CORN AND SOYBEAN GENOTYPES WITH CONTRASTING ROOT SYSTEM: RESPONSE TO FERTILIZER PLACEMENT AND TILLAGE

by

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Abstract

The effect of tillage on crop yield, early growth, and soil nutrient stratification can be influenced by fertilizer placement. In addition, deeper root systems can enhance the crop ability to uptake water and nutrients. A thorough understanding of how these factors interact can result in increased grain yields and profitability for the producer. Three studies were completed to describe and evaluate different aspects of crop root system and response to fertilizer placement and tillage. The objective of the first study was to characterize the root system of two genotypes of corn (*Zea mays*) and soybean (*Glycine max* (L.) Merr.) using image analysis in the greenhouse and in the field, as well as evaluate dry weight accumulation and nutrient uptake patterns by shoot and root plant parts for both crops. Two different genotypes of each crop were sampled during the growing season to access root characteristics such as biomass, length, surface area, average diameter and volume. Significant differences were found in corn where the P1151 AM hybrid had greater root length, surface area and volume than the P1105 AM hybrid. In soybean, the differences were found in nutrient uptake with overall greater nutrient uptake values for the poor drainage variety (PD) compared to the good drainage variety (GD). The objective of the second study was to evaluate the effect of fertilizer placement and tillage system on corn with different genotypes. Three fertilizer treatments were combined with two different corn genotypes selected based on contrasting root systems and two different tillage systems. The three fertilizer placements were sub-surface band, broadcast, and control. The two hybrids of corn used were a P1151 AM hybrid and P1105 AM hybrid. The two tillage systems were no-till (NT) and strip-till (ST). Corn hybrids showed different response in root biomass but did not show a consistent response in other characteristics evaluated. Broadcast and sub-surface band increased nutrient uptake and grain yields over the control but were not significantly different from each other.

Tillage showed no difference in corn response. The objective of the third study was to evaluate the effect of fertilizer placement and tillage system on contrasting soybean genotypes. Three fertilizer treatments were combined with two different genotypes selected based on contrasting root systems and two different tillage operations. The three fertilizer placements were sub-surface band, broadcast, and control. The two varieties of soybean used were one recommended for poor drainage (PD) and one recommended for good drainage (GD). The two tillage operations were NT and ST. Soybean root biomass differences were observed by varieties. Sub-surface band treatment favored early soybean growth, biomass and P uptake at the V3 growth stage, but it did not turn into yield increase. Soybean grain yields did not respond to fertilization in this study. Yield was affected significantly by variety selection and response varies by site-year.

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Dedication

I dedicate this thesis to my family. When I was in doubt about coming for my Master's Program, they encourage me saying that this was the opportunity of my life.

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Chapter 1 - General Introduction and Thesis Organization

Research has shown that conservation tillage contribute to reduce soil erosion and nutrient loss by runoff (McIsaac et al., 1991). Conservation tillage can also contribute to increase grain yield in arid regions with enhanced water storage in the soil (Tyler and Overton, 1982; Webber III et al., 1987). However, some conditions associated with conservation tillage can limit nutrient availability, including low soil temperature in the spring that can reduce root growth (Havlin, 2014) and nutrient uptake (Mackay and Barber, 1985). In Kansas, both no-till (NT) and strip-till (ST) are increasing in popularity especially because of the potential for increased water storage capacity with these systems. No-till contributes to P and potassium (K) stratification due to limits in the vertical movement of these nutrients by minimal mixing of soil and accumulation of crop residue in the surface (Robbins, 1991) (Mallarino and Borges, 2006). Strip-till consists of disturbing only the portion of the soil that is to contain the seed row. Strip-till helps to increase soil temperature and promote root growth and therefore contact with the fertilizer in the soil. According to Al-Kaisi et al. (2002) ST increases soil temperature 1° C in the top 5 cm of soil when compared to NT resulting in faster soil drying in the spring.

The effects of tillage on crop yield, early growth, and nutrient stratification can be greatly influenced by fertilizer placement. A thorough understanding of how these factors interact with other factors such as plant root growth is necessary to help increased nutrient use efficiency in the field. Fertilizer placement can be particularly critical under reduced tillage operations with high amount of crop residue in the soil surface. Moreover, it can change the amount of soil in contact with roots improving the efficiency of plant nutrient uptake and, consequently, increasing crop yield. According to Mengel (1995), nutrient uptake can be limited by the rate at which nutrients can be moved into the root. Results found by Barber (1974) concluded that increasing the root-fertilizer contact will increase the overall P supply to the plant.

Broadcast application is considered of lower cost and efficient when soil has moderate to high levels of P (Mahler, 1985). For a NT system a broadcast application is not incorporated, and therefore generates stratification due to limited movement of P and K in the soil profile. Plant residue decomposition releasing nutrients in the soil surface also contribute to increase stratification (Mackay et al., 1987). Band applications, such as deep band, are alternatives to broadcast applications. Deep band fertilizer is usually applied 10-15 centimeters below the surface where plant roots can potentially access the fertilizer (Troeh and Thompson, 2005). A banded fertilization will provide an area of high nutrient availability when the root system is small and the demand per unit of root length is high. On the other hand, broadcast application provides an opportunity for a large portion of the root system to come in contact with the nutrient as the root system expands and reaches the near-surface soil layers. Randall et al. (2001a) suggest that band applications create zones of high P concentration in the soil and potentially maintaining higher levels of P in solution, and therefore increasing plant P uptake. A review comparing deep band versus broadcast by Boomsma et al. (2007) reported a benefit from deep banding of P and K under dry soil conditions at the surface, low soil temperature, soil compaction, and when soil test P and K levels are low. However, results from studies by Bordoli and Mallarino (1998) showed no differences among broadcast, deep band, or planter-banded P placements across sites or soil conditions. According to Timmons et al. (1984), deep band application produced greater corn (*Zea mays*) yields in NT system than other placements under dry conditions and with low soil test P. On the other hand, Farber and Fixen (1986) suggested that deep band may not alleviate corn early nutrient deficiency in conservation tillage systems.

Furthermore, Mengel et al. (1988) found that various pre-plant placement methods, which included deep band, showed similar corn yield response under NT system. For soybean (*Glycine max* (L.) Merr.), broadcast P application outperform band P placement under a conventional tillage (Ham et al., 1973). Another study conducted by Ham and Caldwell (Ham and Caldwell, 1978) testing different P placements showed greater soybean seed yields with addition of P, but no difference between broadcast and band applications. Kimmel et al. (2001) concluded that total P losses were found to be greater when P was broadcasted.

Different crops can also show different response to P fertilization. According to deMooy et al. (1973), corn has been found to be significantly more responsive to P fertilization than soybean. Besides, crops with contrasting root systems may differ in the ability to extract water and nutrients. Results from previous studies showed significant differences in nutrient concentration and uptake among corn hybrids with different genetic backgrounds (Gordon et al., 1998). However, studies evaluating soybean root and differences in P response are scarce. It is possible that different rooting systems can show a significant interaction with fertilizer application method. The following three chapters evaluate possible differences in root characteristics based on genotype of corn and soybean, and the response of those crops to different fertilizer placements associated with two conservation tillage systems.

Thesis Organization

This thesis is presented as a series of five chapters. The first chapter is a general overview of the thesis research. Chapters 2 through 4 are written in a manuscript format and intended to be published. The titles of chapter 2, 3 and 4 are: “Root characterization of two different corn and soybean genotypes”, “Fertilizer placement and tillage interaction in corn production using different genotypes” and “Soybean response to no-till and strip-till with surface and subsurface fertilization using different varieties". The final chapter (chapter 5) provides general conclusions for the thesis research.

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Chapter 2 - Root Characterization and Nutrient Uptake of Two Corn and Soybean Genotypes

Abstract

Crops with a vigorous root system can potentially explore more soil volume and capture more available water and nutrients. The objective of this study was to evaluate the root system of two genotypes of corn (*Zea mays*) and soybean (*Glycine max* (L.) Merr.) using image analysis. The two commercial hybrids of corn were Pioneer P1151 AM (Pioneer Hi-Bred, Johnston, IA) described as a drought-prone environment suitable, and P1105 AM, a conventional hybrid. The two varieties of soybeans used were Pioneer P94Y40, described as highly suitable for poor drained soils and P44T63R recommended for soils with good drainage. The experimental design was a completely randomized design with three replications. The study was conducted in large columns using greenhouse growing media. A blend of macro and micronutrients was mixed with the growing media at the same rate for all columns and irrigation was provided daily. Temperature was set for day and night and photoperiod was constant. Plant shoots and roots samples were collected at the V6, V10 and VT growth stage for corn and V3 and R3 growth stage for soybean. Roots were scanned and processed with the WinRHIZO Pro image analysis system (Regent Instruments, Inc., Quebec City, QC, Canada) software for root length, surface area, diameter and root volume. Shoots and roots were dried and weighted for total dry weight biomass. Samples were ground and analyzed for total nutrient content (N, P, K, S, Mn and Zn). An additional trial was set in the field, in two locations, where the same hybrids were evaluated with no treatment effects. In the greenhouse study, the P1151 AM corn hybrid showed greater shoot biomass for all sampling times. Values for root length and volume showed at a significant

interaction between hybrid and growth stage, with greater values for the P1151 AM hybrid at VT growth stage. No statistical differences were found for the parameters evaluated in soybean. Nevertheless, nutrient uptake trends were observed with higher values for P94Y40 at R3 growth stage. In the field, the P1151 AM hybrid showed greater root length in Ottawa site. In soybean, the P44T63R variety showed increased root surface area and volume at Ottawa, but less root volume at Scandia compared to the P94Y40 variety. This study showed that root system in corn varies by genotype and these differences can vary throughout the different growth stages. This can have important implications for management at the field level, including interactions with soils, tillage and fertilizer placement.

