_2. Based on US averages from crop inputs, NT generally releases less CO_2 into the atmosphere compared with conventional tillage practices (West and Marland, 2002). A 1993 study by Kern and Johnson discovered that the top layer of soil (top 8 cm) is the region with the largest amount of change in SOC. They concluded from this study that there are significantly larger amounts of SOC within this region for no-tillage systems compared to conventionally tilled fields (Kern and Johnson, 1993). From their results, they hypothesized that only a NT system could significantly increase the rate of soil C retention (Kern and Johnson, 1993). Additionally, a recent review by Christopher and Lal (2007) documented the importance of adding legumes into a crop rotation for carbon sequestration. This was attributed to the activity of soil microbes on the narrow C:N ratios of a leguminous crop (Christopher and Lal, 2007; NRCS, 2011). This may be a beneficial reason for adding a leguminous crop, such as soybean, to more corn production in the future.

Large amounts of surface residue are also responsible for cooler soil temperatures and increased soil moisture through insulation and control of evaporation (Andrews, 2006). Lower soil temperatures with greater residue inputs are well documented (Johnson and Lowery, 1985; Drury et al., 1999; Licht and Al-Kaisi, 2005) and may lead to problems with plant emergence (Kaspar et al., 1987; Licht and Al-Kaisi, 2005). Although issues with emergence and stand in heavy residue are not always apparent (Kaspar et al., 1990; Karlen et al., 2013), planting in heavy residue is one area of concern. Like temperature, higher soil moisture retention in reduced tillage systems is well documented in the upper soil layer (Devita et al., 2007; Govaerts et al., 2007). These are important factors to consider with conservation tillage and the reduction of greenhouse gasses, since both soil temperature (Omonode et al., 2007) and soil moisture (Bauer et al., 2006) have been shown to influence the amount CO_2 released. Due to the varying effects of moisture and temperature (Bauer et al., 2006; La Scala et al., 2006) and the influence of other soil quality factors, such as pH, salinity and texture (Rasogi et. al, 2002), more research is needed.

Tillage and crop rotation can also have distinct effects on other soil physical and chemical parameters. Many changes in soil parameters often occur in the uppermost layer of the soil due to the influence of management practices, such as tillage (Havlin et al., 1990; McVay et al., 2006) . Soil bulk density (BD) is a common measure of field compaction (Horn et al., 2009). Bulk density is greater in some NT experiments (Tollner et al., 1984; Kushwaha et al., 2001), which is attributed to the lack of soil disturbance by machinery (Kushwaha et al., 2001). These results, however, are not consistent with others (Ismail et al., 1994; Lal et al., 1994). This indicates that results may vary depending on soil type, cropping system and the longevity of studies. Crop rotation has been found to have a limited effect on BD (Hammel, 1989; Kelley et al., 2003), but incorporating cover crops could potentially increase any benefits seen (Villamil et al., 2006). Due to the varying results, as with other soil factors, it’s difficult to effectively gauge how BD may or may not change in response to management practices. More research on soil health indicators from long term experimental sites may provide data on long term trends and their responses to treatment.

There are still many questions on the direct correlation between soil C levels and production agriculture methods that need to be addressed. Studies have shown over time that there are many direct and indirect positive soil benefits from the adoption of reduced tillage systems (Ismail et al., 1994; Lal et al., 1994; Hussain et al., 1999b). Methods to reduce runoff and erosion are important for the future of agriculture because of the value and limited supply of productive topsoil. While a lot of information has been compiled from both public and private entities further research is needed to address the interactions of production methods, soil function and plant health.

Objectives

As the demand for crop production across the grain belt continues to increase, producers face unique challenges to meet production goals. In field management decisions play a crucial role in their effectiveness to maximize crop production and sustain soil health. While soybean acreage continues to increase farmers and agronomists have a pressing need to address which management practices provide the most benefit in both the long and short run. Rotations and tillage methods are critical aspects of grain production that play a vital role in sustaining our farms for the future. By studying the influences of long and short term management decisions on soybean growth and soil properties we can effectively manage this crop. The research objectives of this project are 1) to determine the effects of crop rotation on soybean growth, development and yield, 2) to determine the effects of crop rotation on soil characteristics associated with soil health 3) to determine the effects of the long term use of no-tillage on soybean growth and development and 4) to determine the effect of long term use of no-tillage on soil characteristics associated with soil health

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Chapter 2

Long term crop rotation and tillage effects on soil temperature and soybean growth

Abstract

Conservation tillage systems and rotations with corn (*Zea mays* (L.) increases surface residue and make popular choices for erosion control in soybean (*Glycine max* (L.) production. Tillage and system (rotation) affect levels of residue input which in turn affect the response of the soil and plants. Few studies have looked at the long term (23 years) effects of management practices on soil and soybean physiology. The objectives of this study were to (i) determine the effects of surface residue on soil temperature throughout the growing season, (ii) determine the effect of amount of residue on SOC, and (iii) determine the physiological response of soybean to residue, system and tillage treatments. Rotation and NT increased surface residue and soil organic carbon (SOC) for the top 0-5 cm of soil in both years of data collection. Continuous soybean and tillage increased maximum soil temperatures but did not affect minimum temperatures over the course of the study. The differences in plant height and canopy coverage were limited and not directly related to changes in soil temperatures. Long term decisions in tillage and system have a direct effect on soil response but the physiological response of soybean isn't fully understood.

Introduction

Soil erosion has been associated with the rise and fall of human populations throughout history (Montgomery, 2007). Soil erosion robs the soil of its productivity and is not sustainable. The central portion of the USA has not been immune to episodes of large rates of soil erosion. During the Dust Bowl of the 1930's, 176 metric tons/hectare of soil was lost from a large portion of the USA grain belt (Hansen and Libecap, 2003). Tillage practices that incorporate crop residue, leave soil vulnerable to the erosive forces of water and wind (Lindstrom et al., 1992). Conservation tillage practices, such as no-tillage (NT), reduce soil erosion primarily through increased amounts of surface residue (Ghidey and Alberts, 1998).

Corn and soybean are two of the most commonly planted grain crops in the Midwest region of the USA. Residue produced by a typical soybean crop differs in both quantity and quality from corn. Soybean residue decomposes more rapidly than corn residue (Lal, 2005). So, crop rotation choices will likely affect the amount and type of residue that remains on the soil surface after conservation tillage is performed.

