MINIMIZING THE CONTINUOUS MAIZE PENALTY THROUGH INTENSE MANAGEMENT

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THESIS

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ABSTRACT

As maize prices escalate with increasing demand for grain resulting from recent legislation mandating renewable fuel production, more Midwest farmers are interested in producing maize continuously. Increasing or maintaining maize yield levels becomes a challenge in continuous maize systems due to the continuous maize penalty, a commonly-observed phenomenon in dryland agriculture systems characterized by 10 to 15% yield reductions when maize is grown continuously versus a soybean-maize rotation. Recent studies have indicated that stover accumulation in maize systems is a major factor influencing the continuous maize penalty. In addition to stover management, other agronomic management practices are known to enhance maize yields when used individually (e.g. fertilizer application, genetically-engineered traits, crop rotation). Some management practices have been shown to produce greater-than-additive yield effects when combined (e.g. fertilization and irrigation; increased plant population and fungicide application). This study examined the possibility of reducing or eliminating the continuous maize penalty through the use of stover removal, reduced tillage, and an addition/omission design of advanced crop inputs. Nitrogen (N) fertilizer, non-N fertilizer, hybrid trait, plant density, and fungicide were five management inputs used to create an addition/omission design. Additionally, partial stover removal and reduced tillage were examined for their effect on maize yield, the continuous maize yield penalty, and interactions with management inputs. Stover removal in the high technology system demonstrated the value of nutrients provided by maize stover and indicated that removed nutrients must be replaced with. Partial stover removal also greatly reduced the level of nutrient immobilization resulting from accumulated stover. Additionally, this study demonstrated that the rootworm resistance

trait is vital in drought years. When farming continuous maize, removing stover is advantageous; however, crop nutrients removed with the stover must be replaced to take full advantage of the increased yield potential offered by stover removal in continuous maize systems.

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CHAPTER 1

A LITERATURE REVIEW OF FACTORS INFLUENCING MAIZE PRODUCTIVITY

CROP ROTATION

Row crops grown within Illinois are usually planted in rotation of maize and soybean [*Glycine max* (L.) Merr.] in alternating years. However, as commodity prices have changed for numerous reasons, maize tends to be more profitable to produce. As such, growers have the desire to plant a larger proportion of their farms in maize as opposed to soybean. In order to do so, the rotation of maize and soybean is interrupted and a monoculture of maize begins.

As many producers and studies have found, there is a negative impact on yield when growing a maize monoculture. A common view of many producers is that the yield penalty from growing continuous maize only occurs for one or two years before yields level off again. However, as numerous studies have shown, that is not the case. Some studies have demonstrated that the yield penalty of a maize monoculture continues to increase for at least seven years before it levels off (Gentry et al., 2013). Others indicate that the yield penalty can continue beyond seven years for even up to twenty years (Ismail et al., 1994). The decrease in yield through the use of continuous maize is defined as the yield difference between a continuous maize system and a soybean and maize rotation (Gentry et al., 2013).

Through the use of additional fertilizer, the yield penalty from continuous maize is significantly decreased or eliminated (Ma et al., 2012). However, using additional fertilizer to

compensate for the yield penalty loses its effectiveness with each year, and the supplementary fertilizer that is added is less effective when the weather conditions are average or poor (Gentry et al., 2013). One of the more effective ways of avoiding the yield penalty is to simply rotate maize with soybean (Dick & Van Doren, 1985; Nafziger, 2009).

There are multiple conclusions as to the cause of the continuous maize yield penalty. One such conclusion is based on the differences in the carbon (C) to nitrogen (N) ratios in soybean and maize stover. Maize stover has a high C to N ratio which results in high rates of N immobilization (Gentry et al., 2001; Gentry et al., 2013). As such, N immobilization would be much greater in continuous maize production systems compared to a field grown in rotation of maize and soybean. The resulting net immobilization from continuous maize is influenced by the quality and quantity of stover left on the field following harvest. Maize stover is low in quality as it has a high C to N ratio, 57:1, and also produces a large quantity of stover; subsequently, added N is made unavailable for plant use through the microbial-mediated process of N immobilization. As soil-incorporated residues exceed the C to N ratio threshold of 24:1, soil microorganisms must scavenge N from the soil in order to decompose the highly carbonaceous residues (Brady & Weil, 2004), making previously available soil N unavailable for plant uptake. Soybean stover is better in quality than maize stover with a C to N ratio of 20:1 to 40:1 and has a lesser quantity on a per area basis (Brady & Weil, 2004). The greater quality of soybean stover and reduced quantity of stover to be decomposed promotes a net mineralization (Gentry et al., 2001).

Maize grown in rotation with a legume crop is benefitted by greater root growth promotion, improved water holding capacity, increased plant water use efficiency and an improved synergistic effect of water and nutrients (Shisanya et al., 2009). The use of a rotation also

disrupts various weed, insect, and disease cycles which further give a rotational crop a yield advantage over a monoculture (Brady & Weil, 2004).

Although using a crop rotation decreases unit land area for maize production annually, maize yields are sustained or increased and N fertilizer application requirements are reduced. If a maize monoculture is used, maintaining yields requires additional management.

NITROGEN

Nitrogen is an essential nutrient that is commonly added to maize production systems. Generally being one of the cheaper fertilizers, it is commonly viewed by farmers as a cheap source of insurance for maize yields. Environmental concerns have arisen due to excessive N use within cropping areas because of nitrogen's mobility within the soil and drainage tile.

Excessive N in marine systems supplies microbes with a source of N which promotes decomposition of phytoplankton; this eventually leads to hypoxia, depletion of oxygen in water, in surface waters and is detrimental for marine animals. Because of the negative environmental impact that excessive N fertilization promotes, more responsible application rates must be used. Optimal N rate recommendations based on soil tests vary by sampling techniques and locations but are not particularly reliable due to the form of N that is being measured. Tests for N typically measure soil nitrate levels which are subject to numerous N-cycle processes including mineralization, immobilization, nitrification, denitrification, leaching, and plant uptake. To minimize the variability of testing N levels within soil samples, Mulvaney et al. (2006) developed an approach of measuring soil N-supplying capacity by estimating mineralizable organic N because organic N is subject to fewer N-cycle processes than nitrate. The findings

from that study showed that highly productive soils have a reduced yield response to N fertilizer compared to poorly producing soils because of the variances in N supplying power. This is based on the findings that over half of the N taken up by the plant is from the soil and not the fertilizer. With environmental concerns of over-fertilization, using farming practices that increase N use efficiency (NUE) is essential.

Nitrogen use efficiency refers to the relationship between crop yield and applied N. Two components contribute to NUE; these include recovery or uptake efficiency (RE), and physiological or utilization efficiency (PE). Nitrogen use efficiency is the yield response based on the applied N, RE is the proportion of applied N that is taken up by the crop, and PE is the yield produced per unit of plant accumulated N (Cassman et al., 2002; Below, 2012).

One method for increasing NUE is to decrease the amount of N lost due to weather. Nitrogen can be lost from the field through leaching, surface runoff, denitrification or volatilization. Denitrification is the process of nitrate ions converting to gaseous forms of N and thereby lost to the atmosphere. Nitrate ions are subject to loss by leaching, surface runoff, or denitrification and are produced through nitrification of ammonium. Products can be added to fertilizer to minimize the production of nitrate ions. Nitrification inhibitors such as nitrapyrin (N-Serve) and SuperU (dicyandiamide) prevent or reduce nitrification and thus reduce N loss through denitrification or leaching. Volatilization is the process of producing ammonia gas from ammonium ions, and the ammonia gas is lost to the atmosphere; this reaction is further promoted by dry soil conditions (Brady & Weil, 2004). SuperU and Agrotain are products that contain the urease inhibitors (N-(n-butyl) thiophosphoric acid triamide) that limit the breakdown of urea, thereby reducing N losses through volatilization. The addition of these products will reduce N

lost to the environment and retain more available N within the soil, thus increasing the fertilizer NUE.

An additional method of increasing NUE is to alter the previous crop. It has been shown that fields high in carbonaceous residues due to the previous crop require more N applied when maize is grown following that crop. Because of the greater C to N ratio, the decomposition rate of the carbonaceous residues is limited by the level of N available, and much of the added N is taken up by microbes to decompose the residue (Nafziger, 2009). When taken up by the microbes, the N becomes immobilized and is no longer available to the plant. The N will eventually be returned to the soil through mineralization, but the timing of mineralization is difficult to predict and may not coincide with crop uptake (Brady & Weil, 2004).

Nitrogen fertilization varies widely among growers, but one vital component of N availability following fertilization is the moisture present within the field. During dry years, the response to N fertilizer in terms of yield increase is poor relative to years with adequate precipitation (Tremblay, 2004). Often disregarded by growers is that the yield response to N fertilizer by modern maize hybrids is not equivalent to that of older hybrids (Hou et al., 2012). Nitrogen uptake in high yielding, modern hybrids has been measured at 242 kg ha^{-1} and even up to 307 kg ha^{-1}, while an average of 166 kg ha^{-1} was removed with the grain when grain yield is 12.0 Mg ha^{-1} (Hou et al., 2012; Bender et al., 2013). Additionally, maize yield response to N fertilizer is greater in fields that tend to produce less and have less mineralizable N; this observation calls into question the method of N fertilizer application based on expected yield (Kahn et al., 2001).

The timing of N application can further affect the NUE within the field; the earlier the N fertilizer is applied, the more susceptible it is to be lost from the rooting zone. Split applications

can decrease the quantity of fertilizer N lost as well as synchronize N application with the time that the plant is rapidly growing and has a high uptake of N. Most split applications entail either a fall or spring application along with a side dress application by the V5 growth stage. After V5, the stalks become too tall and are susceptible to snapping when the side dress is knifed into the ground. However, multiple sources of N can be used which would allow for later applications. Nitrogen uptake is rapid from V7 or V8 until pollination and greatest at V10 to V14, so delayed application is not recommended (Fernandez et al., 2009; Bender et al., 2013). Nitrogen is a valuable input in terms of maize production, but it is an expense that can often be decreased while also reducing negative environmental impacts through increased NUE.

BALANCED NUTRITION

In addition to N, other essential elements that are commonly added in inorganic forms to commercial maize operations are phosphorus (P) and potassium (K). A study in Ohio by Fixen et al. (2005) showed that there was a positive relationship between the soil K levels, average yield, and nitrogen RE. This may occur because the K cation reduces leaching of the negatively charged nitrate anion which would allow for increased uptake of N.

The rate of P fertilizer used is based on the P-supplying power of the soil which is measured by the Bray P test; with adjustments due to parent materials, weathering of the soil, native vegetation, the natural drainage, and mineralizable P (Fernandez & Hoeft, 2009). Fernandez and Hoeft note that regions of high P-supplying power can maintain maize yields over several years without fertilization; however, omitting P fertilizer decreases the P-supplying power of those soils drastically. Neglecting to add P not only depletes the soil of P, it decreases overall fertilizer

efficiency as P has similar added benefits of K. The omission of P may not result in unfavorable yields, but leaving a field with unbalanced nutrition results in significant yield loss of soil nutrients over time (Dibb et al., 1990). Phosphorus has a positive interaction with other macronutrients, with one major benefit being improved root growth. This allows for greater root penetration into the soil profile to retrieve water during drought periods and uptake additional nutrients such as N (Aulakh & Malhi, 2004). Globally, many studies have shown that yield response to N because of the addition of P fertilizer was a 14% to 54% increase with an average of 37% (Fixen et al., 2005). Studies within the United States have also shown that when an optimum N rate is used along with P, the RE of N has a 38% advantage over the maize without the P application. In addition to an increased RE of N, the P fertilized maize had a significant yield advantage (Fixen et al., 2005).

Sulfur (S) and zinc (Zn) are additional essential nutrients that have recently emerged in the commercial fertilizer market. Sulfur availability has reduced in some soils in recent years due to the use of S-free fertilizers (purer fertilizers), decreased use of S based fungicides and insecticides, increased crop yields, reduced amounts of atmospheric S from recent environmental restrictions, and decreases of soil organic matter which provide mineralized S (Fernandez & Hoeft, 2009). Although Zn is a micronutrient, its importance in soil fertility has increased because of more intense agronomic practices and increased yields. Potarzycki (2010) indicates that increased yield resulting from S and Zn application is attributed increased kernel weight.

Using a balanced fertilizer program can also increase the crop's tolerance to disease pressures (Bradley, 2009). Each nutrient has importance in influencing maize yield, but the presence of multiple nutrients provides a proper balance in which each nutrient can work

together. The combined effect of all nutrients performing together improves maize yield and efficacy (Dibb et al., 1990).