Introduction

Approximately 80% of the world agriculture is rainfed, and based on projections for future precipitation there may be adverse impacts on crop production (Bates et al., 2008). Current breeding programs are taking in consideration the agriculture expansion over the globe, and that includes areas where rainfall and soil fertility are a limitation (Lynch, 2007). Invest in root growth can be a strategy for the plant to support such adverse conditions in the future. According to Duvick (2005), corn hybrids with greater root biomass are likely to be more tolerant to stresses such as drought. In addition, a greater root system can be beneficial to enhance nutrient uptake in environments with low soil test levels for several nutrients. Researchers develop soybean varieties with enhanced root traits for better adaptation to soils with low testing P levels (Yan et al., 2006).

Nutrient acquisition is highly dependent of the root systems, more specifically to characteristics that can identify the root architecture of the plant (Gregory, 2011). Results from previous studies showed significant differences in plant nutrient concentration and uptake among corn hybrids with different genetic backgrounds (Gordon et al., 1998). This suggests that possible differences in root systems among corn hybrids can contribute to differences in nutrient uptake from the soil and from fertilizer application. Root growth is particularly important for the uptake of immobile nutrients such as P and K (Lynch, 2007). Furthermore, previous studies showed a direct relation between root biomass and P and K uptake in wheat (Ehdaie et al., 2010). To increase nutrient uptake roots must reach the soil volume where the nutrient is located, and the nutrient must be able to move into the root (Ober and Parry, 2011).The ability to establish a deep root system early in the season can help plants to increase nutrient uptake. Previous studies evaluated drought tolerant corn hybrids for root morphology, and results showed greater values for both total root length and shoot dry mass ratio when compared to conventional hybrids (Magalhães et al., 2012). Also, drought tolerant hybrids showed greater values for specific root length. Studies evaluating genotypic variation in root systems of soybean are currently very limited.

Root analysis can be a time consuming activity, however root characteristics of length, surface area, diameter and branching patterns can rapidly be assessed with image analysis systems. According to Bouma et al. (2000) and Himmelbauer et al. (2004), root length and root-diameter distribution measurements provided by the WinRHIZO software (Regent Instruments, Inc., Quebec City, QC, Canada) are accurate when the correct scanning protocol is followed. Therefore, computer-assisted root imaging is an opportunity to facilitate the analysis process and improve accuracy.

The objectives of this study were to (i) characterize the root system of two genotypes of corn and soybean using image analysis in the greenhouse and in the field, and (ii) evaluate dry weight accumulation and nutrient uptake patterns by shoot and root plant parts under controlled greenhouse environment.

Materials and Methods

Greenhouse Study

The study was conducted from March - May 2015 under a controlled greenhouse environment. Large polyvinyl chloride (PVC) columns of growing media were used to grow the corn and soybean. Columns were 100 cm high and 20 cm in diameter to allow the entire root harvest with minimal damage. Two genotypes of corn and soybean were seeded the same day with three seeds per column and thinned to one seedling after germination. Each column received 18 kg of Turface Athletics ™ as a growing media. A controlled release fertilizer (14-14-14, N-P_2O_5-K_2O; Osmocote Classic, Everris NA Inc., Dublin, OH, USA) and Micromax (Everris NA Inc., Dublin, OH, USA) (6% Ca, 3% Mg, 12% S, 0.1% B, 1% Cu, 17% Fe, 2.5% Mn, 0.05% Mo and 1% Zn) were thoroughly mixed in each column at the rates of 155 and 37.2 g, respectively. The two corn hybrids selected for the study were Pioneer P1151 AM AquaMax®, considered suitable to drought-prone environments, and Pioneer P1105 AM, a conventional hybrid. The two hybrids of corn selected for this study are 111 days to reach grain maturity. The two varieties of soybeans used for the study were Pioneer 94Y40, considered highly suitable in soil with poor drainage, and Pioneer P44T63R recommended for soils with good drainage conditions. The two varieties of soybean belong to the maturity group 44. The two genotypes of corn and soybean were selected based on possible differences in root characteristics. Drip irrigation provided 5 L of water per day for each column during the study; temperature was set to be 18.3° C at night and 26.7° C during the day; and with a photoperiod of 14 hours.

Whole corn plants were sampled at the V6, V10, and VT growth stages (Abendroth et al., 2011) and divided into shoot and roots. Soybean plants were sampled at the V3 and R3 growth stage (Pedersen, 2003) and divided into shoot and roots. Root samples were cleaned using tap water to separate the growing media and scanned using a root scanner (Epson Perfection; Epson, Long Beach, CA) V700 with 400 dpi resolution. Roots were sliced into 25 cm long portions and placed on a transparent acrylic tray with 20 cm wide and 30 cm length in a thin layer of water (6-8 mm). Images were processed using the software WinRHIZO Pro image analysis system (Regent Instruments, Inc., Quebec City, QC, Canada) to estimate the total root length, surface area, average root diameter, and total root volume. The software works by coloring the imaged roots according to its draw and coding based on diameter. Based on the root diameter distribution and root length, the software calculates the volume and area (Regent Instruments, 1991). After imaging, roots and shoots collected were dried at 65°C for six days and weighted to get the total dry weight. The root/shoot ratio was calculated as the ratio of root dry weight to shoot dry weight. The roots and shoots were ground and analyzed for total nutrient content. Total N, P and K were analyzed by the sulfuric peroxide digest as described by Lindner and Harley (1942). Nitrogen digest was analyzed by an indophenol blue colorimetric procedure using the Rapid Flow Analyzer (Model RFA-300; Alpkem Corporation, Clackamas, Oregon, USA). Total P and K were determined using inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia). Analysis of SO_4, Mn and Zn were done using perchloric digest with inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia) following the method of Gieseking et al (1935).

The experimental design was a completely randomized design with three replications. Analysis of variance was completed using the PROC GLIMMIX procedure in SAS 9.2 (SAS, 2011). Mean separation was completed using the LINES option in PROC GLIMMIX at a significant level of $p \leq 0.05$.

Field Study

Two corn and soybean sites were established in 2015. One site was located in Ottawa, Kansas (38°32´19″N; 95°15´11″W) on a Woodsen silt loam soil (fine, smectitic, thermic Abruptic Argiaquolls) with poor drainage conditions. Another site was in Scandia, Kansas (39°46´23″N; 97°47´19″W) on a Crete silt loam soil (fine, smectitic, mesic Pachic Argiustolls) with good drainage conditions. Corn in Ottawa was planted on April 7th 2015 and soybean on June 10th 2015. The average precipitation for the corn growing season (from April to September) in Ottawa was 653 mm with an average temperature of 21.7°C. For the soybean growing season (from June to October), the average precipitation and temperature was 276 mm and 23.3°C, respectively. Corn in Scandia was planted on April 30th 2015 and soybean on June 9th 2015. The average precipitation for the corn growing season (from April to October) at Scandia was 648 mm with an average temperature of 20.7°C. For the soybean growing season (from June to October), the average precipitation and temperature was 467 mm and 21.5°C, respectively. The corn and soybean genotypes used for the field study were the same as for the greenhouse study.

One composite soil sample of 20 cores was collected for each block. Extractable P was determined by the Mehlich-3 method (Frank, 1998) and extracts analyzed using inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia). Extractable K was determined by the ammonium acetate method (Warncke, 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson, 1998), and soil organic matter (OM) was determined by Walkley–Black method (Combs, 1998). At the Ottawa site for corn soil test P was 24 mg kg^{-1}, soil test K 151 mg kg^{-1}, pH of 6.7 and organic matter 36 g kg^{-1}; for soybean soil test P was 21 mg kg^{-1}, soil test K 124 mg kg^{-1}, pH of 6.6 and organic matter 26 g kg^{-1}. At Scandia site for corn soil test P was 11 mg kg^{-1}, soil test K 450 mg kg^{-1}, pH of 6.4 and organic matter 23 g kg^{-1}; for soybean soil test P was 11 mg kg^{-1}, soil test K 481 mg kg^{-1}, pH of 6.6 and organic matter 31 g kg^{-1} respectively for soybean.

Corn and soybean were grown under no-till conditions in the field, with no fertilizer applied. Root systems were evaluated as affected by genotype only. Ten corn root samples for each genotype were dug from the soil using a shovel at the V6, V10, and VT (Abendroth et al., 2011). Soybean root samples were collected at the V3 and R3 growth stage (Pedersen, 2003). Root samples were collected at 20 cm deep and 40 cm diameter around the stem giving the total root biomass per volume of soil. Soil was removed by hand in the field as much as possible with minimum root loss. Root samples were cleaned in water to separate from the remaining soil material. Root scanning process for the field samples were the same as those for the greenhouse samples.

Results and Discussion

Corn

Analysis of variance showed a significant genotype by growth stage interactions for some parameters, as well as significant main effect of genotype and growth stage (Table 2.1). Root length was found to be 13%, 33% and 30% greater for the P1151 AM hybrid at the V6, V10 and VT growth stages, respectively, (Table 2.2). Root volume showed greater values for P1151 AM hybrid only at the VT growth stage when compared to the P1105 AM hybrid, but no difference in earlier growth stages between the two hybrids (Table 2.2). Root surface area showed a trend of greater values at all growth stages for the P1151 AM hybrid, but no significant differences were found for this parameter in the interaction genotype by growth stage. The P1151 AM hybrid probably enhances root growth especially towards the end of the vegetative stage when corn is most susceptible to stress (VT to R1 growth stages), when pollination occurs (Shaw, 1977). Bigger root systems might have the ability to access water deep in the soils (Hammer et al., 2009) as well as nutrients with an increased area of root soil contact (Ryser, 2006).

Root average diameter was greater at V6 growth stage and lower at the V10 (Table 2.2). Root length, surface area and root volume increased with the corn development during the growing season (Table 2.2).

Root length, surface area, and root volume were greater for the P1151 AM hybrid (Table 2.2). However, there was no significant difference between hybrids for root average diameter (Table 2.2).