The amount of residue on a soil surface can affect soil temperatures, especially near the soil surface (Johnson and Lowery, 1985; Drury et al, 1999; Nelson, et al., 2014). Surface residues slow the warming of the soil because they reflect more solar radiation than bare soil (Sauer et. al, 1997). Other soil characteristics, such as soil organic carbon, are also affected by the quality and quality of residue left on the soil surface after tillage (Havlin et al., 1990; Havorson, et al., 2002; Al Kaisi and Yin, 2005). Differences in soil temperature related to variations in surface residue may affect soybean growth and development (Yusuf et al., 1999; Pedersen and Lauer, 2004; Boomsma et al., 2010). However, previous studies have focused mostly on soil temperatures at or shortly after planting (Nelson et al., 2013). Little information is available that describes the effects of surface residue on soil temperature and soybean growth throughout the entire length of the growing season. The objectives of this study were to (i) determine the effects of long term crop rotation and tillage on surface residue and soil organic carbon (ii), determine the effects of amount of residue on soil temperature throughout the growing season and (iii) determine the physiological responses of soybean plants to crop rotation and tillage.

Materials and Methods

Plot management

This experiment was conducted in 2013 and 2014 at the University of Missouri's Bradford Research Center (BRC) near Columbia, Missouri (38 53' N; 92 12' W). Soil type was a Mexico silt loam (fine, smectitic, mesic, Vertic Epiaqualf). The experiment design was a split plot with whole plots arranged in a randomized complete block with four replications. Whole plots were two tillage treatments: Tilled and No-tillage. Tillage was performed with a chisel plow followed by a field cultivator. Tillage depth varied somewhat by soil conditions, but averaged about 25 cm. Split plots were two cropping systems, continuous soybean (Continuous) and soybean rotated with corn (Rotated). The experiment was established in 1991 and the four treatment combinations were applied to their respective plots from that year forward. The tillage treatment assigned to an individual plot was applied in both the soybean and corn year of the rotation.

Soybean cultivar, Pioneer brand P93Y25, was planted at a rate of 395 000 and 417 000 seeds/ha^{-1} in 2013 and 2014. Planting dates were 15 May in 2013 and 22 May in 2014. In 2013, abundant rain shortly after planting caused emergence to be less than acceptable. Paraquat (1,1'-dimethyl-4,4'-bipyridinium dichloride) was applied to kill emerged soybean plants. Plots were planted, again, on 8 June. Cultivar and planting rate were not changed. Plot size was 8 rows wide and 38 m long. Row spacing was 0.76m. For both 2013 and 2014, Dekalb brand 62-97RIB was planted at 74,000 kernels/ha in the corn-phase of the rotation.

Prior to soybean planting in both years a tank mix of sulfentrazone (N-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide), cloransulam-methyl (*N*-(2-methoxycarbonyl-6-chlorophenyl)-5-ethoxy-7-fluoro[1,2,4]triazolo[1,5-c]pyrimidine-2-sulfonanilide), metolalchlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acet-amide), and glyphosate (N-(phosphonomethyl) glycine) was applied to the entire plot area to kill existing vegetation and for pre-emergence weed control. Additional weed control was provided by post emergence application of glyphosate. Irrigation was applied four times in each of the two year through an overhead, lateral irrigator. Total applications were 10 and 11 cm in 2013 and 2014. Pre-emergence herbicides applied to corn plots were atrazine (6-chloro-N-ethyl-N9-(1-methylethyl)-1,3,5-triazine-2,4-diamine) and metolalchlor.

Data collection

Surface residue was measured after seedling emergence. Metal squares (0.09 m^2) were placed randomly between rows two through seven in 2013 and rows two and three in 2014. selected rows. The edges of the squares had been sharpened so that they cut through the residue when forced into place. All residue on the soil surface from within the square was removed and placed into a paper bag. Residue partially below ground was cut at the soil surface. The below ground portion was not sampled. In 2013, 10 samples were combined from each plot; whereas, in 2014 five samples were utilized. Samples were dried at 48° C until weights were stable. After drying, residue samples were screened to remove soil, weighed, and returned to the plot area from which they were removed.

Soil temperature was recorded in both years with the use of TidbiT v2 Water Temperature data Loggers (Onset HOBO Data Loggers, Cape Cod, Massachusetts). On the day of planting, loggers were placed in every plot of three replications in 2013 and four replications in 2014. They were buried within a row to a depth of 5 cm and marked with a flag for easy recovery. Temperature was measured and recorded every 30 minutes. After plants had matured, the temperature loggers were recovered from plots and data were extracted into excel files. Maximum and minimum temperatures for each day between planting and harvest were determined.

In September of both years, soil samples were collected for SOC analyses. A soil probe was used to extract samples from the top 5 cm of soil in locations distributed throughout each plot. In 2013, 14 samples were combined from each plot in all four replications; whereas 6 samples were used in 2014. The combined soil cores were mixed in a bucket, bagged, and delivered to the MU Soil Health Laboratory. Samples were air dried and ground through a 2 mm sieve. A 0.5 gr subsample was placed into a LECO C-144. SOC was determined using a procedure described by Merry and Spouncer (1988).

Soybean plots were monitored every other day throughout the growing season in both years. Growth stages for emergence (VE), beginning flowering (R1), beginning pod development (R3), beginning seed development (R5) and physiological maturity (R7) were recorded as day of the year. Growth stages were determined as described by Fehr et al. (1971). Lengths, in days, of five phases of soybean development were calculated using growth stage dates. Emergence was calculated as VE - planting date. Average maximum and minimum soil temperatures during each phase was calculated.

Soybean plant height was recorded at each growth stage in 2013 and 2014. Measurements were taken from the plant and soil interface to the tip of the soybean apical meristem. Ten (2013) and 5 (2014) plants were randomly selected for measurement throughout each plot to avoid selecting more or less vigorous plants. Crop canopy coverage was measured four times in 2013 and seven times in 2014. Coverage was estimated from images taken with a Pentax X-5 camera held above the plots on a 2.5 meter pole. Images were taken around mid-day with clear sky conditions to avoid shadowing. Images were analyzed using ImageJ 1.47v software using a procedure similar to Purcell (2000). Coverage data are expressed as the fraction of image area identified as soybean plants based on pixels within a threshold range of green color on image histograms.

All data were analyzed using the PROC MIXED routine in SAS (Singer, 1998). If a significant main effect or an interaction between the main effects was found, the least significant difference (LSD) (P=0.05) was calculated to compare treatment combination means.

Results

Residue and SOC

As expected, both cropping system and tillage greatly affected surface residue amounts, but an interaction occurred between cropping system and tillage for residue in 2013 (Table 2-1). In each year, the treatment combination with the least residue was Continuous/Tilled and the treatment combination with the most residue was Rotated/No-tillage. The addition of corn in the Rotated treatment provided 2.8 and 2.2 times more residue in 2013 and 2014 than the continuous system when comparing averages for the two tillage treatments. The total increase in residue with rotation was 2900 kg/ha in 2013 and 3100 kg/ha in 2014. This is a result of a differences in residue input from the previous year's corn crop compared with the small residue input of soybean (Lal, 2005).