FERTILIZER MANAGEMENT

When dry fertilizer is applied, broadcast and banded are the two most common methods of application; each has its advantages and disadvantages. Broadcasting fertilizer is a fast and inexpensive way to put fertilizer onto the field, and it is spread relatively uniformly throughout the field. However, because it is spread throughout the field, the concentration of the fertilizer will be less in a given area. This reduces the opportunity for the fertilizer to be taken up by the plant, particularly for nutrients acquired by diffusion or root interception. Conversely, when the fertilizer is banded or placed near the seed, specialized equipment is used and more time is required. Despite those disadvantages, the placement of fertilizer can boost plant growth and grain yield. Placing superphosphate (0-20-0) near the seed has been shown to stimulate maize growth in terms of rate of biomass accumulation and higher yields while broadcasting of superphosphate showed less of an advantage (Prummel, 1957). Prummel deduced that the banding of phosphate fertilizer increases the concentration of fertilizer which reduces fixation, and thus increases plant availability. Banding of P fertilizer is critical in calcitic soils, such as Harpster, to minimize fixation of added P fertilizer (Boomsma et al., 2007). Although maize has an extensive root system which allows it to seek broadcast applied nutrients, placing the superphosphate near the roots can be advantageous; this is even more critical in that maize can experience P deficiencies during the early growth stages (Prummel, 1957). By placing the fertilizer near the seed, it is also being placed near the root zone. A study in the Netherlands

showed that twice as much P is needed to match yields when broadcasting fertilizer instead of placing it near the seed (Schroder et al., 2011).

Placement of fertilizer also impacts the development of the roots. When a N and P starter fertilizer is placed near the seed, root length density (RLD; root length divided by root volume) increased nearly threefold compared to plants that did not receive fertilizer (Chassot et al., 2001). The increase of RLD in young plants has proven to be critical in no-till systems due to the decrease in soil temperature; because with decreased soil temperatures, plant growth is slowed and the shoot receives insufficient nutrients because of the smaller roots. By placing a starter fertilizer near the seed, the slower root growth resulting from cooler temperatures in no-till systems can be overcome by an increased RLD from the starter fertilizer (Chassot et al., 2001).

Placing fertilizer also improves the overall uptake of applied nutrients. When large concentrations of P are placed near the root zone, shoot dry matter, shoot P concentration, shoot P content, and root growth all increase. While placing P does increase root growth, the root growth within the fertilized zone does not increase (Lu & Miller, 1993). This finding suggests that the plant extends its roots laterally and vertically, making it more resourceful in seeking and finding additional water and nutrients when phosphorus is placed near the main root zone.

Alternative application methods to broadcasting offer another route of increasing yield and improving fertilizer efficiency.

PLANT DENSITY

The number of plants per unit area, the number of kernels per plant, and individual kernel weight are the three components that constitute yield in maize (Hanway, 1966). Of the three, plant density is the factor over which a grower can exert the greatest control.

The effects of increasing or decreasing plant density are dependent on numerous factors such as water and nutrient availability as well as the consistency of plant spacing. As plant density increases, individual plant yield decreases due to a decrease in effective pollination, increased kernel abortion, and decreased individual kernel weight (Wilson & Allison, 1979).

The number of potential ovules is determined by the V12 growth stage and is generally the same regardless of the plant density; however, the rate of development of primordia into functioning florets is decreased at higher densities (Wilson & Allison, 1979). Silk emergence is delayed under higher plant populations, increasing asynchrony between anthesis and silk emergence, and under stress conditions such as limited water availability and excessive heat, the asynchrony of silk emergence and anthesis is further magnified (Sangoi, 2000). When high plant densities are subjected to these two stress conditions, the chance of successful maximum pollination continues to decrease.

Kernel number is mostly influenced by the rate of kernel abortion which occurs shortly after flowering and is influenced by water and nutrient availability (Wilson & Allison, 1979). In denser stands of maize, intraspecific competition as well as competition for assimilates between grain and vegetative sinks increases.

Achieving improvements in yield from increased plant density requires management strategies to overcome the decrease in kernel number per plant. These strategies include

increasing the weight of individual kernels or optimizing plant density to result in an increase in kernel number on a per unit area basis despite the decrease in kernel number on a per plant basis. Final kernel weight is determined during the final stages of grain filling (R3-R5); lack of water availability and increased heat stress are especially detrimental during these critical periods, as both stresses can reduce photoassimilates partitioned into the dividing and expanding endosperm cells.

Greater plant density increases the unit area leaf area index (LAI; the ratio of leaf area to ground area) which maximizes light interception; however, increased LAI also increases transpiration because of the increased stomata number per unit area. When determining optimum plant densities in non-irrigated production systems, water availability is one of the greatest uncontrollable factors impacting yield. Soil characteristics are important in determining optimum plant density as shallow soil profiles generally do not support higher plant populations compared to deeper soil profiles due to differing water holding capacities and nutrient supplying power (Sangoi, 2000).

Water limited stress conditions have a greater effect on kernel abortion during early grain development rather than at anthesis. Adequate pollination can occur despite water stress, although kernel number can be reduced if drought conditions occur at the right time. Drought stress during grain fill will result in a greater dependence on remobilization of carbohydrates and reduced N compounds from the vegetative portions of the plant (Grant et al., 1989). As such, yield losses from drought stress during grain fill may decline as a result of remobilization. However, as a result of increased remobilization, the plant is susceptible to stalk lodging which contributes to harvest losses.

Plant population is the easiest yield component to manipulate, and this decision is made at planting. However, fertility and other management inputs must be altered to avoid a decrease in kernel weight and kernel number via abortion.

HYBRID TRAIT

Hybrid selection is an important and expensive decision for a grower to make, so it is critical that the hybrid that is chosen fits the management practices and environment of each field. Some hybrids are more responsive than others to greater amounts of management such as additional fertilizer and denser populations.

Whether a grower chooses to operate an organic or conventional farm can also influence hybrid selection decisions. Hybrids used in an organic setting will not have genetically modified traits that allow the plant to be resistant to specific pests or herbicides. One of the more common genetically modified traits in maize is the resistance to glyphosate herbicide, a nonselective herbicide. In addition to this trait, several hybrids have multiple genetically modified traits and are referred to as 'stacked' hybrids. A common stacked hybrid used in the Midwest has resistance to glyphosate herbicide, European corn borer (*Ostrinia nubilalis*), and Western corn rootworm (*Diabrotica virgifera virgifera*). A hybrid such as this is called 'triple-stacked' and is commonly used on conventional farms.

The rootworm resistant hybrids contain a gene from the bacterium *Bacillus thuringiensis* (Bt) inserted into the maize genome that enables the plant to produce a protein that protects the plant from corn rootworm larvae feeding. This trait offers a yield advantage over near-isoline hybrids; when grown in areas of at least moderate western corn rootworm larval densities, the yield

advantage is due to decreased feeding damage on the root systems. In a 3 year study by Ma et al. (2009), Bt hybrids were compared with non-Bt isoline hybrid with no seed treatment and non-Bt isoline hybrid with an insecticidal seed treatment. Among those treatments, the Bt hybrid out yielded the untreated non-Bt isoline hybrid by 11 to 66%. It was also found that the treated non-Bt isoline had a yield advantage over the untreated seed in 2 of the 3 years. This study also demonstrated that the Bt hybrid had greater yield over the treated non-Bt isoline hybrid in 1 of the 3 years. Such data suggests that Bt transgenic hybrids may provide a yield advantage in addition to the resistance to rootworm larvae, and the improved yields may be attributed to better root protection and decreased chances of corn stalk rot (Rice, 2004).

The use of Bt hybrids requires the accompanied use of a non-Bt hybrid to avoid selection pressure on resistance in rootworms to the Bt trait. Use of most of the current Bt hybrids requires that 20% of the planted area be planted with a non-Bt isoline.

Transgenic hybrids offer an effective way of managing common and destructive pests for growers while also reducing the usage of pesticides. Control of pests offers greater yield protection, but transgenic hybrids also offer additional yield boosts due to increased root protection from pests.

FUNGICIDE

Crop diseases affecting maize are numerous and have potential to significantly reduce yields. In order for diseases to develop, a susceptible host, an infectious plant pathogen, and a suitable environment must be present. These three components make up the disease triangle (Bradley, 2009).

Fungicides may be sprayed to limit the development or spread of a disease within a field; however, it is important to scout the field to ensure that the disease is indeed a fungus so the fungicide will protect the plant against infection. Paul et al. (2011) evaluated mean yield responses from 4 different fungicides (azoxystrobin, pyraclostrobin, propiconazole + trifloxystrobin, and propiconazole + azoxystrobin) applied on maize across 14 states; each fungicide increased yields. The fungicides with multiple active ingredients provided the greatest yield increase while the application of single active ingredients increased yield by the least amount. Yields may increase due to application, but yield increases do not always increase enough to account for the cost of application. A phenomenon associated with the use of the fungicide ingredient, strobilurin, commonly referred to as the "greening effect" appears to be related to an enhanced capacity for strobilurin-treated crops to maintain the green leaf area of the canopy later in the growing season, thus prolonging the grain-filling period with the result of higher crop yields (Bartlett, 2002). A number of hypotheses have been suggested for the greening effect of strobilurin, primarily increased photosynthetic capacity and reduced respiration due to a variety of physiological effects on stomatal aperture, chlorophyll content, water use, and endogenous levels of abscisic acid and other plant hormones (Bartlett, 2002). A related hypothesis is that strobilurin fungicides reduce crop stress, thus allowing the plant to come closer to attaining full yield potential by maximizing kernel production and grain fill and increasing kernel weight.

Crop disease damage is variable in production systems but has become more prevalent as certain farming management practices have been adopted such as reduced tillage and lack of rotation (Lipps, 1998). Reducing tillage and abandoning crop rotation have boosted the infectious plant pathogen and susceptible host components of the disease triangle, respectively,

making infection more likely. Some of the more prevalent crop leaf diseases found within the Midwest are gray leaf spot (GLS; *Cercospora zeae-maydis*) and northern corn leaf blight (*Exserohilum turcicum*), with GLS being the predominant leaf disease. Yield reductions due to GLS can to range from 11 to 44% (Gorman et al., 1997; Ward et al., 1999).

Yield is dependent on the leaf area and longevity of photosynthesis after anthesis, and the upper eight or nine leaves prove to be critical in maximizing yield as they contribute 75 to 90% of the plant's photoassimilates following flowering (Eik & Hanway, 1966; Allison & Watson, 1966). When leaf diseases infect the upper canopy leaves, lesions created decrease the amount of photosynthetic tissue that is available for light interception and associated photoassimilate production for developing kernels (Allison & Watson, 1966). When leaf area is lost, the source of carbohydrates required for grain fill must come from another source; this other source is from the stalk which makes the plant susceptible to stalk-lodging. Stalk-lodging increases harvest difficulty and can decrease yield because of the inability to harvest all of the grain (Stromberg, 1986).

With optimal weather conditions, crop diseases can proliferate and greatly decrease yield. The use of fungicides is important in protecting yields, and in susceptible hybrids multiple applications increase grain yield pending a suitable environment for the fungal diseases to grow and proliferate. Due to the variation of the environmental conditions for fungal growth, grain yields can increase by 29 to 68% with three fungicide applications; however, in most hybrids, one application of fungicide is the most economical because increased yield from multiple applications is often not significantly greater than grain yield using one application (Ward et al., 1997). When using a single application the recommended time is after flowering to protect the

uppermost leaves through physiological maturity to maintain photosynthetic activity during grain fill (Munkvold et al., 2001).

High yielding hybrids have further proved the necessity for disease control. These hybrids have a greater demand for photosynthetic assimilates which makes healthy leaves with greater leaf area more essential in order to avoid stalk-lodging. Along with higher yields, these hybrids produce greater amounts of biomass which can serve as an inoculum future years for these diseases (Ward et al., 1999).

TILLAGE

Tillage is a common management practice and has been modified throughout the years. The three common methods of tillage in cultivated maize are chisel plow, no-till, and strip-till.

Conventional tillage utilizes a chisel plow and disturbs the top 15 cm of the topsoil. This action of tillage incorporates residue into the soil and increases surface area contact with the soil where microbes can degrade the material faster. Conventional tillage increases aeration, soil temperature, decreases soil moisture, and if used correctly, decreases weed pressure without the use of additional herbicides. However, there are negative impacts that go along with conventional tillage which include increased erosion, decreased soil organic matter, and decreased soil moisture (Simmons & Nafziger, 2009). Decreasing soil moisture can be helpful in the spring if fields are wet and need to be dried for planting, but further decreasing soil moisture in a dry spring or arid climate can hinder plant growth due to lack of moisture.

In areas with low soil organic matter and soil moisture, minimizing tillage is critical in preserving these two vital components for growing crops. No-till is one method used to protect

those two components. The use of no-till raises concerns regarding soil compaction, however no-till does not always increase the bulk density of soil more than conventional tillage (Ismail et al., 1994). No-till raises additional management concerns when used in continuous maize systems; residue covering the soil bed results in reduced soil temperatures in the spring which can negatively impact yield by delaying plant emergence (Kaspar et al., 1990).