The interaction of genotype by growth stage showed no significant results for root and shoot biomass accumulation (Table 2.2). The P1151 AM hybrid showed greater dry weight biomass for shoot compared to the P1105 AM hybrid (Table 2.2). As the plant grows, shoot and root plant parts increase in total biomass (Table 2.2). Previous studies show that root dry weight increase until the VT growth stage and at a greater rate after the V8 growth stage (Yu et al., 2015).

Corn root/shoot interaction of genotype by growth stage was significant only at V6 growth stage (Table 2.2). At the V6 stage, the P1105 AM hybrid had a 47% greater root/shoot ratio, indicating greater values of root biomass and lower values of shoot dry weight. Corn root/shoot ratio decreased with plant growth indicating greater shoot growth rate than roots later in the growing season (Table 2.2). The P1151 AM hybrid showed lower root/shoot ratio due to increased shoot growth compared to the P1105 AM hybrid (Table 2.2).

Nutrient uptake by shoots and roots did not show a significant interaction of genotype by growth stage (Figure 2.1). Total nutrient uptake was greater at the VT growth stage for shoot and root parts (Figure 2.1). The P1151 AM hybrid had overall greater N and Mn uptake in the shoot compared to the P1105 AM hybrid. This result may be explained by a greater root length, surface area, root volume and shoot growth by the P1151 AM hybrid. Furthermore, previous research evaluating different root systems suggests that N uptake is affected by plant root size and distribution in the soil (Lynch (2013); Peng et al. (2012)). Mengel (1995) suggests that a big root system can increase the total nutrient uptake in the root. Total nutrient uptake in the root biomass was not affected by hybrid selection (Table 2.1 and Fig. 2.1). This result suggests more efficient roots for P1151 AM. With greater shoot biomass and similar root biomass as the P1105 AM, the P1151 AM does a better job at maintaining a more extensive root system (length) while allocating more resources in the shoot.

Evaluation of these corn hybrids in the field showed 30% greater root length for the P1151 AM hybrid at the Ottawa site (Table 2.3). This agree with values found in the greenhouse (Table 2.2) and can imply advantages for the P1151 AM hybrid when exploring deeper soil layers and access to nutrients and water (Hammer et al., 2009). Root length and surface area are considered key parameters for nutrient and water uptake, and therefore is possible that at field conditions these hybrids can show different response to nutrients and water stress conditions (Himmelbauer et al., 2004). Root length, surface area, average diameter and volume increased from V6 growth stage until the VT growth stage (Table 2.3). No interaction of genotype by growth stage was found at the Ottawa site (Table 2.3).

At the Scandia site the interaction genotype by growth stage no statistical differences (Table 2.3). Besides, no differences in corn root length were found at Scandia site. In addition, surface area, average diameter and root volume showed no significant differences among the hybrids at any site (Table 2.3). Results from the Scandia site are different from those found in the greenhouse, and is possible that a genotype by environment interaction can cause a different response at this site.

Soybean

Soybean root characteristics evaluated showed no differences between the varieties (Table 2.1). There were no significant interactions of genotype by growth stage regarding root length, surface area, diameter, volume, root dry weight, shoot dry weight and root/shoot ratio (Table 2.1). Root length, surface area, root volume, root and shoot dry weight increased throughout the growing season, while average root diameter was the same during the season (Table 2.4).

Although no statistical differences were found for the parameters among the varieties, there were trends in the results. The P94Y40 variety showed greater shoot dry weight than the P44T63R variety at the R3 growth stage (Tables 2.4). A genetic trait associated with P94Y40 variety probably stimulates shoot dry weight accumulation. Greater shoot growth can imply in greater demand of nutrients by the plant which can affect the nutrient uptake rate of this variety.

The interaction of genotype by growth stage showed the P94Y40 variety having a trend of greater root/shoot ratio at V3 stage and lower at R3 growth stage. Since the root dry weight from both genotypes were similar at V3 and R3 growth stages, the differences in root/shoot ratio can be explained by the shoot dry weight. Both P94Y40 and P44T63R varieties had similar shoot dry weight at V3, but at R3 the shoot dry weight increase in P94Y40 variety was greater, consequently lowering the root/shoot ratio. According to Shank (1943), the partitioning of dry matter among root and shoot is a characteristic determined by the plant genotype. The soybean varieties evaluated showed similar root/shoot ratio values with a decrease in root/shoot ratio values later in the season (Table 2.4).

Total nutrient uptake increased with growth stage, with greater values at the R3 stage for both shoot and root (Figure 2.2). No significant differences for nutrient uptake were found at any interaction or genotype (Figure 2.2). In the shoot, there was a trend for greater N, P, K, SO_4, Mn and Zn uptake in the P94Y40 variety at the R3 stage (Figure 2.2). Previous studies show that root surface area is the most important characteristic affecting nutrient uptake rate in dicotyledonous species (Barber, 1995). It is possible that the average greater root surface area of the P94Y40 variety in this study could contribute to the increase in nutrient uptake when compared to the P44T63R variety. Other characteristics such as greater root volume may also contribute to the greater nutrient uptake for the P94Y40 variety. These root parameters may be particularly important for immobile nutrients, which may require a good root distribution in the soil volume with greater nutrient content (Shen et al., 2011).

Evaluation of these soybean varieties in the field showed 23% increase in root surface area for the P44T63R variety in Ottawa (Table 2.5). Average root volume was also found to be greater for the P44T63R variety in Ottawa. According to its suitability, the P94Y40 variety is expected to develop better under a poor drainage environment such as Ottawa. Probably the P44T63R variety invests more in root development in detriment of shoots to increase the chances of survival in this environment. On the other hand, P94Y40 variety roots had approximately 0.5 cm^3 more volume than P44T63R variety in Scandia (Table 2.5). Root length, surface area and diameter were found to be greater for P94Y40 variety in Scandia, although not statistically different from P44T63R variety (Table 2.5). Those root characteristics are used to calculate the total root volume and consequently impact in its final value. Both varieties increased their root surface area, diameter and root volume at this site. Lynch and Brown (Lynch and Brown, 2008) found that in limited conditions of P, root growth is stimulated to explore a given volume of soil more effectively. In Scandia, root length, surface area, diameter and volume were greater at R3 than V3 (Table 2.5). Soybean varieties did not show any difference on root length (Table 2.5). No interaction effect of genotype by growth stage was found significant at any site.

Conclusions

The root system of the two corn hybrids evaluated in this study showed a different response at environments evaluated. The P1151 AM hybrid showed greater root length than the P1105 AM hybrid in Ottawa, a dryland environment. No significant differences were found for any parameter at Scandia.

In the greenhouse study, the P1151 AM hybrid showed greater shoot biomass than the P1105 AM hybrid. This combined with greater values of root length, surface area and root volume for the P1151 AM hybrid potentially contributed to the average greater amounts of N and Mn uptake in the shoots. Phosphorus, K, SO_4 and Zn showed a trend of greater values for P1151 AM hybrid, but those results were not statistically different. Results from this study showed that corn root growth characteristics and growth pattern during the growing season can be significantly different for different genotypes. Future studies evaluating the response of these different genotypes to environmental stress such as drought and soil characteristics are needed to evaluate potential differences due to the interaction of environmental stress by genotype. Similarly, the interaction of nutrient source and placement by genotype can help to evaluate the need for adjustments in agronomic management for certain corn genotypes.

The P44T63R soybean variety had greater root surface area and volume at the Ottawa site. Soybean roots did not show significant differences in root biomass, length, surface area, average diameter, volume or root/shoot ratio between varieties in the greenhouse study. Although not statistically significant, some root characteristics may have contributed for greater nutrient uptake values by the P94Y40 variety. The two soybean varieties evaluated in this study showed very limited differences in root characteristic in the greenhouse and in the field. This may suggest less variability in root characteristics by soybean genotypes, however additional studies should evaluate more soybean genotypes and possible interaction with soils and environment.

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Table 2.1. Level of significance (p-values) for dry weight and nutrient uptake in the shoot and root of corn and soybean grown in the greenhouse. Root characteristics for corn and soybean are based on scanning readings.

	Corn			Soybean		
Parameters	Genotype (G)	Stage (S)	G x S	Genotype (G)	Stage (S)	G x S
	- - - - - - - - - - - -	- - - - - - - - - -	- - - - p > F - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - -
			Shoot			
Dry weight	0.007*	<0.001*	0.211	0.107	<0.001*	0.083
N uptake	0.028*	<0.001*	0.143	0.205	<0.001*	0.169
P uptake	0.102	<0.001*	0.623	0.182	<0.001*	0.170
K uptake	0.924	<0.001*	0.125	0.105	<0.001*	0.107
SO_4 uptake	0.385	<0.001*	0.183	0.127	<0.001*	0.113
Mn uptake	0.014*	<0.001*	0.186	0.171	<0.001*	0.135
Zn uptake	0.053	<0.001*	0.506	0.061	<0.001*	0.051
			Root			
Dry weight	0.063	<0.001*	0.060	0.921	<0.001*	0.979
N uptake	0.984	<0.001*	0.542	0.967	0.021*	0.938
P uptake	0.651	<0.001*	0.341	0.764	<0.001*	0.978
K uptake	0.403	<0.001*	0.571	0.444	0.055*	0.945
SO_4 uptake	0.979	<0.001*	0.640	0.702	<0.001*	0.973
Mn uptake	0.238	<0.001*	0.068	0.653	<0.001*	0.688
Zn uptake	0.695	<0.001*	0.147	0.856	0.002*	0.718
Length	<0.001*	<0.001*	<0.001*	0.974	<0.001*	0.865
Surface area	0.008*	<0.001*	0.075	0.884	<0.001*	0.623
Average diameter	0.661	<0.001*	0.543	0.705	0.994	0.340
Root volume	0.002*	<0.001*	0.010*	0.814	<0.001*	0.514
Root/shoot ratio	0.026*	<0.001*	0.011*	0.866	0.002*	0.053

* Statistically significant at 0.05 alpha level.