The two cropping system treatments reacted differently to tillage for the amount of residue remaining on the soil surface. The tillage procedures used in this experiment incorporated 88% of the residue produced by the Continuous cropping system but only 60% of the residue produced by the Rotated cropping system. Differences in response to tillage between the Rotated and Continuous systems likely result from both type and amount of residue. Soybean residue is more physically fragile than corn residue (Broder and Wagner, 1988; Reicosky et al., 1995) and may break into smaller pieces that are easier to bury. Also, soybean plants are cut close to the soil surface during harvest, whereas, large portions of corn plants remain rooted in the soil.

Both cropping system and tillage affected SOC. There was no interaction between cropping system and tillage in either year for SOC (Table 2-1). In both years, crop rotation was associated with greater SOC than Continuous soybean, and SOC was greater for No-tillage than Tilled. These results agree with previous work that demonstrated increases in SOC content in the upper soil layer as a result of reduced tillage and high residue input (Havlin et al., 1990; West and Post, 2002; Al-Kaisi and Yin, 2005b; Dolan et al., 2006). Plots used in this study experienced the four treatment combinations for 23 years. It was somewhat surprising that the added residue from corn in rotation resulted in only moderate responses in increased SOC. While the amount of residue stayed the same for plots receiving a Tillage treatment compared to the No-tillage treatment, the location of the residue changed (Allmaras et al., 1996). For the No-tillage treatment residue was left on the soil surface; whereas, for the Tilled treatment residue was somewhat mixed into the soil up to 25 cm deep. It's important to note that soil samples were from only the top 5 cm of soil. Other long term studies have shown SOC content changes with depth as a result of tillage and C stratification (Dolan et al., 2006; Gál et al., 2007).

Maximum and minimum soil temperature

Table 2-2 presents the average daily maximum soil temperatures during key growth phases in 2013 and 2014. No interaction between cropping systems and tillage treatments occurred in 2013. Soil temperatures for the Continuous treatment were greater compared to soil temperatures of the Rotated soybean treatment during emergence, VE to R1 and R5 to R7. The increase in temperature with continuous soybean occurred during the early growth phases, before canopy closure, and again later in the season. It is unclear why this change was observed. Also in 2013, the No-tillage treatment was significantly cooler than the Tilled treatment for the same growth phases (emergence, VE to R1, R5 to R7).

An interaction between cropping system and tillage treatments occurred in 2014 for average maximum daily soil temperature during the first two development phases: emergence and VE to R1. In both instances, the Rotated/No-tillage treatment combination was significantly cooler than all three other treatment combinations. Unlike 2013, 2014 soil temperatures for the Rotated treatment were cooler than soil temperatures of the Continuous treatment during R1 to R3 and R3 to R5 phases. The reason for the differences among years is not clear, but planting date was earlier in 2014 and there was more residue left on the soil surface in 2014. Tillage treatments differed at the R3 to R5 growth phases in 2014, but differences were small and perhaps not biologically significant.

Our results agree with previous work indicating cooler temperatures associated with NT and corn in rotation (Drury et al., 1999; Parkin and Kaspar, 2003; Licht and Al-Kaisi, 2005; Blanco-Canqui and Lal, 2007; Nelson et al., 2013). Treatment differences are often explained by surface residues reflecting more light than bare soil (McMurtrey et al., 1993) and decreasing soil temperature through retention of moisture (Linn and

Doran, 1984). However, Flerchinger et al. (2003) points out that soil temperature and moisture effects from surface residues are not simply related to the amount of residue. They modeled different residue types and the orientation of the residue. They found that near surface temperatures were greater for standing residue compared to flat residue or even bare soil. This leaves room for discussion and future research on the role and effects of residue on maximum soil temperature.

Average daily minimum temperature was also recorded in both years for the same growth phases as the maximum soil temperature. No interactions or tillage effects were recorded in either year (table 2-3). The only significant effect for cropping system was at the R3 to R5 growth phase in 2014 showing cooler temperatures with Rotation. The lack of response to minimum soil temperature indicates that temperature affects from soil surface residue are more common with maximum temperatures. This is probably due to treatment differences for heat absorption during the daytime and is and indication that residues have relatively little insulative value relative to the heat flux during the day and the wide range of temperature differences.

Soybean growth and development

Plant growth responses to residue amounts and cropping system vary among experiments (Kaspar et al., 1987, 1990; Licht and Al-Kaisi, 2005; Karlen et al., 2013). In this study, tillage and cropping system had little or no effect on the date of five growth stages or on the length of the five growth phases (data not shown). In some incidences, significant effects were found, but the treatment differences were one day or less, a number that is probably not biologically significant.

With the exception of the earliest vegetative stage, V3, an interaction between cropping system and tillage occurred for plant height at all growth stages in both years (Table 2-4). At V3 in 2013, plants in the Continuous treatment were taller than those of Rotation. There were no effects from either cropping season or tillage on V3 plant height in 2014. For stage R1 in 2013, plants of the Rotated/No-tillage treatment combination were shorter than plants of all other treatment combinations. Similar relationships among treatment combinations were found for maximum plant height. At R3 in 2013, this combination resulted in shorter plants than both Continuous/No-tillage and Rotated/Tilled treatment combinations, but similar heights to Continuous/Tilled plots. Relationships among treatment combinations for plant height were similar in 2014 to those of 2013 for stages R1 and R3. However, for maximum plant height the treatment combination that exhibited the shortest plants was Continuous/Tilled.

The treatment effects on plant height were seldom related solely to the amount of surface residue or soil temperatures. For example, the tallest plants at R1 and R3 were associated with the Continuous/No-tillage and the Rotated/Tilled treatment combinations. These treatment combinations had only intermediate amounts of residue (2-1). This is an indication of the complexity of treatment combinations on soybean growth that are not simply a direct effect of residue, tillage or temperature.

Digital imagery analysis of crop canopy coverage provided lateral growth measurements (Table 2-5). Significant interactions between cropping system and tillage occurred on every measurement date for both years, with the exception of 28 July in 2013 and 30 June 30 2014. There were neither cropping systems nor tillage effects for either of these two dates. When measured on 23 July 2013, the Continuous/Tilled treatment combination resulted in less coverage than the Rotated/tilled treatment combination. On 1 August 2013, the Continuous/Tilled treatment combination provided the least amount of canopy coverage. In 2014, the Rotated/No-tillage treatment combination resulted in less coverage than the other treatments on 16 June and 24 June. On 9 July and 15 July, the Rotated/No-tillage treatment combination produced less coverage than either the Continuous/No-tillage or the Rotated/tilled treatment combinations.