To obtain the benefits of no-till while minimizing the negative impacts, strip-tillage has been developed. Strip-tillage only disturbs the seedbed while leaving the rest of the field untouched. Through the act of working the seedbed, soil temperatures in that area are higher than in no-till, and soil moisture with strip-till exceeds areas in that of no-till throughout the entire growing season for maize (Licht & Al-Kaisi, 2005). Licht and Al-Kaisi (2005) also found that strip-tillage had reduced penetration resistance compared to chisel plowing and no-till which allowed for more exploration by the roots to find water and nutrients.

The level of soil organic matter is influence by tillage practices. Under no-tillage or strip-tillage, surface layer organic matter tends to increase while it decreases in conventionally plowed fields; conversely, organic matter levels increase beneath the surface layer in conventionally tilled fields while it remains equal or decreases in minimum tilled areas (Ismail et al., 1994; Cameira et al., 1996). The use of minimum tillage promotes a more balanced soil ecology which helps the soil function as a better medium for plant growth (Brady & Weil, 2004).

The effects of tillage relative to maize yield and overall production varies by year and growth environment. Some studies find that the type of tillage has no influence on maize yield (Eckert, 1984) while others have found that maize yield is favored under minimum tillage practices (Dick & Van Doren, 1985). However, Dick and Van Doren (1985) also found that no-tillage practices suffered a greater yield penalty in continuous maize compared to the conventionally tilled plots.

The most effective form of tillage is dependent on the soil profile and the field's cropping history. In areas of low organic matter and soil moisture, minimum tillage would be advantageous, but rotating crops would also be necessary. Areas with an abundance of organic matter and high water holding capacity can be benefitted by chisel plowing, but still risk losing organic matter and increased erosion over time.

RESIDUE REMOVAL

There are many new possibilities to explore in terms of managing maize stover that provide feed for livestock, produce cellulosic ethanol, and reduce the continuous maize penalty. One common practice with beef farmers is to allow gestating cows to graze maize stover during the winter; this offers multiple benefits in that it provides cheap feed for a beef producer and removes excess residue which can prevent soil temperature from increasing in the spring. Removing stover mechanically acts in a similar way to cattle grazing, except that it results in a greater percentage of removal. Removal of stover is thought to be beneficial on maize yields when maize is grown continuously by reducing inoculum for diseases and reducing N immobilization (Nafziger, 2011). The long-term effects show that stover removal does not affect yield directly; however, there is an interaction between stover management and rainfall. During dry years, removing stover resulted in reduced grain yields (Linden et al., 2000; Coulter & Nafziger, 2008).

Long-term concerns associated with stover removal include sustainability of harvesting biomass from crop production lands. Essential minerals and nutrients are removed with the

grain, but there is still an abundance in the biomass that is retained by the stover (Blevins et al., 1983). In addition to returning nutrients to the soil, stover retention improves soil structure and decreases risk of erosion (Lal, 2009). For these reasons, it is important to evalaute soils and their nutrient supplying power. Soils that have a surplus of nutrients are able to withstand more stover removal compared to more deteriorated soils. Recommendations from regional agronomists are highly advised to determine how much stover can be removed (Wilhelm et al., 2004).

The removal of maize stover offers another possible way of decreasing the continuous corn yield penalty; however, careful considerations must include avoiding deficiencies of essential plant nutrients and soil erosion.

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CHAPTER 2

IDENTIFYING CROP MANAGEMENT FACTORS TO MITIGATE THE CONTINUOUS MAIZE YIELD PENALTY

ABSTRACT

The objective of this experiment was to test the effects of stover removal and tillage on the continuous maize yield penalty. An addition/omission design was used to test the influence of management inputs (nitrogen, fertilizer, plant density, hybrid trait, and fungicide) and how they interact with the stover removal and tillage treatments in continuous maize. This study was conducted over two years (2011 and 2012) in Champaign, IL. Nitrogen and fertilizer were the greatest factors affecting grain yield in 2011. Stover removal in the high technology treatment with additional N omitted demonstrated the value of nutrients that the stover offers and how those removed nutrients must be replaced with mineral fertilizers. The same treatment also shows the level of immobilization of essential nutrients that accumulated stover can induce. For 2012, the most influential factor was hybrid trait which demonstrated that having the corn rootworm resistance trait is vital in drought years. When farming continuous maize, removing stover is advantageous; however, mineral fertilizers must be added to replace nutrient losses and to take full advantage of the increased yield potential that stover removal offers in continuous maize.

INTRODUCTION

Maize grain yields have increased by an average of 1.5% per year since 1945 as a result of the development of hybrid maize seed and improved management practices. Domestic demand for U.S. maize has increased in concert with increased grain yields. In recent years (since 2005), growth in domestic ethanol production from corn grain has increased demand substantially, raising corn prices and returns (USDA, 2007). The increased demand for maize grain, the potential of maize to produce high yields, and increased price for grain have driven the increased production of maize by U.S. producers.

The most common reason for increasing maize acres in the U.S. is through conversion of farmland from the traditional soybean-maize rotation into a continuous maize system. However, yields in typical dryland continuous maize systems exhibit a continuous maize yield penalty; this penalty is the yield difference between the yield of a continuous maize field and the yield of a soybean-maize rotated field. Gentry et al. (2013) concluded that the three main factors influencing the yield reduction in continuous maize systems are nitrogen (N) availability, residue accumulation, and weather. Nitrogen availability decreases as a result of net immobilization caused by the high carbon (C) to N ratio of maize stover, which is produced in large quantities. Maize residues accumulate to substantial levels the longer the system remains in the continuous maize system. Maize residues are well known to introduce a host of yield-reducing effects including pest and disease issues, reduced soil temperature, increased soil moisture, and release of potentially autotoxic compounds. Hot and dry weather conditions were also found to magnify the continuous maize yield penalty. In this follow-up study to Gentry et al. (2013), the three factors influencing continuous maize yield were taken into account. Weather is a factor over

which we have the least control and the optimum N fertilizer application rate is not known until after grain maturity; however, residue management is a viable management option.

This study utilizes an Addition/Omission treatment design to test the effects of intensive management practices and assesses how they are influenced by residue removal in continuous maize production. Finally, the effect of a reduced tillage system (strip tillage) was compared with conventional full-width tillage for its effect on maize yields and interactions with stover removal and intensive management.

MATERIALS AND METHODS

Location and History

The study was conducted in 2011 and 2012 on sites predominantly (>75%) consisting of Flanagan silt loam (fine, smetitic, mesic Aquic Argiudoll) with 0-2% slope. Two sites were used due to the crop rotation treatment. The two sites are within 4.5 km of each other and were approximately 2 ha each at the University of Illinois Crop Sciences Research and Education Center in Champaign, IL. Both sites were tile drained and non-irrigated. To establish the rotation treatment of this experiment, the set-up site established whole blocks of maize and soybean as the previous crop for the next year's rotation treatment. Each site had blocks of 9th year continuous maize or a long-term rotation between maize and soybeans. Soil NO_3-N test levels were relatively low (Table 2.1) which indicates little residual N fertilizer effects. Other nutrients were available in ranges exceeding critical levels (Fernandez and Hoeft, 2009). Soil test results for both years are provided in Table 2.1

Experimental Design

The experimental design was a split-split plot design (Figure 2.1) with four replications; each plot consisted of four rows. The experimental unit for yield and yield component analysis was the center two rows within each plot (rows: 10.2m x 76cm). Each whole plot (rotation) was first split in an east-west direction to create the tillage split-plot treatments (conventional tillage vs. strip tillage). The continuous maize rotation factor was further split in the north-south direction to establish the stover removal treatments; the plots had a 50% stover removal while the other plots had the stover retained. Stover removal was not used in the soybean and maize rotation

because it would greatly increase the potential for soil erosion and depletion of soil organic matter. The Addition/Omission Factors (Table 2.2) were arranged in a randomized complete block design.

Tillage, Stover Removal, and Fertility Treatments

The stover removal, tillage, and fertilizer applications were established during the spring for both the 2011 and 2012 growing seasons. For the stover removed factor, all of the maize stover was flail chopped, raked into windrows, and fully collected. Once all the stover was collected, it was weighed and 50% was replaced and evenly distributed onto the respective plots with a manure spreader. Conventional tillage used chisel plowing which disturbs the top 20cm of soil while strip tillage only disturbed the seedbed with a depth of up to 20cm deep. MicroEssentials SZ (12-40-0-10S-1Zn) fertilizer was applied in a band 10.2cm below the seed with the strip tiller and was also applied in a band at the same depth using a tool bar for the conventionally tilled treatments. Triple stacked hybrids (glyphosate, *Ostrinia nubilalis*, and *Diabrotica virgifera virgifera* resistances) were used along with their respective refuge hybrids (glyphosate resistance only); Syngenta hybrids N68B 3000GT and N68B GT (111 day) were used in 2011, and N63R 3000GT and N63R GT (109 day) were grown in 2012. A different hybrid was selected in 2012 due to N68B's intolerance of high plant density. Planting dates were 5 June 2011 and 25 April 2012. Stand counts were taken at V5 on 15 June 2011 and 21 May 2012. Due to uneven emergence in 2012, plots were thinned to the target density of either 79,072 plants ha^{-1} or 111,195 plants ha^{-1}. A base application rate of 202 kg N ha^{-1} fertilizer was determined based on 16.1 kg N per Mg of grain requirement by maize with a predicted yield of 12.6 Mg ha^{-1}. The base rate was broadcast-applied by hand as SuperU (dicyandiamide) (Treatments 1, 2, 3, 5, 6, 10)

and as urea (Treatments 4, 7, 8, 9, 11, 12) at the V4 growth stage on 20 June 2011 and before planting on 18 April 2012; none of the treatments had the base rate of N fertilizer incorporated. The base application rate of 202 kg N ha^{-1} in 2012 was applied as urea ammonium nitrate (UAN, 28% N) instead of urea and was injected in the conventional tilled plots and sprayed onto the strip-tilled plots. The side-dress application of 67 kg N ha^{-1} was applied as urea mixed with Agrotain (N-(n-butyl) thiophosphoric acid triamide) at V7 on Treatments 1, 2, 3, 5, 6, and 10 (Table 1) on 5 July 2011 and at V4 on 23 May 2012. Quilt Xcel (azoxystrobin with propiconazole; Syngenta, Greensboro, NC) was applied using a backpack sprayer with a boom attachment which treated either side of the two treated rows. Appropriate treatments were sprayed once the field reached VT (8 August 2011, 5 August 2012, and 9 August 2012) at a rate of 876.9mL ha^{-1} of product. The fungicide applications in 2012 were split between replications 1,2 and 3,4 due to phenological differences within the field.

Sampling

Biomass samples were collected at R6 to test dry matter accumulation on all the treatments. Whole plant samples were taken at R6 using a 2-1-2 phenotyping sampling technique. Grain from the R6 sampling was saved and used to determine cob weight and total biomass yield of each plot.

During harvest, a sample of the grain was collected for further analysis. Using a kernel counter, 300 kernels were weighed to determine average kernel weight at 0% moisture. In the 2012 year kernel row number was additionally measured of the grain collected from the sampling at R6. Cobs determined as barren were excluded.

Root biomass was collected following harvest. Using a hollow v-shaped cutting wedge mounted onto the back of a tractor, the soil was sliced around the root ball of the two treated rows. The width of the cut was 76 cm and the depth varied from 40 to 45 cm. The resulting average soil volume extracted was 63840 to 71820 cm^3. Four root balls from each plot were placed in mesh harvest bags and stored under the cover of an open, non-heated shed for several months (December-March). Temperatures were determined to be cool enough to limit microbial activity so that negligible root mass was be lost due to the decomposition. Because of the cold temperatures and low soil moisture, each root ball was soaked in water for 3-4 minutes to help with soil removal. Any loose or broken roots were retrieved and later added back to the root sample. After the root balls had been soaked, the remainder of the soil was removed with a hose. Once all the soil was removed, the roots were placed into an oven until constant moisture was reached. After the roots were weighed, they were ground and analyzed for N concentration.

Soil moisture probes from John Deere were used in the 2012 experimental year and placed in the field on 28 May 2012. These probes took soil moisture readings at 5 different depths: 10, 20, 30, 50, and 100 cm. A total of four moisture probes were used; one in each combination of tillage and previous crop treatments. They were all place in the northern half of replication four. Moisture readings were taken every 30 minutes and sent digitally to a receiver which recorded the readings.

Analysis

All data was subjected to analysis of variance (ANOVA) to detect significant treatment effects and interactions among treatments. The following measurements were assessed for

treatment effects: grain yield, kernel number, kernel weight, harvest index, stover mass at R6, root mass, and the number of kernel rows in 2012.