Table 2.2. Corn shoots and roots dry weight, length, surface area, average diameter and root volume according to scanned images in the greenhouse study.

Genotype/ growth stage†		Root Dry Weight	Root Length	Root Surface Area	Root Average Diameter	Root Volume	Shoot Dry Weight	Root/Shoot Ratio
		g plant^{-1}	cm	cm^2	mm	cm^3	g shoot^{-1}	
Genotype								
P1151 AM		11	76,086 a	7786 a	0.34	66 a	61 a	0.24 b
P1105 AM		10	59,262 b	6079 b	0.34	51 b	54 b	0.29 a
Growth stage								
V6†		4 c‡	24,289 c	2746 c	0.38 a	26 c	9 c	0.44 a
V10		9 b	59,926 b	5469 b	0.29 c	40 b	49 b	0.18 b
VT		19 a	118,807 a	12583 a	0.35 b	110 a	116 a	0.17 b
Genotype by Growth stage								
P1151 AM	V6	3	25,735 e	2851	0.37	26 d	9	0.36 b
P1105 AM	V6	4	22,844 f	2642	0.39	25 d	8	0.53 a
P1151 AM	V10	9	68,399 c	6169	0.29	45 c	53	0.17 c
P1105 AM	V10	8	51,454 d	4768	0.29	36 cd	44	0.18 c
P1151 AM	VT	21	134,124 a	14338	0.35	127 a	122	0.17 c
P1105 AM	VT	18	103,489 b	10827	0.34	93 b	109	0.16 c

† V6, V10, VT growth stage (Abendroth et al., 2011);
‡ Numbers followed by different letters within rows for each main effect and the interaction of genotype and growth stage represent statistically significant differences at the $p \leq 0.05$.

Table 2.3. Corn root length, surface area, average diameter and root volume according to scanned images in the field.

Genotype/ growth stages		Ottawa				Scandia			
		Length	Surface Area	Average Diameter	Volume	Length	Surface Area	Average Diameter	Volume
		cm	cm^2	mm	cm^3	cm	cm^2	mm	cm^3
Genotype									
P1151 AM		7151 a‡	1300	5.12	19.4	5339	1003	4.25	15.4
P1105 AM		5495 b	1097	4.47	17.9	5162	1082	4.72	18.4
Growth stage									
V6†		2001 c	338 c	2.03 c	4.7 c	2047 b	385 c	2.13 c	6.0 c
V10		5188 b	1037 b	4.31 b	17.3 b	3025 b	632 b	3.59 b	10.8 b
VT		11781 a	2220 a	8.03 a	33.9 a	10680 a	2112 a	7.73 a	33.8 a
Genotype by Growth stage									
P1151 AM	V6	2006	360	2.16	5.3	1989	353	1.82	5.3
P1105 AM	V6	1996	315	1.91	4.1	2106	416	2.45	6.8
P1151 AM	V10	5924	1129	4.73	18.2	3301	675	3.74	11.2
P1105 AM	V10	4452	946	3.9	16.5	2748	590	3.44	10.3
P1151 AM	VT	13524	2411	8.46	34.6	10728	1982	7.19	29.6
P1105 AM	VT	10038	2030	7.61	33.1	10632	2241	8.27	38.1
---- level of significance (p > F) ----									
Genotype (G)		0.047*	0.157	0.251	0.501	0.837	0.559	0.275	0.090
Growth stage (GS)		<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
G x GS		0.214	0.614	0.880	0.997	0.948	0.578	0.408	0.087

† V6, V10, VT growth stage (Abendroth et al., 2011);

‡ Numbers followed by different letters within rows for each main effect and the interaction of genotype and growth stage represent statistically significant differences at the $p \leq 0.05$.

* Statistically significant at 0.05 alpha level.

Table 2.4. Soybean shoots and roots dry weight, length, surface area, average diameter and root volume according to scanned images in the greenhouse study.

Genotype/ growth stages		Root					Shoot Dry Weight	Root/Shoot Ratio
		Dry Weight	Length	Surface Area	Average Diameter	Volume		
		g $plant^{-1}$	cm	cm^2	mm	cm^3	g $shoot^{-1}$	
		Genotype						
P94Y40		1.2	8268	1045.28	0.39	10.62	5.2	0.34
P44T63R		1.2	8321	1015.99	0.40	10.06	3.9	0.35
		Growth stage						
V3†		0.4 b‡	2778 b	346.70 b	0.40	3.47 b	1.0 b	0.43 a
R3		2.0 a	13810 a	1714.57 a	0.40	17.21 a	8.3 a	0.26 b
		Genotype by Growth stage						
P94Y40	V3	0.4	2613	311.66	0.38	2.96	0.9	0.47
P44T63R	V3	0.4	2943	381.75	0.41	3.97	1.0	0.39
P94Y40	R3	2.0	13922	1778.9	0.40	18.28	9.9	0.21
P44T63R	R3	2.0	13699	1650.24	0.39	16.14	6.8	0.31

† V3, R3 growth stage (Pedersen, 2003);

‡ Numbers followed by different letters within rows for each main effect and the interaction of genotype and growth stage represent statistically significant differences at the $p \leq 0.05$.

Table 2.5. Soybean root length, surface area, average diameter and root volume according to scanned images in the field.

Genotype/ growth stages		Ottawa				Scandia			
		Length	Surface Area	Average Diameter	Volume	Length	Surface Area	Average Diameter	Volume
		cm	cm^2	mm	cm^3	cm	cm^2	mm	cm^3
					Genotype				
P94Y40		325	48 b‡	0.47	0.56 b	415	83	0.72	1.32 a
P44T63R		374	59 a	0.5	0.73 a	363	61	0.59	0.84 b
					Growth stage				
V3†		315	49	0.47	0.61	213 b	36 b	0.54	0.49 b
R3		384	57	0.49	0.68	566 a	107 a	0.76	1.67 a
					Genotype by Growth stage				
P94Y40	V3	281	42	0.5	0.49	217	40	0.6	0.59
P44T63R	V3	349	57	0.51	0.73	209	32	0.49	0.4
P94Y40	R3	369	54	0.46	0.63	613	125	0.84	2.06
P44T63R	R3	398	61	0.48	0.74	518	90	0.69	1.28
					level of significance (p > F)				
Genotype (G)		0.161	0.046*	0.085	0.020*	0.507	0.105	0.314	0.046*
Growth stage (GS)		0.056	0.122	0.226	0.321	0.001*	<0.001*	0.085	<0.001*
G x GS		0.561	0.428	0.390	0.352	0.573	0.288	0.864	0.207

† V3, R3 growth stage (Pedersen, 2003);
‡ Numbers followed by different letters within rows for each main effect and the interaction of genotype and growth stage represent statistically significant differences at the $p \leq 0.05$.
* Statistically significant at 0.05 alpha level.

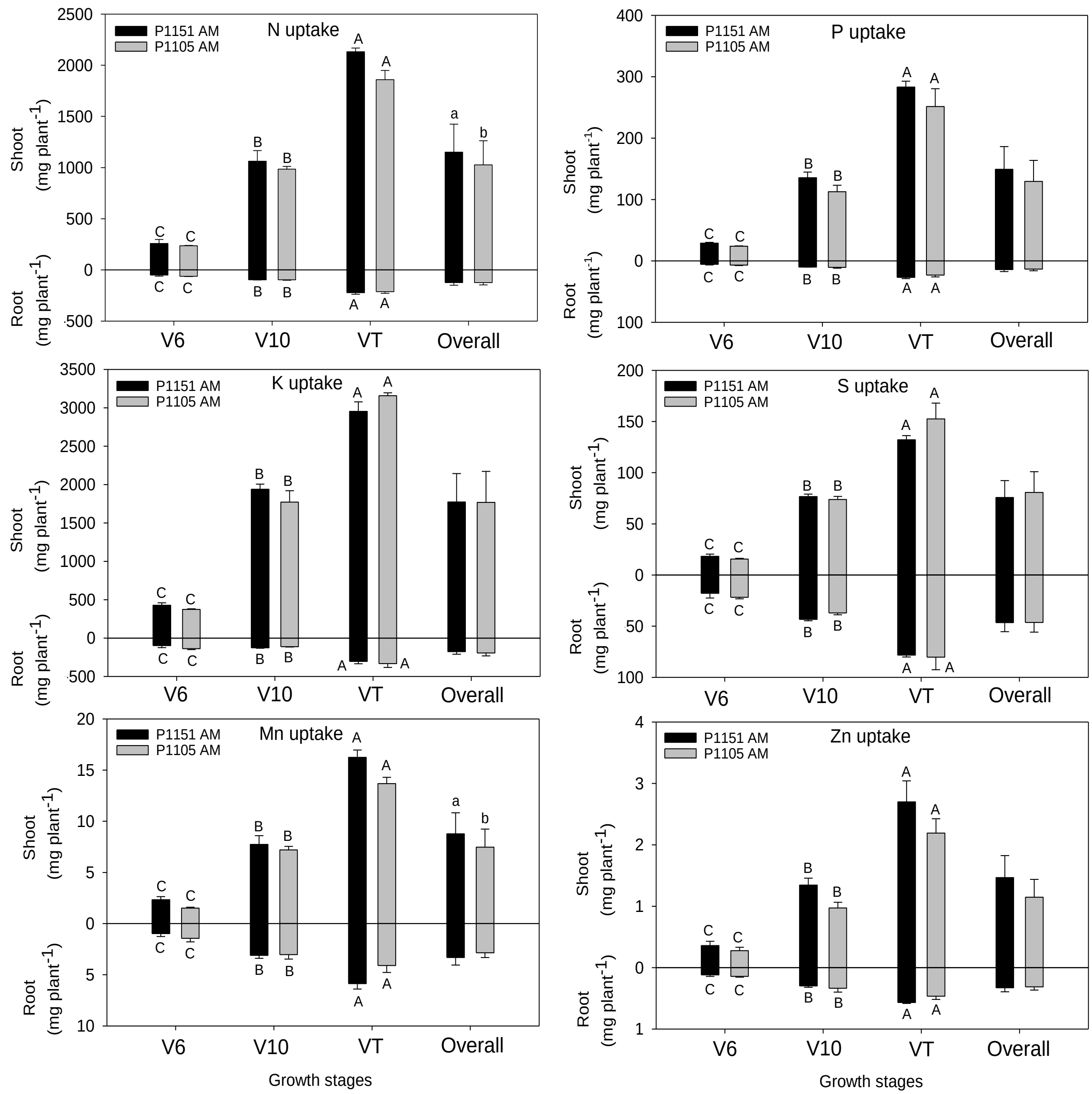

Figure 2.1. Corn nutrient uptake by shoot and root at V6, V10 and VT growth stages (Abendroth et al., 2011) in the greenhouse study. Diferent letters indicate statistically significant differences at the $p \leq 0.05$, uppercase letters for growth stages, and lower case letters hybrid comparisons.