It's unclear as to why treatments affected coverage in the manner in which they did. Continuous Tilled plots produced the least amount of residue (table 2-1) and maybe that affected water retention and availability during dry periods in 2013. Treatment effects on plant height (table 2-4) did not always translate into treatment effects on canopy coverage. However, in 2014 there appeared to be some relationship between plant height and coverage since treatments with taller plants generally had more canopy coverage compared to treatments with shorter plants.

Discussion

This experiment evaluated the long term effects of tillage and rotation on several soil and plant growth factors. Rotation with corn and NT significantly increased soil surface residues. Plots also responded to rotation and NT with an increase in SOC at the surface, although results were only focused on the uppermost (0-5 cm) layer of soil. Increasing surface residues occurred with NT and corn in rotation which decreased maximum soil temperatures but did not affect the minimum temperature. These differences in temperature did not always translate into differences seen in plant height or canopy coverage. This work suggests that tillage and rotation effect surface residues which alters the soil environment and the plants response to that environment.

Table 2-1. Residue amounts and soil organic carbon concentrations for four treatment combinations of cropping systems and tillage practices in 2013 and 2014.

		Residue		Soil organic carbon	
System (S)	Tillage (T)	2013	2014	2013	2014
		---------- kg/ha ----------		---------- g/kg ----------	
Continuous	Tilled	334	575	11.9	11.5
Continuous	No tillage	3032	4740	13.4	14.0
Rotated	Tilled	2635	3309	12.9	13.4
Rotated	No tillage	6638	8238	13.9	15.9
LSD (0.05)†		835	1863	1.1	2.4
Means					
Continuous		1683	2657	12.6	12.7
Rotated		4637	5774	13.4	14.7
P > F		0.00	0.00	0.05	0.02
	Tilled	1484	1942	12.4	12.4
	No tillage	4836	6488	13.6	15.0
	P > F	0.00	0.00	0.00	0.00
S X T	P > F	0.03	0.53	0.49	0.97

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

Table 2-2. Average daily maximum soil temperatures during five soybean growth phases for four treatment combinations of cropping systems and tillage practices in 2013 and 2014.

		2013					2014				
System (S)	Tillage (T)	Emergence	VE to R1	R1 to R3	R3 to R5	R5 to R7	Emergence	VE to R1	R1 to R3	R3 to R5	R5 to R7
		----- °C -----									
Continuous	Tilled	31.0	31.5	26.7	24.7	25.5	28.4	27.8	27.0	25.2	24.0
Continuous	No-tillage	29.3	30.9	27.8	23.6	24.8	28.2	27.7	26.8	24.9	23.1
Rotated	Tilled	29.7	31.1	26.7	23.4	24.5	27.2	26.9	25.8	23.9	24.5
Rotated	No-tillage	27.7	28.0	26.4	23.1	23.1	24.1	25.2	25.2	23.1	23.1
LSD (0.05)†		1.9	2.4	ns	Ns	1.3	1.3	1.1	1.4	0.8	ns
Means											
Continuous		30.2	31.2	27.3	24.2	25.1	28.3	27.7	26.9	25.0	24.2
Rotated		28.7	29.6	26.6	23.2	23.8	25.6	26.1	25.5	23.5	23.8
P>F		0.04	0.05	0.11	0.08	0.01	0.00	0.00	0.01	0.00	0.70
	Tilled	30.4	31.3	26.7	24.1	25.0	27.7	27.4	26.4	24.5	24.3
	No-tillage	28.5	29.5	27.1	23.4	24.0	26.2	26.4	26.0	24.0	23.7
	P>F	0.01	0.03	0.32	0.18	0.03	0.01	0.02	0.35	0.04	0.55
S X T	P>F	0.84	0.13	0.13	0.41	0.34	0.01	0.04	0.65	0.43	0.38

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

Table 2-3. Average daily minimum soil temperatures during five soybean growth phases for four treatment combinations of cropping systems and tillage practices in 2013 and 2014.

		2013					2014				
System (S)	Tillage (T)	Emergence	VE to R1	R1 to R3	R3 to R5	R5 to R7	Emergence	VE to R1	R1 to R3	R3 to R5	R5 to R7
		------ °C ------									
Continuous	Tilled	20.6	21.5	21.9	21.0	20.7	19.7	20.5	21.3	21.3	19.1
Continuous	No tillage	20.2	21.4	22.0	20.8	20.6	18.5	20.3	21.1	21.1	19.7
Rotated	Tilled	20.6	22.0	21.9	21.0	20.5	18.6	20.5	21.0	20.6	20.7
Rotated	No tillage	19.8	21.1	21.9	20.8	19.2	18.0	20.3	21.1	20.1	19.4
LSD (0.05)†		Ns	ns	ns	Ns	ns	Ns	ns	ns	1.1	ns
Means											
Continuous		20.4	21.4	22.0	20.9	20.7	19.1	20.4	21.2	21.2	19.4
Rotated		20.2	21.6	21.9	20.9	19.8	18.3	20.4	21.1	20.3	20.1
P>F		0.53	0.80	0.73	0.32	0.17	0.08	0.93	0.21	0.04	0.32
	Tilled	20.6	21.8	21.9	21.0	20.6	19.2	20.5	21.2	20.9	19.9
	No tillage	20.0	21.3	22.0	20.8	19.9	18.2	20.3	21.1	20.6	19.6
	P>F	0.06	0.37	0.73	1.00	0.26	0.07	0.16	0.21	0.35	0.61
S X T	P>F	0.52	0.50	0.73	1.00	0.30	0.54	0.93	0.09	0.79	0.16

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

Table 2-4. Plant height of soybean plants measured at three soybean stages and maximum plant height for four treatment combinations of cropping systems and tillage practices in 2013 and 2014.