RESULTS AND DISCUSSION

Weather

Monthly average temperatures (Figure 2.2) and precipitation (Figures 2.3, 2.4) varied by year and influenced treatment effects on grain yield and other aspects of plant growth accordingly. As such, the 2011 and 2012 data were analyzed separately. The 2011 growing season had similar temperatures to the 30-year average, however, precipitation varied widely throughout the season, with an abundance of rainfall early in the growing season followed by precipitation far below the 30-year average during flowering and grain fill. The 2012 growing season was much dryer than average and had greater temperatures throughout the growing season than the 30-year average. Although average rainfall occurred late in the 2012 season, it occurred following grain maturity.

Grain Yield

In 2011, analysis of variance (ANOVA) for grain yield determined significant differences ($P<0.05$) for Rotation and among Addition/Omission treatments; in 2012, significant yield differences were found for Rotation, Tillage, and among Addition/Omission treatments (Table 2.3). Analysis of variance for grain yield effects within the continuous maize system determined significant differences for Tillage and Addition/Omission treatments in 2011 and for Addition/Omission treatments in 2012 (Table 2.4).

In 2011, grain yields for the High Technology treatment were significantly greater than the Traditional treatment within each production system, with an average yield advantage of approximately 1.04 Mg ha^{-1} (Table 2.5). A continuous maize yield penalty significantly decreased yields and demonstrated a greater impact on the High Technology treatment than Traditional treatment; yields decreased by 1.5 Mg ha^{-1} for the High Technology treatment while yields decreased by 0.7 Mg ha^{-1} for the Traditional treatment. The greater continuous maize yield penalty for the High Technology treatment is likely the result of increased plant population in a drought. Although not always significant, the use of conventional tillage consistently decreased the continuous maize yield penalty. The continuous maize yield penalty is obvious when the stover management aspects are averaged; however when viewed separately, it is clear that stover removal effectively reduced the continuous maize yield penalty (Tables 2.5 and 2.6). The removal of stover in combination with conventional tillage in continuous maize presented a method of overcoming the continuous maize yield penalty by providing a 0.3 Mg ha^{-1} yield advantage over a soybean-maize rotation. The yield advantage of removing maize stover in continuous maize was observed in strip tillage as well, but the advantage was not as great as with conventional tillage as reported by Dick and Van Doren (1985).

The Addition/Omission factors that exerted the greatest impact on grain yield in 2011 were N and Fertilizer. For the Soybean-Maize Rotation, -N significantly decreased yields and +N significantly increased yields for both Tillage factors; similar results were observed for the continuous maize system with stover removal. When stover was retained in continuous maize, no significant differences were found for the -N and +N treatments. The -Fertilizer treatment for the Soybean-Maize Rotation resulted in a yield decrease for the strip tillage alone while the +Fertilizer treatment increased yields for both tillage types. Within the stover removed

continuous maize system, -Fertilizer decreased yields in only the conventional tillage while +Fertilizer increased yields for both tillage types. When stover was retained in continuous maize, no yield response was measured for the -Fertilizer effect; however, +Fertilizer provided a significant yield increase. The yield reduction resulting from omitting P, S, and Zn application in the Stover Removed continuous maize treatment reflects the value of corn residues for supplying nutrients. When 50% of the stover was removed, substantial amounts of plant nutrients were also removed and must be replaced with mineral fertilizer to avoid crop deficiencies and related yield loss.

The high C to N ratio in maize stover increases the potential for immobilization of essential nutrients such as N, P, and S. When stover is retained in continuous maize systems, immobilization of essential nutrients can result in crop deficiencies; however, potential yield reductions resulting from plant nutrient deficiencies can occur when stover is removed. Omission of the side dress N application in continuous maize system with stover removal resulted in a significant yield reduction; despite the yield reduction, the resulting yield of 8.25 Mg ha^{-1} matched the High Technology yield of the continuous maize with stover retention of 8.15 Mg ha^{-1} for combined Tillage. As such, the removal of stover acted, in effect, as a 67 kg N ha^{-1} credit by reducing the amount of N immobilized.

Grain yields for the High Technology treatment were significantly greater than Traditional treatment within each production system (with the exception of continuous maize with conventional tillage) in 2012. The average yield advantage of High Technology was 0.85 Mg ha^{-1} relative to the Traditional system (Table 2.5). The continuous maize yield penalty was large in 2012. As in 2011, the penalty was greater in the High Technology system compared to the Traditional system as yields decreased by 3.75 Mg ha^{-1} and 2.45 Mg ha^{-1}, respectively. Tillage

type did not have an effect on yield in the Soybean-Maize rotation but significantly reduced yields in the Continuous Maize system. While stover removal in 2012 did not have the consistently positive yield effect as in 2011, yields were increased within the High Technology treatment by 0.55 Mg ha^{-1} for combined Tillage systems (Table 2.6).

In 2012, the Addition/Omission factor that had the greatest influence on yield was Hybrid Trait. For the Soybean-Maize Rotation, -Hybrid Trait significantly decreased yields and +Hybrid Trait significantly increased yields for each Tillage treatment. The Hybrid Trait effect was consistent for the continuous maize regardless of whether the stover was retained or removed; however, the Hybrid Trait effect was greatest in continuous maize with stover removal.

Crop rotation may not be effective in reducing rootworm pressure in areas containing the rootworm variant, leaving a rotated crop susceptible to rootworm damage. Continuous maize also promotes increased rootworm beetle numbers, making the use of a rootworm resistant trait an important aspect in hybrid selection. The data from 2012 suggests that increased root protection is vital in a drought to maximize water and nutrient uptake as omission of the rootworm trait consistently decreased yields while adding the rootworm trait greatly increased yields.

Grain Yield Components

In 2011 and 2012, ANOVA for kernel number determined significant differences ($P<0.05$) for Rotation, Tillage, and Addition/Omission factors (Table 2.3). Analysis of variance for 2011 kernel number within continuous maize determined significant differences in Tillage and Addition/Omission factors; significant kernel number differences in 2012 were only found among Addition/Omission factors (Table 2.4). Kernel weight was significantly different among

Addition/Omission factors in 2011 while differences were found for Rotation and Addition/Omission factors in 2012 (Table 2.3); kernel weight within the continuous maize was only significantly different among Addition/Omission factors for both 2011 and 2012 (Table 2.4). Kernel row was significantly different for Rotation and Addition/Omission factors (Table 2.3); kernel row within the continuous maize was different only among the Addition/Omission factors (Table 2.4).

In 2011, the most influential factors on grain yield of the Addition/Omission treatment were N and Fertilizer. Examination of the kernel number shows that the effects that occurred on grain yield by the N and Fertilizer factors of the Addition/Omission factors had similar effects on kernel number (Tables 2.7 and 2.8). Kernel weight did not have similar changes by the N and Fertilizer factors of Addition/Omission factors (Tables 2.9 and 2.10). Because kernel number had a similar response to the N and Fertilizer factors as grain yield and kernel weight did not, changes in grain yield were primarily influenced by kernel number.

In 2012, the most influential factor on grain yield of the Addition/Omission treatment was Hybrid Trait. The same influence was seen in the kernel number; -Hybrid Trait decreased kernel number and +Hybrid Trait increased kernel number for all systems (Tables 2.7 and 2.8). Kernel weight did not have similar changes as grain yield and kernel number did for Hybrid Trait (Tables 2.9 and 2.10). Changes in grain yield were primarily influenced by kernel number because kernel weight did not have a similar response to Hybrid Trait as grain yield and kernel number did. Kernel row was similar to kernel weight; kernel row was not affected by Hybrid Trait (Tables 2.11 and 2.12).

R6 Root Mass

In 2011, ANOVA for root mass determined significant differences ($P<0.05$) for Tillage, and Addition/Omission factors; in 2012, significant root mass differences were found for Tillage and Addition/Omission factors (Table 2.3). Analysis of variance for 2011 root mass within continuous maize determined significant differences in Tillage, and Addition/Omission factors; significant root mass differences in 2012 were found in Stover and among Addition/Omission factors (Table 2.4).

The greatest influential factors of 2011 (N and Fertilizer) varied in influence on root mass; N did not change root mass, however, Fertilizer positively influenced root mass (Tables 2.13 and 2.14). Fertilizer response was much greater in conventional tillage than strip tillage and in continuous maize with stover removed than continuous maize with stover retained. Figure 2.5 presents a visual demonstration on the impact high plant density has on individual root mass and the importance of supplying mineral nutrients to those plants to promote individual root growth.

The greatest factor of influence of 2012 (Hybrid Trait) had little influence on root mass (Tables 2.13 and 2.14).

Soil Moisture Probes

The soil moisture probes used in 2012 demonstrated a difference of precipitation penetrance during light rain events based on the previous crop (Figures 2.6 to 2.9). The peaks in the upper 20.3cm of soil showed higher peaks during the light rain events in the maize-soybean rotation than in the continuous maize system and was consistent across both tillage types. The accumulated biomass on top of the soil from continuous maize acted as a sponge which prevented moisture from going deep into the soil profile.

CONCLUSIONS

Factors of the Addition/Omission treatments varied between the experimental years due to weather differences. In 2011, grain yield was primarily influenced by N and Fertilizer; omission of these factors decreased yield while addition of them increased yield. Grain yield increased with the removal of stover in continuous maize; removal of stover in continuous maize with -N treatment produced similar yields as the High Technology treatment with stover retained in continuous maize which insinuates that removal of stover prevents 67 kg N ha^{-1} from being made unavailable through immobilization. Yield components indicate that kernel number had the greatest influence in determining yield. Root mass was increased by the Fertilizer treatment; use of conventional tillage created a greater response to the Fertilizer treatment on root mass.

In 2012, N and Fertilizer were no longer the primary influential factors as lack of precipitation may have prevented these nutrients to be mobile in the soil; Hybrid Trait was the greatest factor of influence in 2012. Yields decreased with -Hybrid Trait and yields increased with +Hybrid Trait. The removal of stover in continuous maize promoted a greater response to the Hybrid Trait factor. Kernel number was the greatest influence in determining yield over kernel weight; kernel row had little effect on yield.

Continuous maize produces a vast amount of biomass which can easily accumulate; this accumulated stover acts a sponge during light rain events and inhibits moisture from going deep into the soil profile.

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TABLES

Table 2.1 Site summary data for the 2011 and 2012 field sites. Soil test nutrient levels measured in Fall 2010 and 2011 are listed for continuous maize and soybean-maize split blocks. The Bray P_i test was used to estimate P availability, and the 1N acetate test was used to test K availability.

Rotation	**2011 Experimental Year**							
	NO_3^- (0-86.4cm)	**P (0-15.2cm)**	**K (0-15.2cm)**	**S (0-15.2cm)**	**S (15.2-61cm)**	**Zn (0-15.2cm)**	**OM (0-15.2cm)**	**pH (0-15.2cm)**
	ppm						%	
Maize-Maize	9	28	164	9	18	1	4.2	5.1
Soybean-Maize	14	20	133	9	17	1	3.8	6.1
	2012 Experimental Year							
	NO_3^- (0-106.7cm)	**P (0-15.2cm)**	**K (0-15.2cm)**	**S (0-15.2cm)**	**S (15.2-61cm)**	**Zn (0-15.2cm)**	**OM (0-15.2cm)**	**pH (0-15.2cm)**
	ppm						%	
Maize-Maize	16	35	125	15	26	2	4.1	5.2
Soybean-Maize	20	35	112	13	25	2	4.3	5.9

Table 2.2 Addition/Omission treatments (subplot treatments) for the 2011 and 2012 Sustainability Omission Plot Design. The twelve addition/omission treatments were created by selectively combining the following five technology treatments: population, hybrid trait, nitrogen rate, fertilizer, and fungicide. The fertilizer treatment was established with application of a 12-40-0-10(S)-1(Zn) product.

Trt #	Treatment	Plant Density (plants ha^{-1})	Hybrid[1]	Nitrogen[2]	Fertilizer	Fungicide
1	High Technology	111,195	Multi-Traited	Base+Side Dress	MESZ	Applied
2	-Population	79,072	Multi-Traited	Base+Side Dress	MESZ	Applied
3	-Hybrid Trait	111,195	Refuge	Base+Side Dress	MESZ	Applied
4	-Nitrogen	111,195	Multi-Traited	Base	MESZ	Applied
5	-Fertilizer	111,195	Multi-Traited	Base+Side Dress	None	Applied
6	-Fungicide	111,195	Multi-Traited	Base+Side Dress	MESZ	None
7	Traditional	79,072	Refuge	Base	None	None
8	+Population	111,195	Refuge	Base	None	None
9	+Hybrid Trait	79,072	Multi-Traited	Base	None	None
10	+Nitrogen	79,072	Refuge	Base+Side Dress	None	None
11	+Fertilizer	79,072	Refuge	Base	MESZ	None
12	+Fungicide	79,072	Refuge	Base	None	Applied

[1]Multi-traited hybrids contain glyphosate tolerance as well as the rootworm resistance trait. The refuge hybrids only had the glyphosate tolerance.