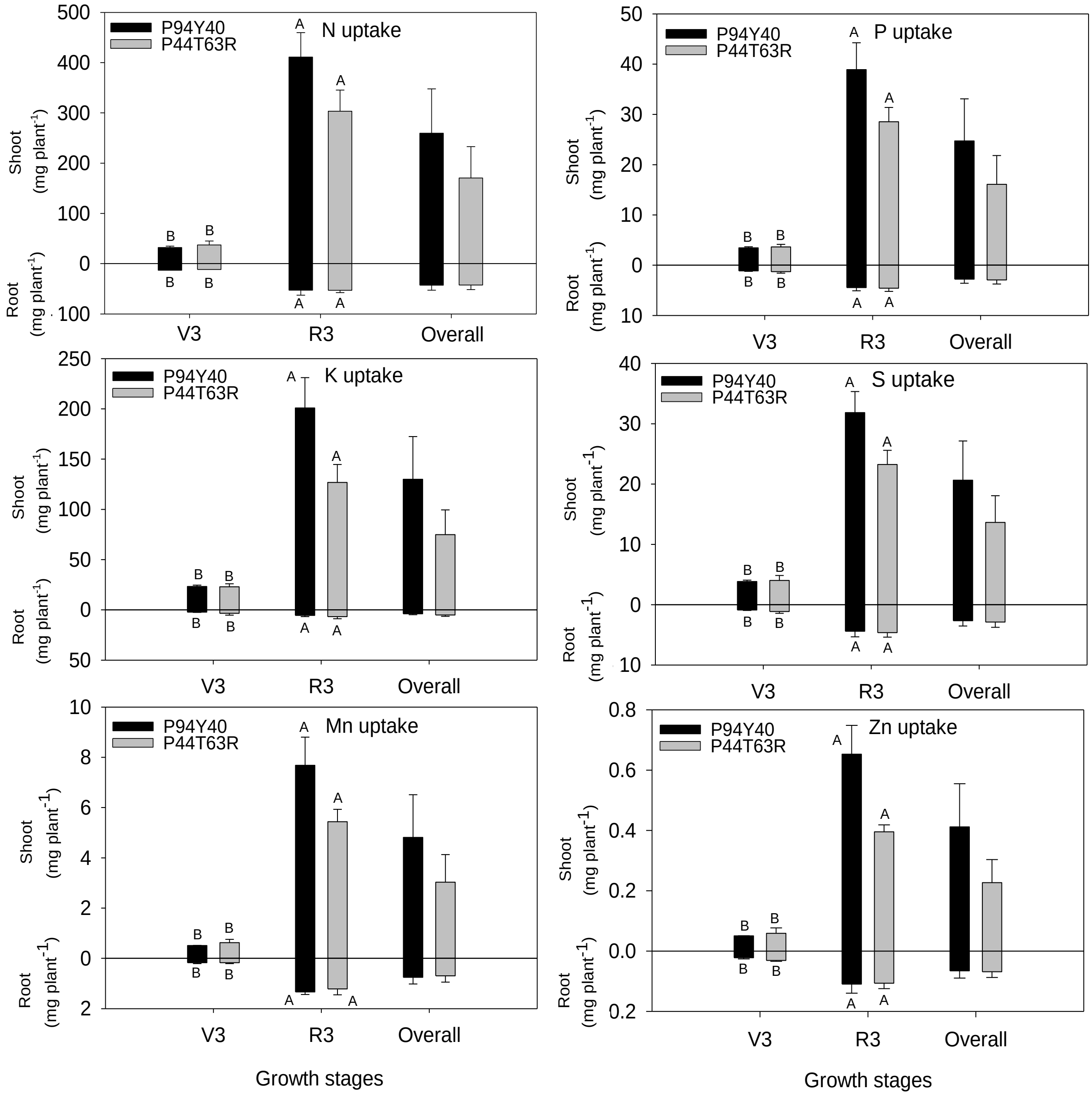

Figure 2.2. Soybean nutrient uptake by shoot and root at V3 and R3 growth stages (Pedersen, 2003) in the greenhouse study. Diferent letters indicate statistically significant differences at the p ≤ 0.05, uppercase letters for growth stages, and lower case letters variety comparisons.

Chapter 3 - Evaluation of Corn Response to Fertilizer Placement and Tillage Interaction Using Different Hybrids

Abstract

Fertilizer placement and tillage are management practices that can generate a significant impact on corn (*Zea mays*) yields. The objective of this study was to evaluate the effects of fertilizer placement and tillage system on different corn genotypes. The study was established at four at two sites in Kansas during 2014 and 2015 totaling four site-years in Kansas. The experimental design was a split-plot in a randomized complete block design with four replications. Three fertilizer treatments and two different tillage operations were combined with two corn genotypes selected based on contrasting root systems. The three fertilizer placements were sub-surface band, broadcast and control. The two corn hybrids were a drought-prone suitable hybrid and a conventional hybrid. The two tillage operations were no-till (NT) and strip-till (ST). Fertilizer application rates were calculated based on nutrient sufficiency recommendation. Roots and above ground plant tissue samples were collected during the vegetative and reproductive growth stages to evaluate above ground biomass and nutrient uptake. Grain yield was recorded at harvest and analyzed for nutrient concentration. The P1151 AM hybrid showed greater root biomass, but differences among hybrids regarding aboveground dry weight, nutrient uptake and grain yields were inconsistent. Broadcast and sub-surface band increased nutrient uptake and grain yields but were not significantly different from each other. Interaction with tillage showed NT combinations with greater results for the parameters evaluated in this study. Future studies should be done to clarify if the fertilizer placement can

stimulate or inhibit the root growth and how it affects the dynamic of nutrients in the soil-plant interactions.

Abbreviations: NT, no-till; ST, strip-till.

Introduction

United States produced more than 360 million metric tons of corn with an average yield of 10,734 kg ha^{-1} in the 2014 crop season, being the biggest corn producer in the world (USDA, 2014). To support this productive system, conservation practices need to be considered. No-till (NT) is a conservation tillage recommended to reduce soil erosion (Unger and McCalla, 1980) and improve soil quality in a cost effective way. Due to reduced rainfall amount in Kansas during the months of corn pollination, NT can be a strategy used by farmers to conserve moisture in the soil for longer periods. Torbert et al. (2001) found greater corn grain yields under NT in a black clay soil when compared to chisel tillage system.

However, NT can potentially create a cool and wet condition in early spring affecting corn early growth (Vetsch and Randall, 2002), reducing nutrient uptake and decrease grain yields. Erbach et al. (1992) found a corn yield reduction under NT system in a wet to poorly drained soil when compared to conventional tillage. In addition, NT usually leads to P stratification. Phosphorus accumulate in the soil surface due to nutrient uptake by roots from deeper layers in the soil, nutrient accumulation from decomposing past crops leaving its residue in the soil surface (Karlen et al., 1991) and, in some cases, by surface fertilization such as broadcast. The accumulation of P in the soil surface may decrease P availability to plants because of the likelihood of dry conditions in this zone.

Strip-till (ST) can be an alternative over NT since combines the benefits of soil and water conservation with the improved seedbed conditions provided by the conventional tillage (Farmaha et al., 2011). Strip-till only tills the future corn row, leaving the rest of the field undisturbed maintaining crop residues just less than NT system (Vyn and Raimbault, 1992). In poorly drained soils, ST was found to increase soil temperature (Bolton and Booster, 1981) and decrease the soil bulk density in the row when compared to NT (Overstreet and Hoyt, 2008). According to a study made by Vetsch et al. (2007), ST had increased corn yields compared to NT. Disadvantages of ST can be the P losses by soil erosion due to the disturbance generated by the tillage. Also, some studies report no difference for corn yield among tillage system. Licht and Al-Kaisi (2005) found no effect of tillage in N uptake, plant biomass or in corn grain yields in Iowa.

Tillage systems are highly related to fertilizer efficiency. The correct fertilizer placement can enhance nutrient uptake by plants and consequently increase grain yields. Deep band fertilization can minimize the retention of immobile nutrients by the soil increasing fertilizer use efficiency. Therefore, band fertilizer application concentrate fertilizer near the root zone increasing the uptake of immobile nutrients such P and K (Barber and Kovar, 1985). Tarkalson and Bjoneberg (2013) found greater corn yields under deep band treatments when compared to broadcast in a study conducted in the Pacific Northwest. Some studies report no difference among deep band and broadcast fertilization. Bordoli and Mallarino (1998) found that P fertilization increased corn yields in soils testing low for P, although no difference was found for placement. Later, in a study conducted in Illinois, Fernández and White (2012) found a 24% increase in P uptake under deep band application of a P and K mix when compared to broadcast, but the greater uptake did not turn to a corn grain yield difference.