		2013				2014			
System (S)	Tillage (T)	V3	R1	R3	maximum	V3	R1	R3	maximum
		-- m -- -----							
Continuous	Tilled	0.107	0.199	0.446	0.783	0.126	0.279	0.502	0.710
Continuous	No tillage	0.110	0.199	0.467	0.802	0.136	0.297	0.540	0.762
Rotated	Tilled	0.100	0.192	0.466	0.800	0.133	0.298	0.566	0.768
Rotated	No tillage	0.096	0.165	0.427	0.738	0.123	0.259	0.495	0.745
LSD (0.05)†		0.005	0.015	0.028	0.045	ns	0.017	0.034	0.026
Means									
Continuous		0.108	0.199	0.457	0.792	0.131	0.288	0.288	0.736
Rotated		0.098	0.179	0.447	0.769	0.128	0.279	0.279	0.757
P>F		0.00	0.00	0.29	0.13	0.57	0.12	0.12	0.03
	Tilled	0.103	0.195	0.456	0.792	0.129	0.289	0.289	0.739
	No tillage	0.103	0.182	0.447	0.770	0.129	0.278	0.278	0.754
	P>F	0.70	0.03	0.32	0.16	1.00	0.08	0.08	0.11
S X T	P>F	0.08	0.03	0.01	0.02	0.06	0.00	0.00	0.00

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

Table 2-5. Fraction of area identified as soybean plants from images taken on three dates in 2013 and five dates in 2014 of plots from four treatment combinations of cropping systems and tillage practices.

		2013			2014				
System (S)	Tillage (T)	23 July	28 July	1 August	16 June	24 June	30 June	9 July	15 July
Continuous	Tilled	0.718	0.814	0.878	0.237	0.426	0.649	0.796	0.901
Continuous	No tillage	0.786	0.841	0.920	0.250	0.423	0.697	0.847	0.944
Rotated	Tilled	0.799	0.883	0.922	0.241	0.500	0.666	0.858	0.958
Rotated	No tillage	0.742	0.856	0.923	0.204	0.314	0.621	0.751	0.894
LSD (0.05)†		0.074	ns	0.030	0.022	0.065	Ns	0.063	0.034
Means									
Continuous		0.752	0.827	0.900	0.244	0.427	0.673	0.822	0.922
Rotated		0.771	0.870	0.923	0.223	0.407	0.643	0.804	0.926
P>F		0.45	0.07	0.03	0.02	0.41	0.44	0.41	0.76
	Tilled	0.759	0.849	0.900	0.239	0.463	0.657	0.827	0.929
	No tillage	0.764	0.849	0.921	0.227	0.369	0.659	0.799	0.919
	P>F	0.82	0.99	0.05	0.11	0.00	0.97	0.19	0.36
S X T	P>F	0.03	0.23	0.05	0.01	0.00	0.24	0.00	0.00

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found

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CHAPTER III

LONG TERM CROP ROTATION AND TILLAGE EFFECTS ON SOIL CO2 EVOLUTION

ABSTRACT

Soil CO_2 emissions can be used to monitor the biological response of the soil to management practices, such as tillage and rotation with corn (*Zea mays*) and soybean (*Glycine max*). Although results are variable, the majority of previous work has shown decreased CO_2 emissions with reduced tillage practices. Most of this work however, is focused on early season responses and does not encompass the rest of the growing cycle. The objectives of this study were to (i) determine the biological response of the soil to management through the release of CO_2 and (ii) determine any underlying factors that contribute to this response. While active carbon (AC) concentration was consistently higher for No-tillage (NT) plots, CO_2 emission values (referred to as efflux rates) did not always coincide. Soil moisture increased under NT which affected efflux rates until the point of saturation where biological activity was likely starved of oxygen. The effect of soil temperature on these values was very limited. Using CO_2 efflux rates may be a good indicator of soil biology and soil health, although results are extremely complex. Future research incorporating various soil types over longer periods of time is required to determine the underlying reasons for changes in response.

INTRODUCTION

Soil conservation management practices have grown in popularity as both producers and the public look for sustainable methods in food production. In the US, an estimated $44 billion is lost annually to both on-site and off-site cropland erosion (Pimentel et al., 1995). This would take an additional $6.4 billion a year in investments to offset (Pimentel et al., 1995). It's widely accepted that reducing soil erosion will maintain and improve the quality of the soil for agricultural production. In Chapter 2, the role of both rotation and conservation tillage practices was discussed in regards to controlling soil erosion and promoting soil health. The term soil health is often used to describe the integrated biological, physical, hydrologic and chemical function of the soil and its subsequent ability to provide and sustain productivity for agricultural land and ecosystems (Doran and Zeiss, 2000). This term is not limited to specific fractions of the soil, but encompasses an overall view of how the soil functions as a living organism. Chapter three discusses the changes in soil health in relation to management practices in long term corn-soybean cropping systems.

Alterations in tillage system and residue induce physical and chemical soil responses that alter the soil microbial habitat (Doran, 1980). These microbial populations are important biotic factors that mediate physical and chemical soil processes (Nannipieri et al., 2003). As reported in Chapter 2, the amount and type of residue that remains on the soil surface through conservation tillage affects soil carbon levels. Rotating soybean with a large residue input crop, such as corn, increased soil organic carbon (SOC). Understanding the impact of residue management on SOC decomposition is important for understanding the relationships between crop management and soil health factors. Microbes use labile fractions of soil carbon as an energy source. These labile carbon fractions are often referred to as active carbon (AC), and the soil concentration of AC is highly responsive to soil management (Weil et al., 2003; Melero et al., 2009).

The processes of residue accumulation and degradation inevitably lead to the release of carbon in the form of gasses, including CO_2. However, evolution of CO_2 from the soil is not limited to microbial activity. Respiration in plant roots and other soil macro-organisms are additional sources of CO_2 (Rasogi et. al, 2002). Human interactions also play a major role in the magnitude and the timing of release of CO_2 from soil. Tillage buries surface residues and causes a rapid release of CO_2 due to accelerated decomposition (Reicosky and Lindstrom, 1993; Lal and Kimble, 1997). Previous work has shown conflicting results related to the response of soil CO_2 emissions to tillage (Hendrix et al., 1988; Franzluebbers et al., 1995; Al-Kaisi and Yin, 2005a; Bauer et al., 2006). Most studies have focused on the immediate response of soil health to tillage and cropping system, but understanding responses throughout the growing season and beyond will be helpful in developing residue management strategies.

Residue management leads to changes in soil environment, including temperature and moisture. This influences the response of soil microbial activity, including the release of CO_2 (Bauer et al., 2006; La Scala et al., 2006; Omonode et al., 2007). Complex relationships among soil environment parameters and microbial and root activity exist, but are poorly understood. Additional research is needed to add to our understanding of how biological activity responds to cropping system and tillage management choices. This study uses CO_2 evolution from soil as an indicator of biological activity. The objective was to determine the effects of tillage and rotation on soil biological activity.