[2]Base rate of nitrogen was 202 kg N ha^{-1} as urea or SuperU in 2011; UAN or SuperU in 2012. Side dress was 67 kg N ha^{-1} as urea treated with Agrotain.

Table 2.3 Analysis of variance for grain yield, number of kernels m^{-2}, kernel weight, stover biomass at R6, and root biomass following R6 for 2011 and 2012. The 2012 growing season also includes the number of kernel rows. Stover removal factors (retained vs. 50% removed) are combined within the continuous maize factor of the rotation treatment. Stover removal is treated separately in a different analysis. Treatment (Trt) consists of the twelve addition/omission factors.

Sources of Variation	**2011 Experimental Year**				
	Yield	**Kernel Number**	**Kernel Weight**	**Stover Biomass**	**Root Mass**
Rotation (R)	0.0389	0.0366	0.4666	0.1091	0.1733
Tillage (Till)	0.2177	0.0149	0.1315	0.0030	0.0043
R*Till	0.2585	0.0252	0.1766	0.0531	0.7806
Treatment (Trt)	<.0001	<.0001	<.0001	<.0001	<.0001
R*Trt	0.2060	0.0390	0.2538	0.9864	0.8802
Till*Trt	0.5193	0.1919	0.6749	0.8070	0.0006
R*Till*Trt	0.4296	0.1689	0.7127	0.6175	0.0061

	2012 Experimental Year					
	Yield	**Kernel Number**	**Kernel Weight**	**Kernel Row**	**Stover Biomass**	**Root Mass**
Rotation (R)	0.0117	0.0239	0.0011	0.0477	0.2606	0.0862
Tillage (Till)	0.0171	0.0290	0.9788	0.1046	0.3972	0.0071
R*Till	0.4481	0.2774	0.7452	0.1774	0.1901	0.2943
Treatment (Trt)	<.0001	<.0001	<.0001	0.0478	<.0001	<.0001
R*Trt	0.1719	0.0061	0.9608	0.2987	0.7785	0.2816
Till*Trt	0.9369	0.9320	0.6871	0.6286	0.2140	0.0550
R*Till*Trt	0.9820	0.9377	0.9176	0.9081	0.4143	0.3346

Table 2.4 Analysis of variance within continuous maize for grain yield, number of kernels m^{-2}, kernel weight, stover biomass at R6, and root biomass following R6 for 2011 and 2012. The 2012 growing season also includes the number of kernel rows. Stover removal (S) includes retained vs. 50% removal. Treatment (Trt) consists of the twelve addition/omission factors.

Sources of Variation	**2011 Experimental Year**				
	Yield	**Kernel Number**	**Kernel Weight**	**Stover Biomass**	**Root Mass**
Tillage (Till)	0.0269	0.0363	0.2475	0.0090	0.0174
Stover (S)	0.1105	0.2234	0.2242	0.4675	0.6729
Till*S	0.9228	0.6240	0.4860	0.1212	0.5501
Treatment (Trt)	<.0001	<.0001	<.0001	<.0001	<.0001
Till*Trt	0.0335	0.0286	0.4558	0.3748	0.0581
S*Trt	0.3801	0.8828	0.1917	0.9958	0.8311
Till*S*Trt	0.3027	0.3449	0.7159	0.3636	0.1038

	2012 Experimental Year					
	Yield	**Kernel Number**	**Kernel Weight**	**Kernel Row**	**Stover Biomass**	**Root Mass**
Tillage (Till)	0.2730	0.2027	0.9971	0.1625	0.0636	0.1253
Stover (S)	0.8831	0.8891	0.1899	0.4684	0.0274	0.0424
Till*S	0.9009	0.9280	0.8243	0.8456	0.9878	0.0417
Treatment (Trt)	<.0001	<.0001	<.0001	0.0282	<.0001	0.0042
Till*Trt	0.9870	0.9950	0.3040	0.9628	0.5593	0.2844
S*Trt	0.9567	0.9817	0.9254	0.7146	0.5341	0.8668
Till*S*Trt	0.9395	0.7915	0.8429	0.8926	0.6411	0.3631

Table 2.5 Grain yield from 2011 and 2012. Yields displayed for each treatment are from the soybean-maize rotation and continuous maize and within each tillage system of conventional and strip.

Treatment	Conventional Tillage				Strip Tillage			
	Soybean-Maize[1, 2, 3]		Maize-Maize[1, 2, 3]		Soybean-Maize[1, 2, 3]		Maize-Maize[1, 2, 3]	
	2011	2012	2011	2012	2011	2012	2011	2012
	Mg ha^{-1}				Mg ha^{-1}			
High Technology	9.5	8.9	8.8	5.1	9.8	8.3	7.5	4.6
-Population	9.7	8.8	10.3	6.7	9.7	8.7	9.4	6.6
-Hybrid Trait	9.3	7.9	8.7	4.3	9.2	7.3	7.9	3.6
-Nitrogen	8.4	8.8	8.4	6.3	8.9	8.5	7.3	6.0
-Fertilizer	9.3	8.6	9.0	5.8	9.5	9.0	7.4	5.4
-Fungicide	9.8	8.4	8.3	6.5	9.3	8.9	7.8	5.7
Traditional	8.3	7.3	7.9	5.4	8.1	6.9	7.1	3.9
+Population	7.8	6.7	6.5	3.3	7.8	6.5	6.6	3.3
+Hybrid Trait	8.3	8.8	7.1	7.0	8.5	7.9	8.1	6.3
+Nitrogen	9.3	7.4	8.7	4.6	8.4	7.2	8.4	4.1
+Fertilizer	8.7	7.8	8.6	4.8	8.6	7.3	8.4	4.7
+Fungicide	8.2	6.8	6.5	3.8	8.4	6.9	7.5	3.8
Column Avg	8.9	8.0	8.2	5.3	8.9	7.8	7.8	4.8

[1] LSD (P<0.10) for Addition/Omission x System within Tillage (compare values within Conventional Tillage OR Strip Tillage treatments) are 0.8 and 1.0 Mg ha^{-1} for 2011 and 2012, respectively

[2] LSD (P<0.10) for System x Tillage (compare values from Addition/Omission within a Rotation x Tillage treatment) are 0.3 and 0.4 Mg ha^{-1} for 2011 and 2012, respectively

[3] LSD (P<0.10) for Addition/Omission x System x Tillage (compare Addition/Omission values averaged across System and Tillage OR between System/Tillage treatments) are 1.1 and 1.3 Mg ha^{-1} for 2011 and 2012, respectively

Table 2.6 Grain yield from 2011 and 2012 of continuous maize. Yields displayed for each treatment are from the conventional and strip tillage systems and within each stover management aspect of either stover that was removed or stover that was retained.

Treatment	Stover Removed				Stover Retained			
	Conventional[1, 2, 3]		Strip[1, 2, 3]		Conventional[1, 2, 3]		Strip[1, 2, 3]	
	2011	2012	2011	2012	2011	2012	2011	2012
	Mg ha^{-1}				Mg ha^{-1}			
High Technology	9.8	6.0	8.2	4.8	8.8	5.1	7.5	4.6
-Population	10.0	6.3	9.1	5.9	10.3	6.7	9.4	6.6
-Hybrid Trait	9.0	4.7	8.4	3.4	8.7	4.3	7.9	3.6
-Nitrogen	8.8	5.8	7.7	6.1	8.4	6.3	7.3	6.0
-Fertilizer	7.8	5.7	8.4	5.3	9.0	5.8	7.4	5.4
-Fungicide	9.0	6.6	8.6	6.2	8.3	6.5	7.8	5.7
Traditional	8.1	4.4	7.6	4.3	7.9	5.4	7.1	3.9
+Population	6.3	3.3	6.5	2.4	6.5	3.3	6.6	3.3
+Hybrid Trait	8.7	6.9	8.1	6.5	7.1	7.0	8.1	6.3
+Nitrogen	8.9	4.5	8.2	3.9	8.7	4.6	8.4	4.1
+Fertilizer	8.9	5.0	8.1	3.6	8.6	4.8	8.4	4.7
+Fungicide	7.7	4.3	8.0	4.1	6.5	3.8	7.5	3.8
Column Avg	8.6	5.3	8.1	4.7	8.2	5.3	7.8	4.8

[1] LSD (P<0.10) for Addition/Omission x System within Tillage (compare values within Conventional Tillage OR Strip Tillage treatments) are 0.8 and 1.0 Mg ha^{-1} for 2011 and 2012, respectively

[2] LSD (P<0.10) for System x Tillage (compare values from Addition/Omission within a Rotation x Tillage treatment) are 0.3 and 0.4 Mg ha^{-1} for 2011 and 2012, respectively

[3] LSD (P<0.10) for Addition/Omission x System x Tillage (compare Addition/Omission values averaged across System and Tillage OR between System/Tillage treatments) are 1.1 and 1.3 Mg ha^{-1} for 2011 and 2012, respectively

Table 2.7 Kernel number from 2011 and 2012. Kernel numbers displayed for each treatment are from the soybean-maize rotation and continuous maize and within each tillage system of conventional and strip.

Treatment	Conventional Tillage				Strip Tillage			
	Soybean-Maize		Maize-Maize		Soybean-Maize		Maize-Maize	
	2011	2012	2011	2012	2011	2012	2011	2012
	kernels m^{-2}				kernels m^{-2}			
High Technology	3287	3069	3048	1949	3332	2852	2494	1887
-Population	3017	2913	3228	2505	3146	2890	2809	2341
-Hybrid Trait	3074	2797	2881	1662	3003	2588	2632	1486
-Nitrogen	3053	3011	2860	2431	3174	2893	2361	2256
-Fertilizer	3183	2886	3100	2271	3205	3083	2265	2133
-Fungicide	3313	2884	2812	2483	3173	3020	2521	2183
Traditional	2755	2541	2534	2116	2675	2426	2161	1537
+Population	2713	2469	2229	1410	2738	2382	2213	1331
+Hybrid Trait	2722	2921	2405	2636	2779	2669	2565	2408
+Nitrogen	2940	2613	2767	1963	2653	2530	2453	1610
+Fertilizer	2799	2708	2746	1920	2699	2561	2606	1858
+Fungicide	2715	2396	2245	1583	2781	2425	2356	1570
Column Avg	2964	2767	2738	2077	2947	2693	2453	1883

Table 2.8 Kernel number from 2011 and 2012 of continuous maize. Kernel numbers displayed for each treatment are from the conventional and strip tillage systems and within each stover management aspect of either stover that was removed or stover that was retained.

Treatment	Stover Removed				Stover Retained			
	Conventional		Strip		Conventional		Strip	
	2011	2012	2011	2012	2011	2012	2011	2012
	kernels m^{-2}				kernels m^{-2}			
High Technology	3118	2331	2620	1939	3049	1949	2494	1887
-Population	3175	2442	2621	2216	3228	2505	2809	2341
-Hybrid Trait	2897	1896	2621	1412	2881	1662	2632	1486
-Nitrogen	2925	2341	2545	2487	2860	2431	2361	2256
-Fertilizer	2796	2278	2763	2069	3100	2271	2265	2133
-Fungicide	2971	2476	2624	2355	2812	2483	2521	2183
Traditional	2513	1827	2381	1808	2554	2116	2161	1537
+Population	2226	1432	2120	1044	2229	1410	2213	1331
+Hybrid Trait	2726	2559	2609	2544	2405	2636	2565	2408
+Nitrogen	2790	1839	2548	1665	2767	1963	2453	1610
+Fertilizer	2671	2081	2510	1466	2746	1920	2606	1858
+Fungicide	2474	1861	2380	1689	2245	1583	2355	1570
Column Avg	2774	2114	2529	1891	2740	2077	2453	1883

Table 2.9 Kernel weight from 2011 and 2012. Kernel weights displayed for each treatment are from the soybean-maize rotation and continuous maize and within each tillage system of conventional and strip.

Treatment	Conventional Tillage				Strip Tillage			
	Soybean-Maize		Maize-Maize		Soybean-Maize		Maize-Maize	
	2011	2012	2011	2012	2011	2012	2011	2012
	mg kernel^{-1}				mg kernel^{-1}			
High Technology	289	291	292	258	292	291	300	245
-Population	322	302	318	266	307	302	334	275
-Hybrid Trait	302	282	302	253	306	280	302	239
-Nitrogen	275	292	294	258	281	294	321	263
-Fertilizer	291	297	289	254	297	292	327	254
-Fungicide	295	290	294	261	293	294	314	259
Traditional	299	288	309	253	304	284	333	247
+Population	286	271	293	231	284	273	299	249
+Hybrid Trait	303	303	298	267	304	296	320	260
+Nitrogen	316	283	315	236	315	283	341	250
+Fertilizer	309	287	314	252	319	285	323	255
+Fungicide	300	286	290	241	301	286	321	242
Column Avg	299	289	301	253	300	288	320	253

Table 2.10 Kernel weight from 2011 and 2012 of continuous maize. Kernel weights displayed for each treatment are from the conventional and strip tillage systems and within each stover management aspect of either stover that was removed or stover that was retained.