Because nitrogen (N) is present in most of the liquid fertilizer applied prior planting together with phosphorus, is hard to identify which nutrient is contributing more to the crop. Moreover, large yield response is not expected in different fertilizer placements for N since nitrate is a mobile nutrient in soils, unless dry conditions predominate (Jones and Jacobsen, 2009). On the other hand, according to Roth et al. (2006), in soils testing high in P, the response to starter fertilization is explained by the N in the mixture. Phosphorus response in corn depends much on the soil test P levels. When the P levels in soils are medium or high the likelihood of response to P fertilization is low, as many studies indicate (Mallarino et al., 1991; Rehm, 1986).

Crops with contrasting root systems may differ in the ability to extract nutrients. Results from previous studies showed significant differences in nutrient concentration and uptake among corn hybrids with different genetic backgrounds (Gordon et al., 1998). It is possible that different rooting systems can show a significant interaction with fertilizer application method. Studies done by Ge et al. (2000) in common bean (*Phaseolus vulgaris L.*) was found that shallow roots were more efficient to recover P from the surface layer when compared to deeper root system due to less inter-root competition.

The objective of this study was to evaluate the effects of fertilizer placement and tillage system on corn aboveground dry weight, nutrient uptake, grain yield and grain nutrient concentration using two different hybrids. In addition, this study aims to find possible differences in root biomass among those hybrids in a field basis.

Materials and Methods

Four corn sites were established in 2014 and 2015. Locations 1 and 2 were in Ottawa, Kansas (38°32′19″N; 95°15′11″W) on a Woodsen silt loam soil (fine, smectitic, thermic

Abruptic Argiaquolls) with poor drainage conditions. Locations 3 and 4 were in Scandia, Kansas (39°46′23″N; 97°47′19″W) on a Crete silt loam soil (fine, smectitic, mesic Pachic Argiustolls) with good drainage conditions. Description of each location is presented in Table 3.1. Row spacing was 76 cm; plot size was 12.2 m in length and 3 m in width (36.6 m^2) – in all sites.

Experimental design was a split-plot in a randomized complete block design, where tillage and hybrid were whole plots and fertilizer placement was split-plot, with four replications. Fertilizer treatments consisted of a control, sub-surface band only and broadcast only. These three fertilizer treatments were combined with two different hybrids selected based on contrasting root systems and two different tillage operations. The two hybrids of corn were selected based on possible differences in root characteristics, being Pioneer P1151 AM (Pioneer Hi-Bred, Johnston, IA), considered suitable to drought-prone environments, and Pioneer P1105 AM (Pioneer Hi-Bred, Johnston, IA), a conventional hybrid . The two tillage operations were no-till and strip-till. Sub-surface band fertilizer was applied 15 cm deep in the soil, 2-3 weeks before planting using the ST applicator Yetter (Yetter Mfg., Colchester, IL) pull caddy with Maverick Generation 2 openers and residue managers (model 2984) and a 5 cm mole knife, equipped with a Gandy Orbit Air model 623016 box and metering system (Gandy Co, Owatanna, MN). For NT, starter (5 cm deep and 5 cm to the side of the seed) was applied with the planter. Broadcast treatments were applied at planting. At Scandia was applied 184 kg ha^{-1} N as anhydrous ammonia (82-0-0, N-P_2O_5-K_2O respectively). Sub-surface band treatment rate was 45 kg ha^{-1} N as UAN (28-0-0) and 45 kg ha^{-1} P_2O_5 as ammonium polyphosphate (10-34-0). Broadcast and starter treatment rates were the same as sub-surface band. Broadcast sources were Urea (45-0-0) and MAP (11-52-0). At Ottawa, the sub-surface band treatment rate was 134 kg ha^{-1} N as UAN (28-0-0) and 45 kg ha^{-1} P_2O_5 as ammonium polyphosphate (10-34-0). Treatment rates can be considered commonly used by producers in a corn-soybean rotation based on nutrient sufficiency recommendations.

A composite soil sample of 20 cores was collected from each replication (block). Extractable P was determined by the Mehlich-3 method (Frank, 1998) and extracts analyzed using inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia). Extractable K was determined by the ammonium acetate method (Warncke, 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson, 1998), and soil organic matter (OM) was determined by Walkley–Black method (Combs, 1998).

Plant tissue samples were taken during the vegetative and reproductive growth stages. Whole plant samples were taken in the growth stages V6, V10, and VT growth stages (Abendroth et al., 2011). This was accomplished by removing ten corn plants at random from non-harvest rows of each plot at V6 growth stage. For V10 and VT growth stages were collected six plants with the same criteria. Plants were weighted and dried in a forced air oven at 70 °C for a minimum of six days and weighted for biomass calculation. Once dry and weighted, plants were ground then analyzed for total Nitrogen (N) and Phosphorus (P). Total N and P were analyzed by sulfuric peroxide digest as described by Lindner and Harley (1942). Nitrogen digest was analyzed by an indophenol blue colorimetric procedure using the Rapid Flow Analyzer (Model RFA-300; Alpkem Corporation, Clackamas, Oregon, USA). Phosphorus was determined using inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia). Biomass weight and concentration in tissue were used to calculate N and P uptake. Root samples were collected from the control plots, with no treatment application, to evaluate possible differences in rooting system among genotypes. Ten root samples of each hybrid were dug from the soil using a shovel at V6, V10 and VT growth stages.

Root samples were collected at 20 cm deep and 40 cm diameter around the stem giving the total root biomass per volume of soil. Soil was removed by hand in the field as much as possible with minimum root loss. Later, roots collected were washed with water to remove remaining soil, dried at 65°C for six days and weighted to get the total dry weight.

The two central rows of each plot were machine harvested. Grain weight was recorded and adjusted for 150 g kg^{-1} moisture. Grain was dried at 60°C for a minimum of four days, ground to a powder and digested with a sulfuric acid and hydrogen peroxide digest (Thomas, 1967). Samples were then analyzed as previously described for leaf samples.

Data was analyzed by site using PROC GLIMMIX in SAS 9.2 (SAS, 2011) assuming block as a random factor in the model. The starter treatment was analyzed as part of the sub-surface band treatment. Separation of means at a significant level of $p \leq 0.10$ was completed using the LINES option in PROC GLIMMIX.

Results and Discussion

Root System Analysis

Corn root system was evaluated for differences among corn genotypes under the no fertilized treatment. The interaction of hybrid by growth stage revealed differences between the hybrids for root biomass only at VT stage in 2014 (Table 3.2). The P1151 AM hybrid showed 45% more root dry weight than the P1105 AM at VT growth stage at Ottawa and almost two times more than P1105 AM hybrid at Scandia (Table 3.2). Since corn is most susceptible to stress at VT-R1 growth stage, when pollination occurs (Shaw, 1977), the P1151 AM hybrid probably has a genetic factor that induced the root growth towards the end of the vegetative growth period to increase the root soil contact for water and nutrient uptake. In addition, the soil characteristics from each site likely contributed for different results. The biggest difference among the hybrids was found in Scandia, where the soil is more coarse texture compared to Ottawa site. This property of the soil could have facilitated the P1151 AM hybrid to express its greater root biomass since less mechanical impedance is found in those scenarios.

With genotype as a main factor, significant differences were found in 3 out of 4 site-years for total root biomass accumulation among hybrids with greater values to the P1151 AM hybrid (Table 3.2). The drought tolerance mechanism could be related to a genetic trait responsible for increased root biomass. Corn root dry weight increased with the corn development during the growing season (Table 2.2).

Dry Weight Accumulation

Tillage by fertilizer placement showed a significant interaction effect on dry weigh (DW) accumulation, with NT showing greater values for corn dry weight in Ottawa (Table 3.4). No-till by sub-surface band or broadcast showed the greater DW accumulation in Ottawa 2014, with significant increase at V10 and VT growth stages (Table 3.4). However, in Ottawa 2015 the differences where only at V6 growth stage with combinations of NT and broadcast showing greater biomass accumulation (Table 3.4). It is possible that NT contributes with moisture storage early in the season, enhancing fertilizer availability to corn. On the other hand, as the corn develops and rainfall amounts decrease, are created dry conditions especially near the soil surface. In this scenario, the sub-surface band placement showed advantages increasing nutrient availability to the crop stimulating the biomass accumulation at VT growth stage. This result agrees with Timmons (1984) and Robertson et al. (1958) who found that sub-surface band fertilization increased corn yields under dry conditions. No interaction effect of tillage by hybrid

(Table 3.5) and hybrid by fertilizer (Table 3.6) were observed regarding dry weight accumulation at Ottawa.

Fertilized treatments had greater aboveground biomass compared to the control treatment at Ottawa (Table 3.7). Results regarding differences between sub-surface band and broadcast were not consistent. In Ottawa 2014, sub-surface band treatment increased 7% shoot biomass over broadcast at V6 growth stage (Table 3.7). The dryer conditions in 2014 probably favored sub-surface band treatment in the early stage. Since the soil dries faster near the surface, sub-surface band fertilization reached layers where moisture was present contributing to N and P availability near the root system. The opposite happened in the following year when broadcast fertilizer had greater corn shoot dry weight at V6 growth stage (Table 3.7). With wetter conditions in 2015, the broadcast fertilizer possibly solubilizes faster increasing N and P availability for corn growth.

Differences among corn hybrids were found in Ottawa 2014 where the P1151 AM hybrid developed more total dry weight than the P1105 AM (Table 3.7). Reduced rainfall amounts occurred in 2014, especially around June/July. Assuming the AQUAmax technology of the P1151 AM hybrid and, in addition, the greater root biomass in 2014, the P1151 AM hybrid had a favorable scenario to reach greater dry weight values. King and Ruiz Diaz (2012) found hybrid differences early growth biomass with advantages to a deep root hybrid. The wetter scenario in 2015 probably allowed the P1105 AM hybrid to reach similar biomass accumulation to the P1151 AM hybrid.