Materials and Methods

Site location and plot management are described in Chapter 2. In summary, this experiment was conducted in 2013 and 2014 at the University of Missouri's Bradford Research Center (BRC) near Columbia, Missouri on a Mexico silt loam (fine, smectitic, mesic, Vertic Epiaqualf). The experiment design was a split plot with whole plots arranged in a randomized complete block with four replications. Whole plots were two tillage treatment, Tilled and No-tillage. Tillage was performed with a chisel plow followed by a field cultivator. Tillage depth varied somewhat by soil conditions, but averaged about 25 cm. Split plots were two cropping systems, continuous soybean (Continuous) and soybean rotated with corn (Rotated). The experiment was established in 1991 and the four treatment combinations were applied to their respective plots from that year forward. All plot management practices were identical as described in chapter 2.

Data collection

Soil CO_2 efflux was measured with a 6400-09 Soil CO_2 Flux Chamber attached to a LICOR 6400 Portable Photosynthesis System (LICOR Biosciences, Lincoln, NE). Three 6.35 x 7.62 cm PVC rings (48.39 cm^2) were positioned between rows 2 and 3 of each plot in the middle of the row. This row position was selected because soil was not compacted by either tractor or planter tires. Insertion depth was 2.5 cm. Rings were not moved after the insertion to avoid flushes in gas released from the soil that may have occurred due to soil disturbance. Measurements were taken in the early afternoon where microbial and plant respiration was expected to be the greatest. To begin data collection, soda lime was used to scrub the initial CO_2 concentration inside the chamber to below ambient conditions at the soil surface, referred to as drawdown mode. The machine then goes into measurement mode. Here CO_2 concentrations rise from a low point and through the set ambient conditions to a high point. The instrument then records the data by a comparison of the CO_2 concentration inside the chamber in relation to ambient conditions, referred to as a flux. Each flux was computed every 2-3 seconds based on a running average of the time passed and rate of change in CO_2. Each flux data set was then fit with a regression. Measurements were taken four times in 2013 and six times in 2014.

Soil temperature and soil moisture was measured on the same dates on which CO_2 efflux was measured. Soil temperature was measured directly next to each PVC ring with a Type E thermocouple. The thermocouple was buried approximately 5 cm below soil surface and took a running temperature average over a four second window. Soil for moisture data was sampled near the chambers. Approximately six soil samples from the top 5 cm at each plot were collected with a soil sampling probe. Soil moisture of these samples was determined gravimetrically. The samples were weighed in aluminum tins and oven dried at 41°C until constant weight.

Soil for active carbon (AC) determination was sampled similarly to the process described in chapter 2 for soil organic carbon (SOC). A soil probe was used to extract soil from the top 5 cm of soil from locations distributed throughout each plot. In 2013, 14 cores were combined from each plot on two dates. These two dates matched two of the four CO_2 evolution measurement dates. In 2014, 6 cores were combined on the same seven dates on which CO_2 efflux was determined. Once collected, these samples were thoroughly mixed, air dried and ground through a 2 mm sieve. Samples were analyzed for AC by the MU soil health lab following a procedure adapted from Weil et al. (2003).

All data were analyzed using the PROC MIXED routine in SAS (Singer, 1998). Replication was considered a random variable. All other main effects and their interactions were considered fixed. If a significant main effect or an interaction between the main effects was found, an LSD (P=0.05) was calculated to compare treatment combination means.

Results

Soil CO_2 efflux was used as a measure of biological activity within the soil. Sources of CO_2 are microbes that use soil organic carbon as an energy source and plant roots (Rastogi et al., 2002). The amount of biological activity in soil is influenced by complicated interactions between soil biota, energy sources, such as active carbon, and the soil environment. All of these factors can be affected by the treatments used in this experiment. It is not surprising that the response of soil biological activity to cropping system and tillage practices was highly variable (Table 3-1). But, each measurement date provides information that helps us understand the complex nature of soil biological activity in crop fields.

2013

An interaction between cropping system and tillage for CO_2 efflux was found for the 15 August measurement (Table 3-1). On that date, Rotated/No-tillage and Continuous/Tilled treatment combinations exhibited less CO_2 efflux than the other two treatment combinations. These two treatment combinations differed greatly relative to the amount of surface residue. Rotated/No-tillage resulted in the greatest amount of surface residue, whereas, Continuous/Tilled had the least (Ch. 2: table 2-1). As a result of the differences for surface residue, these two treatment combinations also differed for AC when soil was sampled on 15 August (Table 3-2). Melero et al. (2009) also found that NT increased AC in the uppermost layer of soil compared to conventional tillage, so the relationship between greater surface residue and greater AC makes sense. It was considered that the greater amount of AC of the Rotated/No-tillage treatment combination would have stimulated greater CO_2 efflux because microbes feed off labile fractions of carbon. However, this was not true for the 15 August measurement date. CO_2 efflux rates of the Rotated/No-tillage and the Continuous/Tilled treatment combinations were similar. So, something other than the amount of a microbial energy source affected CO_2 efflux on 15 August.

Soil temperature can affect both microbial activity and root respiration, but neither cropping system nor tillage practices affected soil temperatures during CO_2 measurement on 15 August (Table 3-4). Large amounts of surface residue frequently reduce water evaporation and increase soil moisture (Devita et al., 2007; Govaerts et al., 2007). Soil moisture was much greater for the Rotated/No-tillage treatment combination than for the Continuous/Tilled treatment combination (Table 3-3). Excessively large soil moisture starves aerobic microbes and plant roots of oxygen (Bouma et al. 1997, Linn and Doran, 1984). At greater than 60% water filled pore space (WFPS) aeration in the soil is limited, which in turn limits the activity of aerobic soil microbes (Linn and Doran, 1984). Although not displayed in a table, WFPS was calculated and was found to be greater than 60% for portions of the field on 12 August 2013. Perhaps a reduction in aeration from increased WFPS reduced soil biological activity on this date, especially for the Rotated/No-tillage treatment combination.

Similar to 15 August, an interaction between cropping system and tillage practices for CO_2 efflux occurred on 23 August (Table 3-1). But, unlike 15 August, the CO_2 efflux rate for the Rotated/No-tillage treatment combination was much greater than that of the Continuous/Tilled treatment combination for the 23 August date. It was suggested that greater soil moisture associated with the Rotated/No-tillage reduced soil oxygen which, in turn, decreased CO_2 emissions seen on 15 August. One week later, soil moisture for the Rotated/No-tillage treatment combination decreased to a much less saturated state. Although soil oxygen content wasn't measured, the decrease in soil moisture may have increased oxygen availability and ultimately led to an increase in CO_2 efflux.