Treatment	Stover Removed				Stover Retained			
	Conventional		Strip		Conventional		Strip	
	2011	2012	2011	2012	2011	2012	2011	2012
	mg kernel^{-1}				mg kernel^{-1}			
High Technology	316	245	316	248	292	258	300	245
-Population	316	256	349	266	318	266	334	275
-Hybrid Trait	309	244	322	239	302	253	302	239
-Nitrogen	301	249	307	244	294	258	321	263
-Fertilizer	277	249	304	254	289	254	327	254
-Fungicide	305	262	335	260	294	261	314	259
Traditional	323	243	325	238	309	253	333	247
+Population	285	229	309	236	293	231	299	249
+Hybrid Trait	317	268	312	258	298	267	320	260
+Nitrogen	319	245	321	232	315	236	341	250
+Fertilizer	334	241	328	245	314	252	323	255
+Fungicide	313	233	337	244	290	241	321	242
Column Avg	310	247	322	247	301	253	320	253

Table 2.11 Average kernel row number from 2012. Row numbers displayed for each treatment are from the soybean-maize rotation and continuous maize and within each tillage system of conventional and strip.

Treatment	Conventional Tillage		Strip Tillage	
	Soybean-Maize	Maize-Maize	Soybean-Maize	Maize-Maize
	rows cob^{-1}		rows cob^{-1}	
High Technology	13.1	13.2	12.7	11.8
-Population	13.4	13.7	13.0	13.0
-Hybrid Trait	13.1	12.9	13.1	11.7
-Nitrogen	12.7	12.5	12.8	12.0
-Fertilizer	12.8	12.9	12.9	12.7
-Fungicide	12.7	12.5	12.6	11.9
Traditional	13.0	12.4	13.2	12.6
+Population	12.8	11.1	13.2	11.7
+Hybrid Trait	13.0	12.3	12.7	12.3
+Nitrogen	13.1	12.8	13.3	11.9
+Fertilizer	13.4	13.0	13.4	12.7
+Fungicide	13.3	11.8	13.3	12.3
Column Avg	13.0	12.6	13.0	12.2
Tillage Avg	12.8		12.6	

Table 2.12 Average kernel row number from 2012 of continuous maize. Row numbers displayed for each treatment are from the conventional and strip tillage systems and within each stover management aspect of either stover that was removed or stover that was retained.

Treatment	Stover Removed		Stover Retained	
	Conventional	Strip	Conventional	Strip
	rows cob^{-1}		rows cob^{-1}	
High Technology	12.6	12.8	13.2	11.8
-Population	13.3	12.8	13.7	13.0
-Hybrid Trait	12.5	11.8	12.9	11.7
-Nitrogen	12.3	12.7	12.5	12.0
-Fertilizer	12.7	11.9	12.9	12.7
-Fungicide	12.5	12.1	12.5	11.9
Traditional	13.3	13.6	12.4	12.6
+Population	12.2	11.1	11.0	11.7
+Hybrid Trait	13.2	13.2	12.3	12.3
+Nitrogen	13.1	12.7	12.8	11.9
+Fertilizer	12.2	12.0	13.0	12.7
+Fungicide	12.5	12.2	11.8	12.3
Column Avg	12.7	12.4	12.6	12.2
Tillage Avg	12.6		12.4	

Table 2.13 Root mass sampled after harvest from 2011 and 2012. Masses displayed for each treatment are from the soybean-maize rotation and continuous maize and within each tillage system of conventional and strip.

Treatment	Conventional Tillage				Strip Tillage			
	Soybean-Maize		Maize-Maize		Soybean-Maize		Maize-Maize	
	2011	2012	2011	2012	2011	2012	2011	2012
	g plant^{-1}				g plant^{-1}			
High Technology	15.5	9.9	16.9	13.1	12.6	10.1	9.1	11.9
-Population	21.4	13.9	35.4	20.1	17.7	12.9	13.9	15.1
-Hybrid Trait	15.3	13.6	19.3	14.7	13.0	10.2	16.1	11.8
-Nitrogen	15.9	11.0	25.4	11.5	13.0	11.4	8.9	10.1
-Fertilizer	13.7	11.0	16.3	11.7	10.8	11.2	12.3	12.8
-Fungicide	15.7	13.2	17.6	13.7	14.9	8.1	15.5	11.9
Traditional	20.0	14.3	20.3	19.2	19.6	12.2	27.6	10.8
+Population	13.4	11.8	11.9	16.8	11.6	11.3	16.2	11.0
+Hybrid Trait	18.9	14.2	16.7	16.5	17.4	12.6	17.0	13.8
+Nitrogen	18.2	14.4	18.1	13.8	17.4	14.8	23.7	15.6
+Fertilizer	27.3	11.8	22.1	17.8	16.6	11.4	22.3	15.3
+Fungicide	18.9	15.0	20.1	15.1	17.0	12.6	19.3	14.7
Column Avg	17.9	12.8	20.0	15.3	15.1	11.6	16.8	12.9

Table 2.14 Root mass sampled after R6 from 2011 and 2012 of continuous maize. Masses displayed for each treatment are from the conventional and strip tillage systems and within each stover management aspect of either stover that was removed or stover that was retained.

Treatment	Stover Removed				Stover Retained			
	Conventional		Strip		Conventional		Strip	
	2011	2012	2011	2012	2011	2012	2011	2012
	g plant^{-1}				g plant^{-1}			
High Technology	18.6	11.3	11.7	11.7	16.9	13.1	9.1	11.9
-Population	26.1	12.4	20.4	15.4	35.4	20.1	13.9	15.1
-Hybrid Trait	15.9	10.7	14.2	13.7	19.3	14.7	16.1	11.8
-Nitrogen	19.9	10.7	15.5	13.4	25.4	11.5	8.9	10.1
-Fertilizer	13.8	11.9	12.5	11.6	16.3	11.7	12.3	12.8
-Fungicide	16.4	10.3	10.6	13.3	17.6	13.7	15.5	11.9
Traditional	28.1	15.4	21.1	12.2	20.3	19.2	27.6	10.8
+Population	11.3	10.5	13.8	12.4	11.9	16.8	16.2	11.0
+Hybrid Trait	24.4	15.2	16.0	13.8	16.7	16.5	17.0	13.8
+Nitrogen	23.8	13.4	22.3	12.1	18.1	13.8	23.7	15.6
+Fertilizer	37.1	15.4	21.3	12.1	22.1	17.8	22.3	15.3
+Fungicide	22.4	12.7	19.5	13.0	20.1	15.1	19.3	14.7
Column Avg	21.5	12.5	16.6	12.9	20.0	15.3	16.8	12.9

FIGURES

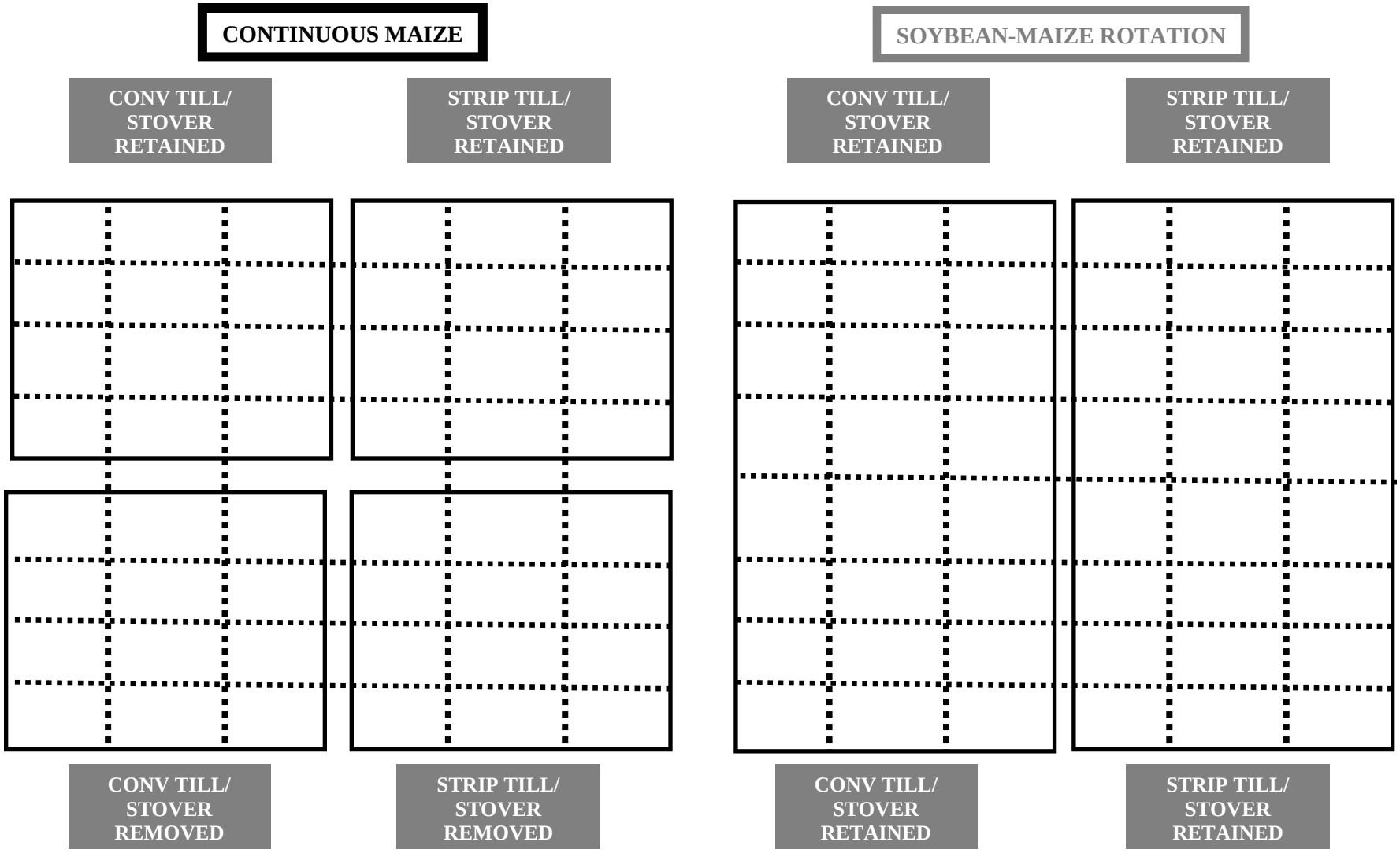


Figure 2.1 One of four replications of the experimental design for the 2011 and 2012 study. The 12 treatments are repeated in each quarter-plot. A check plot of zero nitrogen (not shown) divided the top and bottom halves of the experiment.