Corn biomass accumulation was greater in NT treatments in Ottawa 2015 (Table 3.7). Similar result was found in Ottawa 2014 at VT stage only. No-till system probably held moisture longer when compared to ST, enhancing corn growth especially towards the end of the vegetative stage when dryer conditions predominate in Kansas.

In Scandia, the interaction tillage by hybrid was significant (Table 3.8), but no statistical difference for the interaction tillage by fertilizer (Table 3.9). In strip-till, P1105 AM hybrid had 18% more g plant^{-1} at V10 when compared to NT (Table 3.10). This result suggests that under ST, the P1105 AM hybrid probably had more access to nutrients due to faster mineralization generated by the tillage in the planting row. In a study conducted by (Balesdent et al., 1990) the soil organic matter decomposed faster under ST rather than NT in the top 30 cm of the soil. No significant differences were found in the interaction between hybrid and fertilizer for Scandia (Table 3.11).

In Scandia 2015, fertilized treatments showed greater aboveground biomass compared to the control treatment at all growth stages (Table 3.12). Broadcast had greater biomass accumulation than sub-surface band treatments at V6 and V10 growth stages in Scandia 2015 (Table 3.12). The wetter conditions of 2015 most likely helped the broadcast fertilizer to become available to corn since early in the season. Those processes of nutrient availability could be enhanced by the nutrient leaching in the soil and greater diffusion rate under high moisture conditions. In Scandia 2014 and Scandia 2015 at VT growth stage, broadcast and sub-surface band had similar corn dry weight accumulation.

No significant differences were found between tillage systems in Scandia (Table 3.12). As a main factor, the P1151 AM hybrid had 17% greater dry weight compared to the P1105 AM hybrid at V6 growth stage. This is probably associated with a genetic factor where the potential shoot and root biomass are greater for the P1151 AM hybrid.

Nutrient Uptake

Differences were found for nutrient uptake at corn development stages related to treatments in Ottawa (Tables 3.3). Tillage by fertilizer and tillage by hybrid were the most significant interactions for nutrient uptake in Ottawa (Table 3.3). Combinations of NT with fertilized treatments increased N and P uptake V6 and V10 growth stages (Table 3.4). The combination of NT by P1151 AM hybrid showed the highest N and P uptake at V10 in Ottawa 2015 (Table 3.5). However, under ST the P1105 AM hybrid showed greater uptake values compared to P1151 AM hybrid at V10 in Ottawa 2015 (Table 3.5). According to Raper et al. (1994), ST reduces penetration resistance in the row when compared to between rows. Strip-till system probably reduced the resistance for root growth increasing soil-root contact, and then, nutrient uptake. Under ST, there may not be an advantage for the bigger root systems. In Ottawa 2014, NT associated with fertilized treatments had increased N uptake compared to control regardless if it the fertilizer was broadcasted or banded (Table 3.4). In Ottawa 2015, an increased N uptake at V6 was found significant with NT by broadcast treatment reaching the greater value (Table 3.4). The mobility of nitrate in the soil associated with a greater rainfall amount registered at Ottawa 2015 could enhance the incorporation of this nutrient in the soil. Thus, the N from broadcast had more root contact compared to the sub-surface band application at V6 growth stage. Phosphorus uptake was increased by NT combinations with fertilized treatments as well. In Ottawa 2014, under NT by fertilized treatments P was increased in about 16% over the same treatments under ST at V10 and VT growth stages (Table 3.4). In Ottawa 2015, at V6 growth stage, broadcast increased in 46% the P uptake compared to ST by broadcast, while NT by sub-surface band was not different from ST by sub-surface band (Table 3.4). At the same site and growth stage, corn P uptake was less in the ST by control treatments, reinforcing the greater P uptake under NT combinations. Phosphorus uptake was probably enhanced at NT interactions due to the trend of water storage promoted by this conservation tillage practice, enhancing P diffusion in soil, especially in conditions such as Ottawa, a dryland site.

The tillage by hybrid interaction also revealed statistical differences for Ottawa. The combination of NT by P1151 AM hybrid increased in 36% the N uptake compared to the combination of ST by P1151 AM hybrid at V10 growth stage in Ottawa 2015 (Table 3.5). This advantage of NT system can also be attributed to the amount of rain and N mineralization rate. Since Ottawa 2015 registered greater rainfall, we can predict that the N losses due runoff under ST were greater than NT. In addition, the mineralization rate at NT is lower compared to ST (Balesdent et al., 1990). No-till probably induced a steady and constant N mineralization while ST accelerated this process increasing the probability of N losses by the rainfall. At the same growth stage, the P1151 AM hybrid grown in NT increased P uptake in 14% when compared to the P1105 AM hybrid in Ottawa 2015 (Table 3.5). The greater root biomass showed by the P1151 AM hybrid, as shown before, probably contributed to P accessibility as more soil volume was likely more explored by this hybrid. No differences among the hybrids were found under the ST combinations, which can be related to less mechanical impedance for the roots to grow. The interaction between hybrid and fertilizer showed significant differences in Ottawa. In Ottawa 2014, P uptake was increased at V10 growth stage by the combination of P1151 AM and broadcast application when compared with P1105 AM, but with no significant differences from sub-surface combinations (Table 3.6). The root biomass accumulation showed by P1151 AM probably enhanced the root-soil contact, and consequently, P uptake.

Sub-surface band and broadcast increased N and P uptake in corn at most of the growth stages compared to the control in Ottawa (Table 3.7). In Ottawa 2014, sub-surface band contributed for greater N and P uptake at V6 stage but was equal to broadcast as the corn developed to V10 and VT growth stages (Table 3.7). Sub-surface band application probably increased fertilizer access to the plant since the soil-fertilizer contact is reduced when compared to broadcast, resulting in less P fixation (Tisdale and Nelson, 1975). Phosphorus uptake was increased by band applications in corn production according to Schwab et al. (2006) in a study done in Southeast Kansas. Broadcast fertilization was essential towards the end of vegetative period since corn develops superficial root system (brace and adventitious systems) taking advantage of the nutrient availability in the soil surface (Barber, 1995). In Ottawa 2015, broadcast and sub-surface band fertilizer had similar N and P uptake at most growth stages (Table 3.7). However, sub-surface band fertilization increased N uptake at VT growth stage (Table 3.7). The increased rainfall amounts in 2015 (653 mm in 2015 against 438 mm in 2014) probably contributed for N runoff from the broadcast treatment. On the other hand, P uptake was increased at corn V6 by broadcast fertilization (Table 3.7).

No-till provided greater nutrient uptake than ST at V6 and V10 growth stages in Ottawa 2015 (Table 3.7). Besides the advantages of NT related to moisture content in the soil explained before, the warmer temperatures registered earlier in this year probably helped the soil to reach temperatures demanded by the crop. A soil temperature requirement for corn emergence is around 12°C (Nielsen, 2010). Higher temperatures early in the season possibly contributed for soil organic nitrogen mineralization, providing readily available N for plant uptake (Dinnes et al., 2002). Therefore, the advantage of ST related to warm up the soil earlier compared to NT did not apply for this growing season. There were no significant differences for tillage effect, as a main factor, in nutrient uptake in Ottawa 2014 (Table 3.7).

Hybrids had different nutrient uptake patterns in Ottawa 2014 (Table 3.7). The P1151 AM hybrid had greater N and P uptake than the P1105 AM hybrid at V6. According to Lynch (1995), P acquisition is highly influenced by root characteristics since it helps to explore more effectively a given soil volume. Although differences were found at V6 growth stage, based on the root dry weight data, it was expected that the P1151 AM hybrid would be able to access more soil and consequently increase nutrient uptake towards the end of the vegetative stage of corn. However, the results for N and P uptake at VT growth stage did not confirm this hypothesis.

In Scandia, there were fewer differences from the treatments on nutrient uptake (Table 3.8) and no interaction were found for tillage by fertilizer (Table 3.9), tillage by hybrid (Table 3.10) or hybrid by fertilizer (Table 3.11). Results in Scandia 2014 revealed broadcast and sub-surface band fertilizer with similar results for N and P uptake at all growth stages (Table 3.12). Phosphorus uptake was found to be similar among sub-surface band and control treatments at V10 and VT growth stages (Table 3.12). In Scandia 2015, broadcast treatment had similar results to sub-surface band at V6 and VT growth stages. However, at V10, N uptake increased 27% in broadcast compared to sub-surface band and 72% to control. Phosphorus uptake was increased by broadcast at V6 and V10 growth stages (Table 3.12). Those results from N and P uptake showed by corn can be attributed to the coarse texture of the soil in Scandia site. The coarse soil texture can imply in more suitability to nutrient incorporation of broadcast fertilizer by irrigation or rain. Thus, the sub-surface band fertilization could have been lost at somehow by nutrient leaching. Another reason is that with irrigation the plant tends to set up shallow root system getting advantage from the surface application of fertilizer. In a study conducted by Pandey et al. (1984), crops were found to stimulate deeper root growth in periods of drought and to keep shallower root systems where water was not a limiting factor.

There were no differences for tillage effect in nutrient uptake in Scandia at any year (Table 3.12). In Scandia 2014, N uptake was greater at V6 growth stage for the P1151 AM hybrid, while P uptake was increased at V10 for the same hybrid (Table 3.12). The root dry weight data showed greater values for the P1151 AM hybrid as a main factor. This characteristic probably contributed for more N and P uptake.