The last two measurement dates in 2013, 4 September and 9 September, occurred late in the growing season about 14 and 9 days before soybean physiological maturity. Carbon dioxide efflux rates appear to have decreased from the August dates (Table 3-1). Soil temperatures were not cooler, so that was not the reason for the decrease. Perhaps, soybean root respiration had decreased as plants neared maturity. There was no relationship between AC and CO_2 efflux. Tilled and No-tillage differed for 9 September AC, but not for CO_2 efflux on either September date. Continuous and Rotated did not differ for 9 September AC, but CO_2 efflux for Continuous was less than that of Rotated on both dates.

2014

There was no difference between cropping systems for CO2 efflux when measured on 20 June. However, the Tilled treatment had a greater efflux rate than No-tillage treatment. AC rates followed a similar trend as CO_2, with increased levels of AC for the No-tillage treatment (Table 3-2). This was the earliest date of data collection and roughly six weeks after a tillage for the Tilled treatment. It is known that tillage causes a rapid release in gas trapped in air pockets in the soil, incorporates surface residue and increases carbon mineralization (Reicosky and Lindstrom, 1993; Lal and Kimble, 1997). This process of burying residue into the soil profile places it in a location where it's more likely to be degraded by the microbial biomass. Studies focusing on early season soil responses to tillage treatments have shown decreased CO_2 emissions close to planting/tillage with reduced tillage (La Scala et al., 2006; Omonode et al., 2007). Therefore, it would make sense that we see a response for greater CO_2 emissions in tillage plots on the date closest to a tillage procedure. WFPS was greater than 60% for portions of the field. Soil moisture was also the greatest for the Rotated/No-tillage treatment. As described on 12 August 2013, when WFPS is greater than 60% aeration is limited. This in turn limits the activity and respiration of aerobic soil microbes, which may have caused a reduction in CO_2 emissions. No-tillage and Rotation treatments both exhibited reduced temperatures, however the effect does not appear to be a major factor on this date. Despite No-tillage plots having more AC (Table 3-2) Tilled plots still had greater efflux values. This indicates that the effect and proximity of a tillage treatment is likely more important than soil AC concentration.

On 2 July, there were no significant effects from either tillage practices or cropping systems on CO_2 efflux rates (Table 3-1). Both tillage practices and cropping system did, however, affect AC (Table 3-2). This is further indication that AC and CO_2 efflux do not always have a direct relationship.

On 10 July, an interaction between tillage practices and cropping system showed that Rotated/No-tillage had a smaller CO_2 efflux rates compared to the other three treatment combinations (Table 3-1). The reasons why this effect was seen are unclear. Based on the other data points collected it was not a direct function of AC, soil moisture or soil temperature. On 22 July, there was a significant effect of tillage practice on CO_2 efflux rates, but not cropping system. No-tillage treatment had greater rates of emissions compared to Tilled treatment (Table 3-1). Whereas AC was greater on this date for No-tillage (Table 3-2) the general trend throughout this study doesn't indicate this to be a significant determining factor of CO_2 emissions. During this period, weather was extremely dry and NT plots retained greater soil moisture (Table 3-3). La Scala et al. (2006) demonstrated that soil moisture was the controlling factor in soil CO_2 emissions, especially during periods of less moisture. It would makes sense that increased moisture seen for the No-tillage treatment during an excessively dry period likely stimulated microbial activity and increased CO_2 efflux rates. However, this doesn't explain why more soil moisture associated with the Rotation treatment on this date failed to increase efflux rates.

On 12 August, the Continuous treatment exhibited greater efflux rates compared with Rotation, however, there was no significant effect from tillage practices. At this point in the growing season it is unlikely that there is any influence from a spring tillage treatment. While there were no differences between treatments for soil moisture, the overall soil profile was fairly saturated and WFPS was greater 60%. It's not exactly clear how this high moisture may or may not have effected CO_2 emissions at this time in the season. Given that this change in CO_2 efflux was relatively small later in the soybean growth cycle, the differences seen here may not be biologically significant. There were no main effect differences for CO_2 efflux on 29 August (Table 3-1). Efflux values on this date were overall lower compared to earlier in the season. This may be an indication of the plant cycle shutting down as discussed in 2013. As demonstrated these interactions are complex and difficult to explain based on the soil parameters observed for this date.

Discussion

Soil CO_2 efflux rates were highly variable throughout both years of data collection across treatment combinations. Greater levels of AC for the No-tillage treatment failed to consistently relate to larger efflux values. Temperature showed minimal effects on CO_2 emissions compared with soil moisture. Soil moisture was greater under NT and appeared to increase biological activity up until reaching greater than 60% WFPS, which limited aeration. Throughout this study the overall biotic activity and soil emission rates decreased as sampling dates moved later into the season. Measuring soil CO_2 efflux rates is a valuable tool for gauging the biological response of the soil to management. Recently there have been increased efforts to research the ability of agricultural soils to sequester C and reduce greenhouse gas emissions (Lal, 2004). However, from this study I was unable to conclude whether or not NT significantly increases C sequestration by reducing CO_2 emissions compared with tillage treatments. These biological responses are extremely complex and are reliant on a wide variety of factors including seasonal variation. Temporal effects on CO_2 evolution are clearly important from this study. Future research efforts should include in depth soil assessments over extended periods.

Table 3-1. Soil CO_2 flux for four treatment combinations of cropping systems and tillage practices measured on four dates in 2013 and seven dates in 2014.

		2013				2014					
System (S)	Tillage (T)	15 Aug	23 Aug	4 Sept	9 Sept	20 June	2 July	10 July	22 July	12 Aug	29 Aug
		---------- $\mu mol\ m^{-2}\ s^{-1}$ ----------									
Continuous	Tilled	3.59	3.46	1.42	2.13	3.02	2.64	4.63	2.97	3.99	1.94
Continuous	No-tillage	5.25	5.41	1.65	2.43	2.62	2.87	4.68	3.89	4.77	2.78
Rotated	Tilled	4.44	5.34	2.93	2.90	3.39	2.86	4.89	3.16	3.71	2.76
Rotated	No-tillage	3.28	5.84	1.99	2.76	1.86	1.90	3.19	3.34	3.20	2.54
LSD (0.05)†		0.84	0.86	0.79	0.54	1.12	ns	1.10	0.68	1.27	ns
Means											
Continuous		4.42	4.43	1.53	2.28	2.82	2.76	4.75	3.43	4.38	2.36
Rotated		3.86	5.59	2.46	2.83	2.62	2.38	4.04	3.25	3.46	2.65
P>F		0.06	0.00	0.03	0.01	0.57	0.23	0.07	0.42	0.05	0.26
	Tilled	4.01	4.40	2.17	2.51	3.20	2.75	4.76	3.07	3.85	2.35
	No-tillage	4.26	5.63	1.82	2.60	2.24	2.39	4.03	3.61	3.99	2.66
	P>F	0.37	0.00	0.31	0.23	0.02	0.24	0.06	0.03	0.74	0.23
S X T	P>F	0.00	0.02	0.12	0.24	0.13	0.07	0.02	0.12	0.14	0.07

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

Table 3-2. Soil active carbon concentrations for four treatment combinations of cropping systems and tillage practices determined on dates on which CO_2 flux was measured in 2013 and 2014.