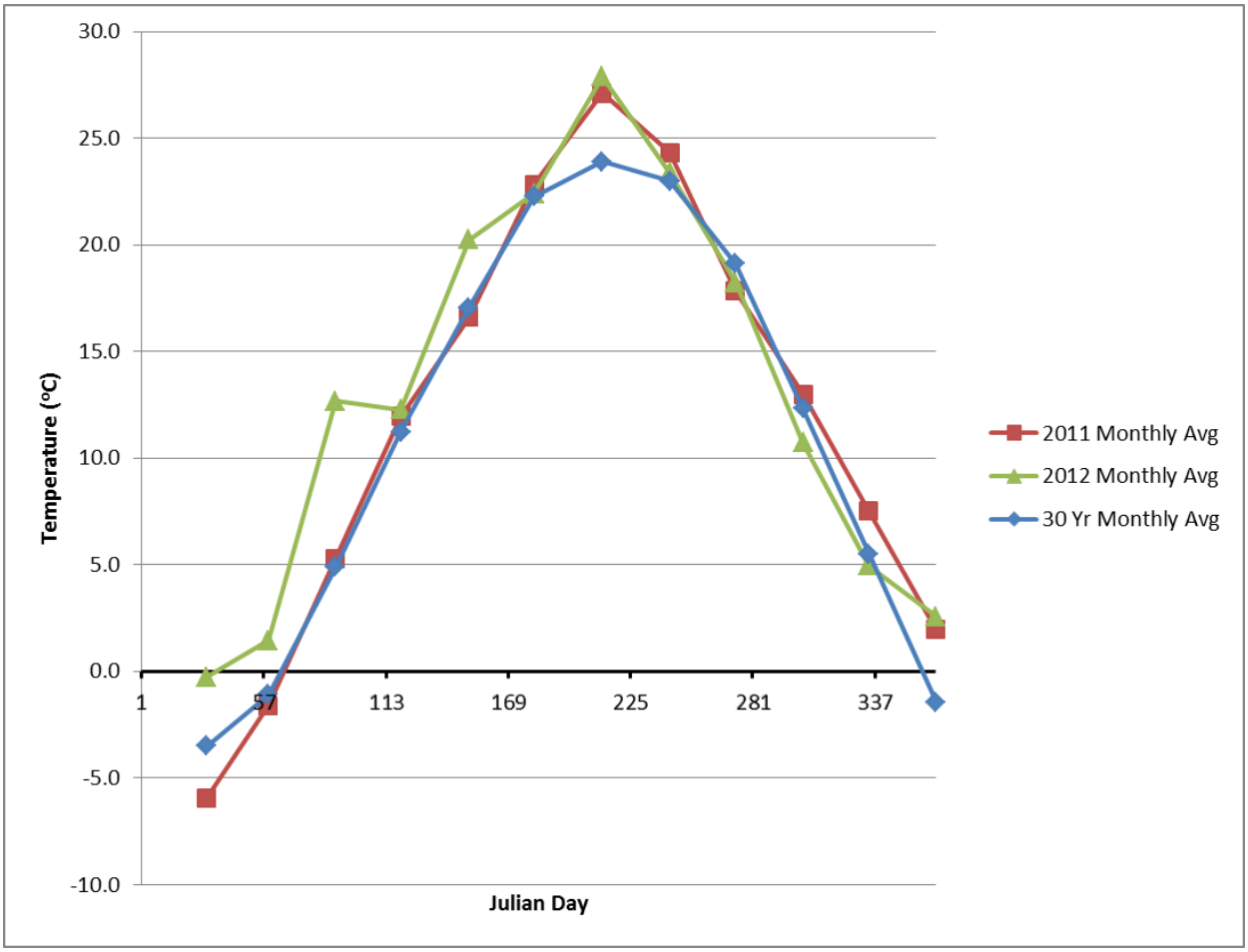


Figure 2.2 Monthly average temperatures of 2011, 2012, and the 30 year average. In 2011, planting, flowering, and R6 were June 5, August 9, and September 16, respectively (Julian Days 156, 221, and 259). The average temperature between June 1 and September 31 was 21.72ºC (21.1ºC 30 year average). In 2012, planting, flowering, and R6 were April 25, July 8, and August 21, respectively (Julian Days 115, 189, and 233). The average temperature between April 1 and August 31 was 19.8ºC (17.1ºC 30 year average).

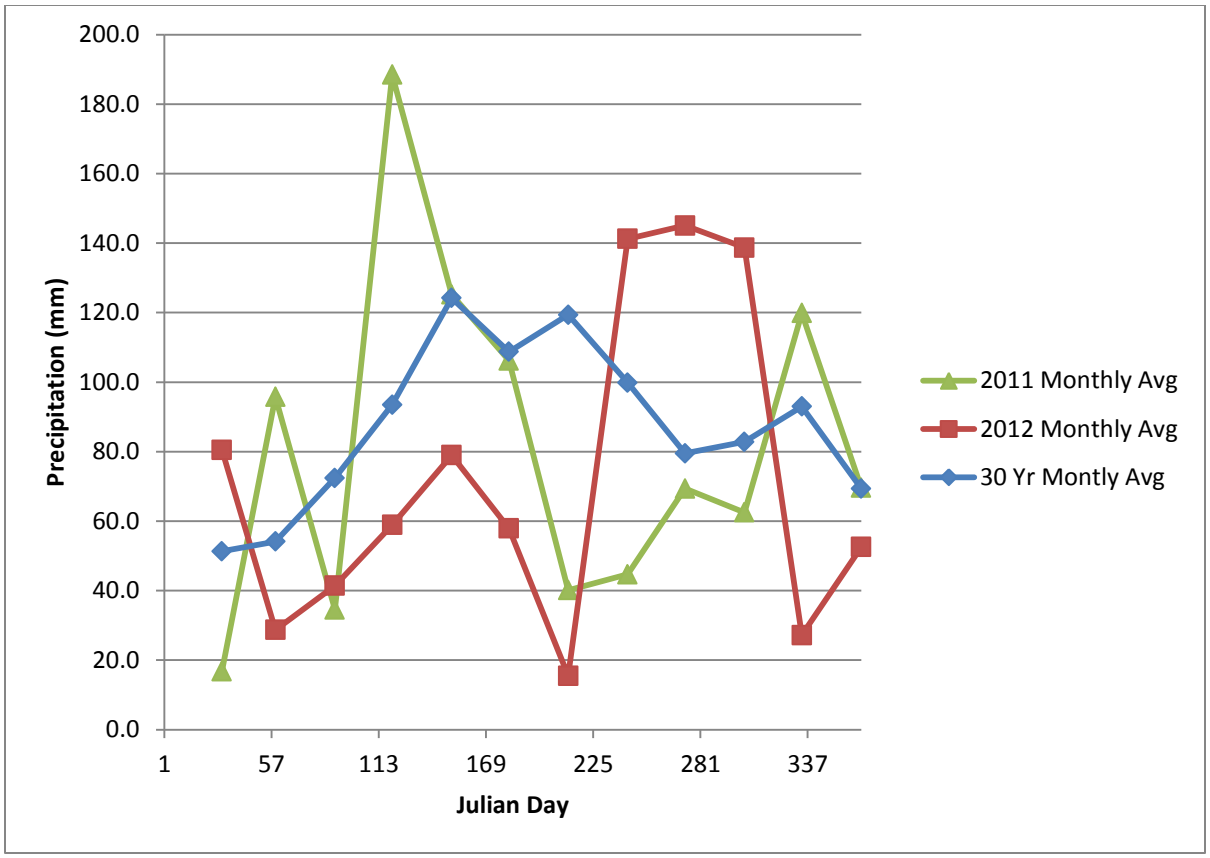


Figure 2.3 Monthly precipitation of 2011, 2012, and the 30 year average. In 2011, planting, flowering, and R6 were June 5, August 9, and September 16, respectively (Julian Days 156, 221, and 259). In 2012, planting, flowering, and R6 were April 25, July 8, and August 21, respectively (Julian Days 115, 189, and 233).

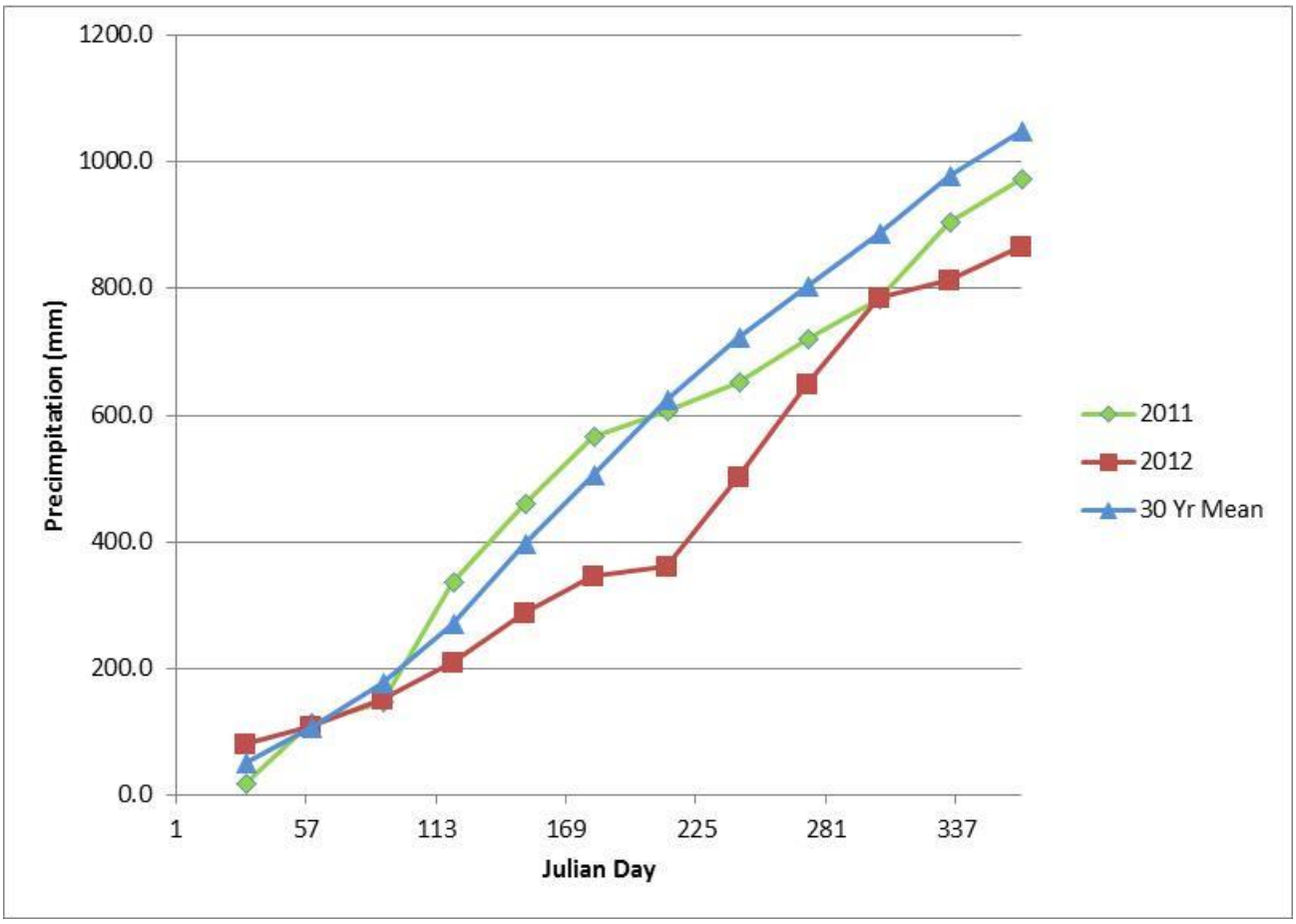


Figure 2.4 Cumulative precipitation by month for 2011, 2012, and the 30 year mean. In 2011, planting, flowering, and R6 were June 5, August 9, and September 16, respectively (Julian Days 156, 221, and 259). In 2012, planting, flowering, and R6 were April 25, July 8, and August 21, respectively (Julian Days 115, 189, and 233).



Figure 2.5 Starting with the top left picture and rotating clock-wise, pictured are the high technology, high technology with omitted high plant density, traditional, and traditional with high plant density added treatments.

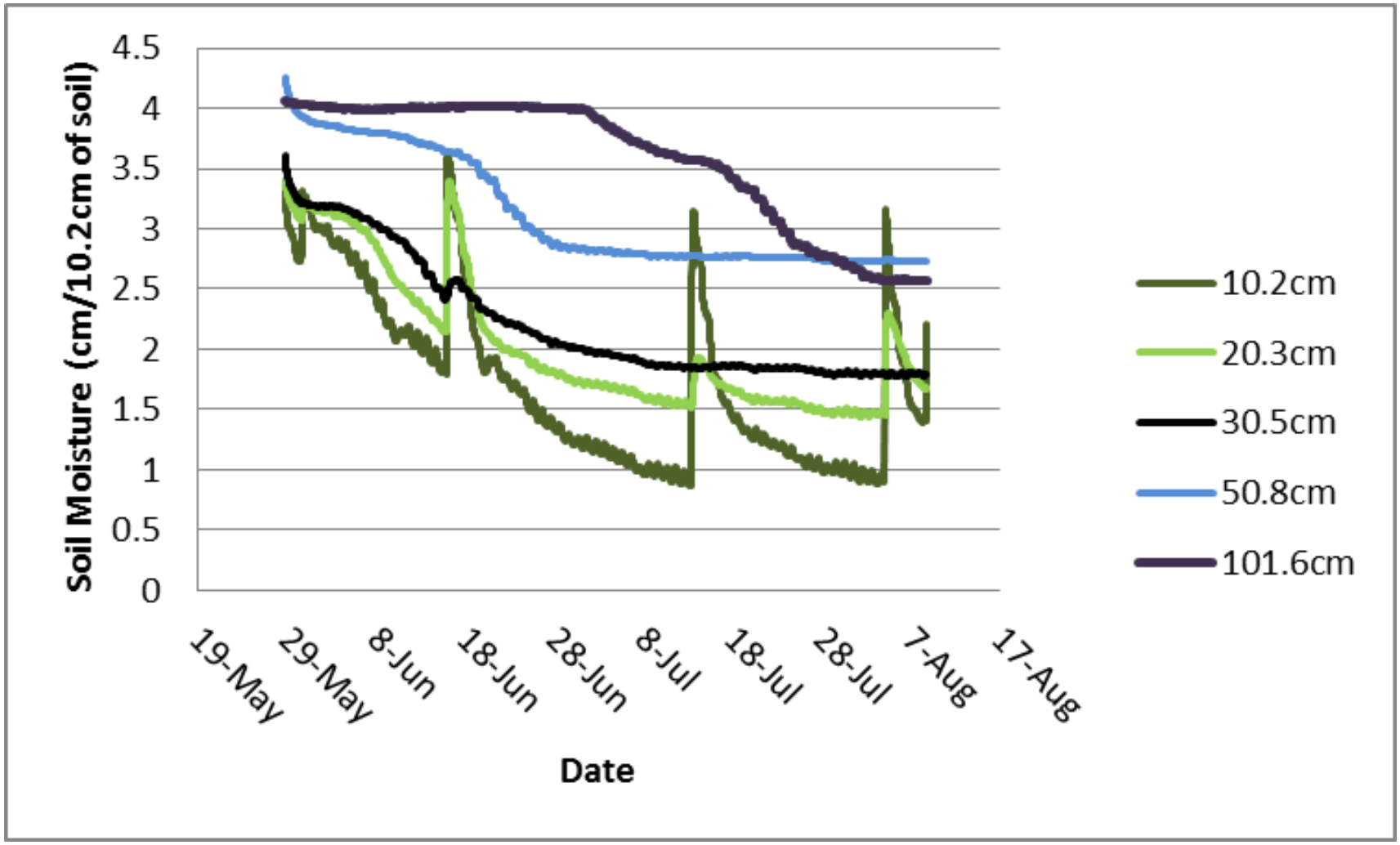


Figure 2.6 Soil moisture probe readings from one plot in a soybean-maize rotation that was conventionally tilled.