		2013		2014					
System (S)	Tillage (T)	15 Aug	23 Aug	20 June	2 July	10 July	22 July	12 Aug	29 Aug
		mg/kg soil							
Continuous	Tilled	325	335	487	336	320	338	335	317
Continuous	No-tillage	432	439	646	469	458	443	468	461
Rotated	Tilled	374	371	374	350	360	337	349	350
Rotated	No-tillage	430	451	571	480	494	488	451	502
LSD (0.05)†		48	60	127	87	130	125	102	119
Means									
Continuous		379	387	415	402	389	390	401	389
Rotated		402	411	472	415	427	412	400	426
P>F		0.13	0.23	0.18	0.00	0.37	0.58	0.97	0.33
	Tilled	349	353	358	343	340	337	342	333
	No-tillage	431	445	529	475	476	465	460	482
	P>F	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
S X T	P>F	0.10	0.54	0.53	0.95	0.96	0.57	0.64	0.92

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

Table 3-3. Soil moistures for four treatment combinations of cropping systems and tillage practices determined on the dates on which CO_2 flux was measured in 2013 and 2014.

		2013				2014					
System (S)	Tillage (T)	15 Aug	23 Aug	4 Sept	9 Sept	20 June	2 July	10 July	22 July	12 Aug	29 Aug
		g/kg									
Continuous	Tilled	177	90	233	193	124	134	171	63	220	49
Continuous	No-tillage	213	110	267	214	134	154	193	78	235	63
Rotated	Tilled	231	126	237	244	132	163	195	80	225	61
Rotated	No-tillage	251	163	258	254	233	204	220	107	240	92
LSD (0.05)†		37	25	38	20	31	24	28	16	ns	32
Means											
Continuous		195	100	250	204	129	144	182	70	227	56
Rotated		241	145	248	249	182	183	207	93	232	77
P>F		0.00	0.00	0.87	0.00	0.00	0.00	0.02	0.00	0.59	0.06
	Tilled	204	108	235	219	128	148	183	71	222	55
	No-tillage	232	137	263	234	184	179	206	92	237	78
	P>F	0.03	0.01	0.04	0.04	0.00	0.00	0.03	0.00	0.14	0.05
S X T	P>F	0.51	0.31	0.57	0.39	0.00	0.18	0.86	0.27	0.97	0.40

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

Table 3-4. Soil temperatures for four treatment combinations of cropping systems and tillage practices determined during CO_2 flux measurements on four dates in 2013 and seven dates in 2014.

		2013				2014					
System (S)	Tillage (T)	15 Aug	23 Aug	4 Sept	9 Sept	20 June	2 July	10 July	22 July	12 Aug	29 Aug
		°C									
Continuous	Tilled	18.8	24.7	22.5	25.2	28.5	21.6	22.0	24.3	21.0	25.7
Continuous	No-tillage	19.2	23.4	22.0	24.6	27.3	21.8	22.0	23.9	21.1	25.2
Rotated	Tilled	18.8	23.4	21.4	24.3	27.0	21.4	21.3	23.2	20.7	24.7
Rotated	No-tillage	18.8	22.9	20.7	24.3	25.0	21.1	21.7	22.7	20.7	24.1
LSD (0.05)†		ns	1.0	1.6	0.5	??	ns	ns	1.0	ns	1.5
Means											
Continuous		19.0	24.0	22.2	24.8	27.9	21.7	22.0	24.1	21.0	25.5
Rotated		18.6	23.2	21.1	24.3	26.0	21.3	21.5	22.9	20.7	24.4
P>F		0.13	0.02	0.05	0.01	0.00	0.26	0.07	0.00	0.09	0.04
	Tilled	18.6	24.0	22.0	24.7	27.7	21.5	21.7	23.7	20.8	25.2
	No-tillage	19.0	23.2	21.3	24.4	26.2	21.5	21.8	23.3	20.9	24.7
	P>F	0.13	0.02	0.22	0.08	0.01	0.90	0.52	0.15	0.58	0.25
S X T	P>F	0.65	0.27	0.81	0.13	0.35	0.59	0.43	0.82	0.76	0.92

† LSD (0.05) to compare any two system and tillage combinations; ns indicates that no significant main or interaction effects were found.

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Reflection of Knowledge

Protecting and improving the soil for future generations and a growing population is one of the most challenging issues in agriculture today. The research opportunities presented in my project gave me the chance to explore characteristics of crop and soil interactions in response to management. In researching and writing my literature review I came to understand the complex nature of these systems. Before this project, I gave little thought as to how management decisions affect cropping systems beyond what is seen in yield or visual plant responses. It's important to realize the impact that decisions in rotation and tillage system have at the soil level, which in turn affects soybean growth. Rotation with corn and NT increased residue. This increased soil Carbon in the uppermost layer and altered the overall soil environment. The biological soil response of the soil was highly variable and dependent on the conditions of the day it was measured. These complicated interactions are the reason why future research is needed to explore soil and plant relationships which are yet to be fully understood.

Throughout my graduate school career I have gained a tremendous amount of knowledge and experience both in the classroom and in the field. I have grown as a student and a young professional by following and learning from my committee and the educators around me. I have also gained a greater understanding and appreciation of the scientific processes and why thorough research is necessary. My hope is to take the skills and knowledge I have gained in my time at the University of Missouri into my future career and continue to build my agronomic base of knowledge.

VITA

Brandon Witte Nystrom is the son of Becky and Bruce Powers and Tim Nystrom, born in St. Louis, Missouri on June 7, 1989. He was raised in High Hill, Missouri and attended grade school in Jonesburg, Missouri. He graduated from Montgomery County High School in 2008. Brandon first attended the University of Missouri in the fall of 2009. He graduated with a bachelor's degree in Plant Sciences – Crop Management and a minor in Agricultural Economics in December 2012. Upon graduation he remained at the University of Missouri and entered a Master's program under the direction of Dr. Bill Wiebold in January 2013. Brandon's Master's degree was in Plant, Insect and Microbial Sciences emphasizing in Crop, Soil and Pest Management. His thesis title is *The Effect of Tillage and Rotation on Soybean and Soil Health*.