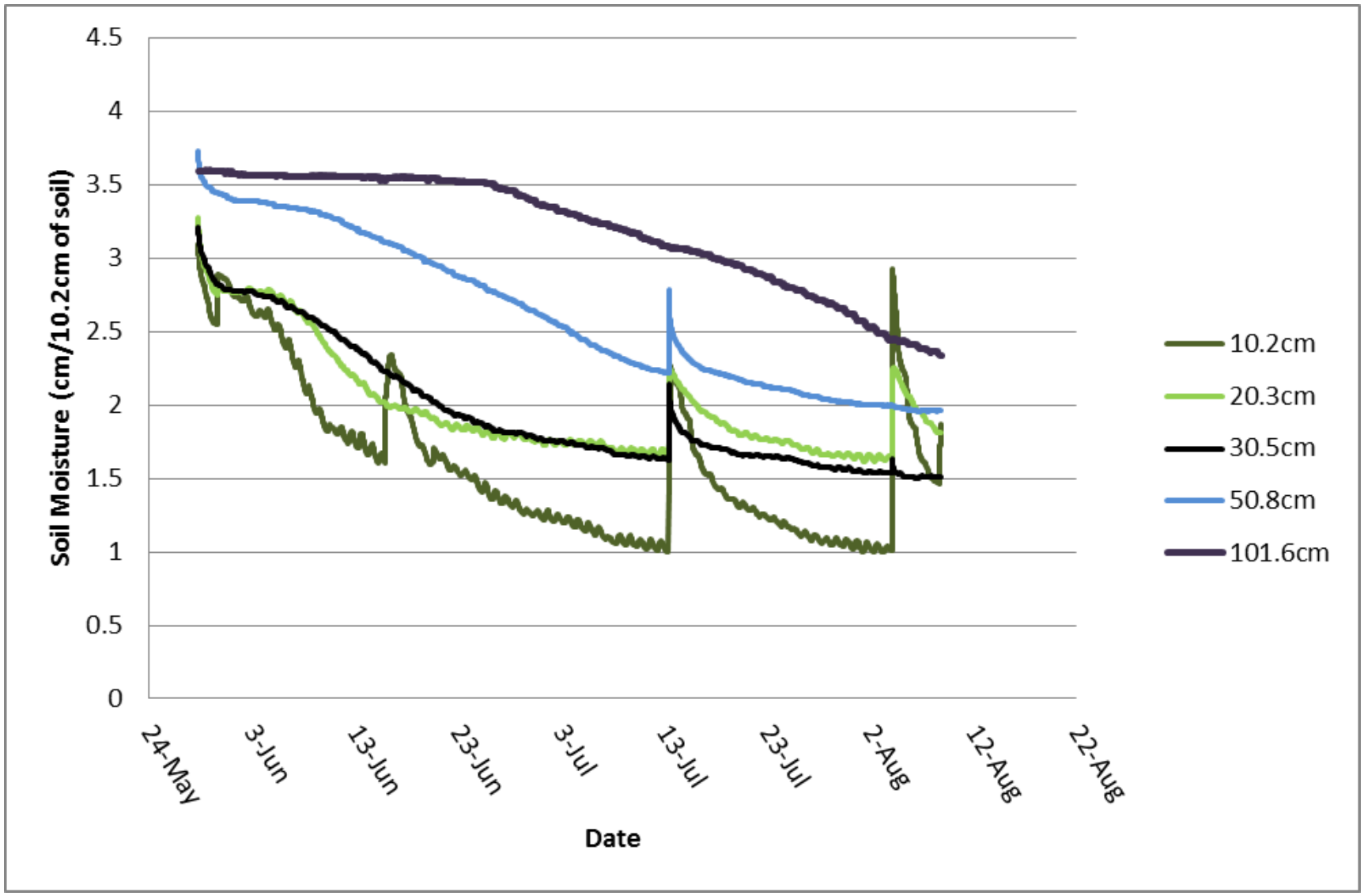


Figure 2.7 Soil moisture probe readings from one plot in a continuous maize system that was conventionally tilled.

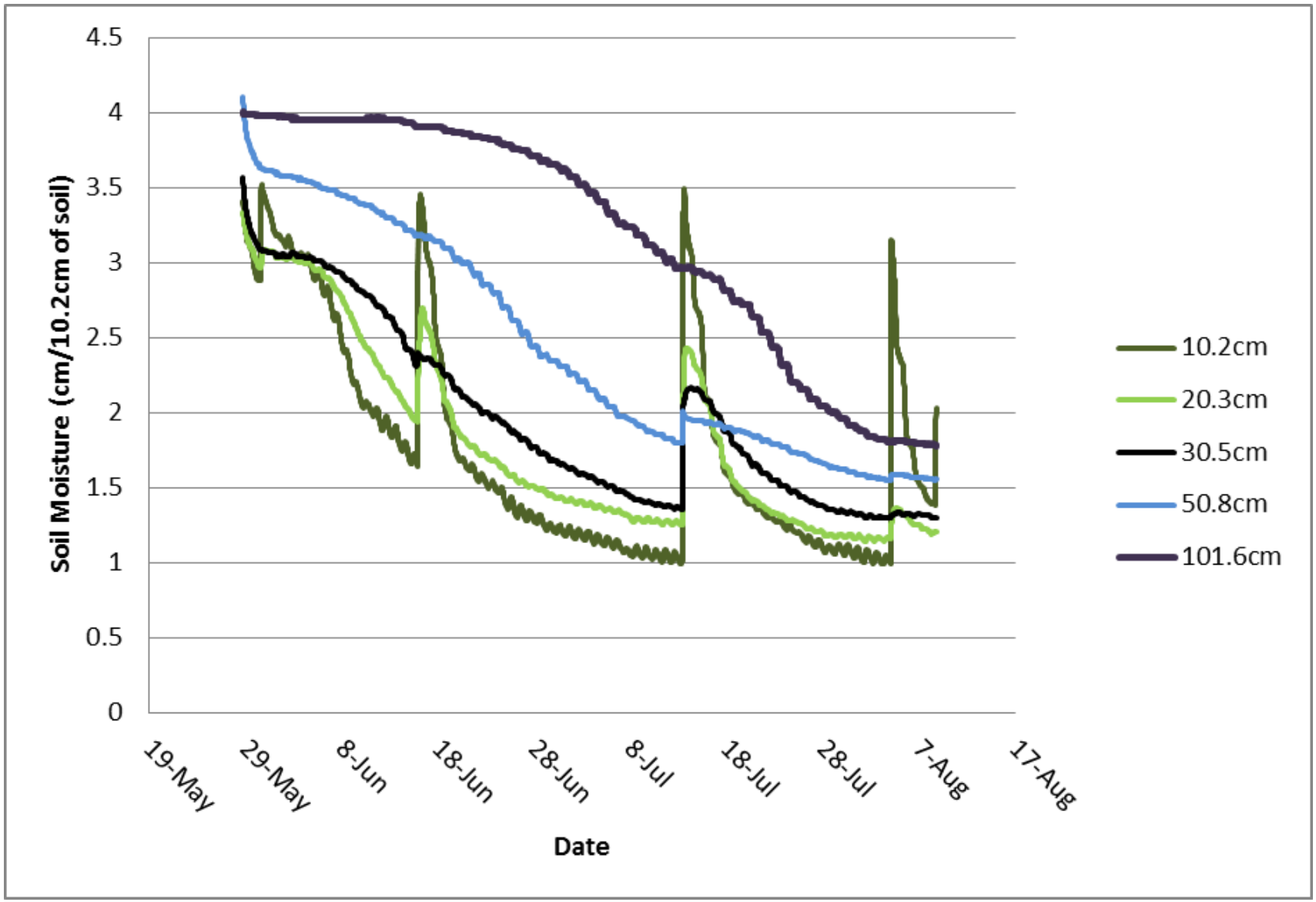


Figure 2.8 Soil moisture probe readings from one plot in a soybean-maize rotation that was under strip tillage.

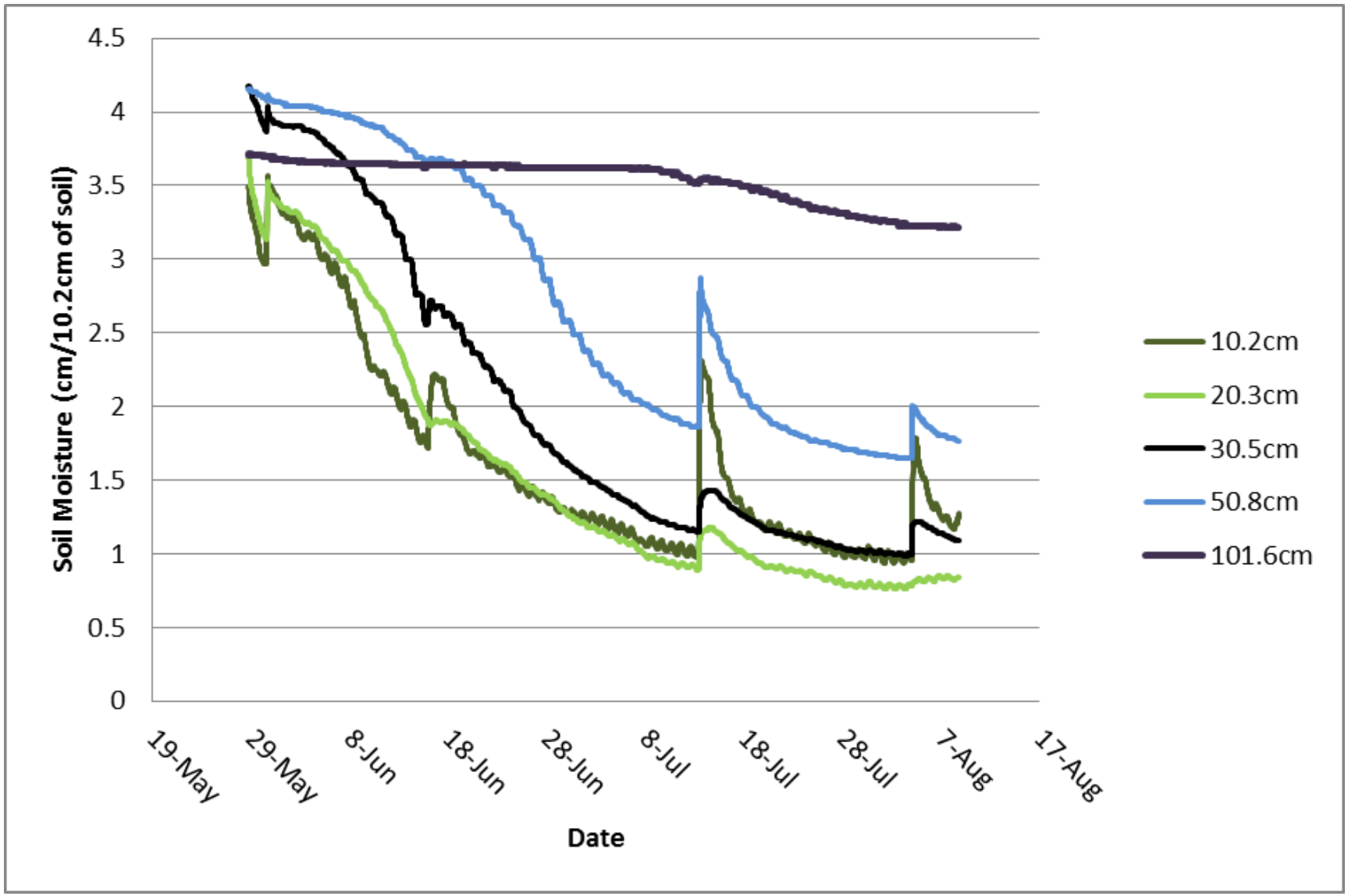


Figure 2.9 Soil moisture probe readings from one plot in a continuous maize system that was under strip tillage.