Grain Yield

The interaction tillage by fertilizer placement was found to be significantly different for corn yields in Ottawa 2014 (Table 3.4). No-till by sub-surface band increased corn yields 7% compared to ST (Table 3.4). No-till probably increased the soil moisture for longer, increasing the N and P availability from sub-surface band application. In addition, the corn-soybean rotation at this field likely contributed to enhanced soil fertility. The soybean straw possibly enriched N availability to corn throughout the growing season. Schoessow et al. (2010) showed that soybean residue can contribute with 27 to 60 kg ha^{-1} of N. There was no interaction between tillage and hybrid for corn grain yield (Table 3.5). The interaction hybrid by fertilizer was found to be significant with greater yields showed by the combinations under broadcast in Ottawa 2014 (Table 3.6). In Ottawa 2015, combinations with broadcast and sub-surface band were not different among each other, but showed greater grain yields compared to control (Table 3.6).

Fertilizer placement influenced grain yield in Ottawa. Broadcast and sub-surface band treatments increased corn grain yield over the control (Tables 3.6). In 2014, broadcast had 500 kg ha^{-1} of grain more than sub-surface band at Ottawa site (Table 3.7). Greater values showed by broadcast application can be explained by the sufficient P levels in the soil, where the broadcast treatment probably contributed for later N and P supply to the plant. In Ottawa 2015, broadcast and sub-surface band treatments had similar corn yields. On soils testing medium to high in P levels, grain yield difference between band applications and broadcast tend to disappear (Randall et al., 2001b). This result agrees with Rehm (1986), who developed a 2 year study in Nebraska testing different fertilizer placements finding no differences among broadcast and sub-surface band in corn yields.

Tillage by fertilizer placement was found to be significantly different in Scandia 2015 (Table 3.8). In Scandia 2015, ST by sub-surface band had greater grain yields than the combination of NT and sub-surface band (Table 3.9). In this scenario, according to well drained conditions presented in Scandia, ST operation probably contributed to a better plant emergence, and consequently, more uniform plant standing. There was no significant difference in grain yields regarding the interactions tillage by hybrid (Table 3.10) and hybrid by fertilizer (Table 3.11) in Scandia.

Fertilizer placement, as a main factor, influenced grain yield in Scandia. Broadcast and sub-surface band treatments increased corn grain yield over the control at both years of study, but were not different from each other (Tables 3.10). According to soil test P in Scandia, it was expected corn yield response since the P levels were below the critical level for P response in Kansas, which is 20 mg kg^{-1} (Leikam, 2003). The supplemental irrigation provided at the Scandia site probably was a key factor that contributed to minimize the differences among broadcast and sub-surface band application. With more water available, enhances the P diffusion in the soil, as well as the nitrate movement in the soil solution. In addition, the fertilizer applied in the soil surface (broadcast) can be easily incorporated by the irrigation.

No significant differences were found for tillage and hybrid factors for grain yield at any site-year (Tables 3.3 and 3.7). Similar results were found by Licht and Al-Kaisi (2005) in Iowa where ST did not differ from NT and chisel plow treatments in corn grain yield.

Grain Nutrient Concentration

Interactions of tillage by fertilizer were found to be significant for corn grain N concentration in Ottawa (Table 3.3). In Ottawa 2014, sub-surface band and broadcast treatment combined with NT or ST had greater N concentration in corn grain when compared to control (Table 3.4). No-till combination with fertilized treatments was found to have the greater grain N concentrations. Since the previous crop planted was soybeans, the N mineralization from soybean residues possibly contributed to the increased N under NT compared to ST. However, in Ottawa 2015, the control treatment responded similar to the fertilized treatments under NT, but was significantly lower compared to sub-surface band under ST (Figure 3.4). With wetter condition in 2015, N losses likely contributed for leveled results showed by fertilizer placements. No significant differences in grain P concentrations were found for tillage by fertilizer interaction (Table 3.4). There were no significant differences for grain nutrient concentration in the interaction of tillage by hybrid (Table 3.5). The interaction hybrid by fertilizer showed greater grain N concentration under broadcast and sub-surface band fertilization in Ottawa 2014 (Table 3.6). In Ottawa 2015, combinations with P1151 AM were found to increase grain N concentration compared to P1105 AM (Table 3.6).

Grain N concentration was found to be greater in fertilized treatments in Ottawa 2014 (Table 3.7). However, in Ottawa 2015, broadcast and control had similar results but lower than sub-surface band fertilization (Table 3.7). Grain P concentration decreased in fertilized treatments compared to control in Ottawa (Table 3.7). This lack of response can be explained by the soil test P levels which were above the critical level for Kansas (20 mg kg^{-1} soil) (Leikam, 2003) supplying the required amounts for corn grain without fertilizer addition.

Grain N concentration was found to be greater under NT than ST only in 2014 (Table 3.7). The P1151 AM hybrid grain had greater P concentration in Ottawa 2014 and greater N concentration in Ottawa 2015 in comparison to the P1105 AM hybrid (Table 3.7). The interaction genotype by growth stage showed 27% more root biomass for the P1151 AM hybrid at VT growth stage, although those numbers were not statistically different. Even though, this result possibly implied advantages for the P1151 AM hybrid regarding N and P uptake.

At Scandia, most of the differences were observed according to fertilizer placement (Table 3.8). No significant differences were observed for the interactions tillage by fertilizer (Table 3.9), tillage by hybrid (Table 3.10) and hybrid by fertilizer (Table 3.11). Broadcast application increased P concentration in corn grain over the control in both years at Scandia (Table 3.12). Broadcast probably contributed to late P uptake by corn, taking advantage of the superficial root system formed late in the vegetative stage. Scandia soil test P levels are 11 and 12 mg kg^{-1} where P fertilization response was expected to occur based on Kansas State University Fertilizer Recommendation (Leikam, 2003). On the other hand, N concentration was increased by sub-surface band application only in Scandia 2015 (Table 3.12).

At both years in Scandia, P1151 AM hybrid showed greater N concentration than the P1105 AM hybrid (Table 3.12). In Scandia 2015, P concentration in the P1151 AM hybrid was greater than the CT hybrid (Table 3.12).

Conclusions

The P1151 AM hybrid showed greater root biomass accumulation when compared to the P1105 AM hybrid. This result can contribute to greater nutrient uptake by one genotype over the other.

Corn responded to fertilization increasing aboveground biomass and nutrient uptake. Sub-surface band and broadcast treatment were found to be different only in nutrient uptake, where sub-surface band contributed for greater uptake in early growth and broadcast contributing towards the VT growth stage. Grain yields were increased by fertilization. However, only one site registered differences favoring broadcast application. The low and medium levels of P in the soil favored the P fertilization but the placement was not found significant. Corn seed N and P concentration also increased with fertilization although some results show the control treatment with similar values. Since broadcast is a cheaper way to apply nutrients it can be chosen by the producer without yield loss. On the other hand, sub-surface band fertilization can reduce P stratification, reduce nutrient loss through runoff and consequently water contamination. A combination of both placement treatments could enhance nutrient uptake and aboveground biomass in the entire crop cycle building a strong plant structure to fill the grains and increase yields.

Nutrient uptake was enhanced in NT conditions in 2015. However, in 2014 the differences when compared to ST were not consistent. Thus, tillage as a single factor did not show many differences among NT and ST. Interactions including NT were found to be the most significant of the study due to water storage contribution enhancing nutrient availability especially of P.

Grain yield was not affected by hybrids as a main factor, but when in combination with broadcast or sub-surface band, where P1151 AM hybrid by broadcast or sub-surface band increased significantly corn production over the P1105 AM interaction with the same treatments. Future studies regarding contrasting root system genotypes associated with different fertilizer placements to clarify possible root growth patterns as an influence of the fertilizer, and the response of them for nutrient uptake and grain yields.

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Table 3.1. Average soil test values, total precipitation, average temperature and planting date by site.

Location	Year	Soil test values				Precipitation‡	Average temperature§	Planting date
		STP†	STK	pH	OM			
		mg kg^{-1}			g kg^{-1}	mm	°C	
1	2014	25	158	6.4	37	438	22.0	22-Apr
2	2015	24	151	6.7	36	653	21.7	7-Apr
3	2014	12	489	6.5	27	559	20.1	6-May
4	2015	11	450	6.4	23	648	20.7	30-Apr

† STP, soil test for phosphorus (Mehlich-3 method); STK, soil test for potassium (Ammonium acetate method); pH (1:1 soil:water ratio); OM, organic matter (Walkley-Black method).

‡ Total precipitation during April to October 2014 and April to October 2015 growing season. Sites 3 and 4 received supplemental irrigation.

§Average temperature during April to October 2014 and April to October 2015 growing season.

Table 3.2. Corn root dry weight by hybrid and growth stage in Ottawa and Scandia. Samples collected from the control treatment only.

Hybrid/ growth stages		Ottawa		Scandia	
		2014	2015	2014	2015
		- - - - - - - - - - - - - - - - g - - - - - - - - - - - - - - -			
		Hybrid			
P1151 AM†		13.4 a‡	6.8 a	12.1 a	5.4
P1105 AM		9.6 b	5.6 b	8.3 b	5.7
		Growth stage			
V6		1.0 c	1.2 c	2.6 c	1.3 c
V10		8.2 b	6.3 b	8.5 b	4.0 b
VT		25.2 a	11.1 a	19.6 a	11.3 a
		Hybrid by Growth stage			
P1151 AM	V6	0.9 d	1.4	2.5 d	1.2
P1105 AM	V6	1.1 d	0.9	2.7 d	1.3
P1151 AM	V10	9.3 c	6.5	8.4 c	4.3
P1105 AM	V10	7.1 c	6.1	8.7 c	3.8
P1151 AM	VT	29.8 a	12.4	25.5 a	10.6
P1105 AM	VT	20.6 b	9.8	13.7 b	12.1
		- - - - - level of significance (p > F) - - - - - - -			
Hybrid (H)		0.015*	0.078*	0.007*	0.487
Growth stage (GS)		<0.001*	<0.001*	<0.001*	<0.001*
H x GS		0.035*	0.286	0.001*	0.270

† V6, V10, VT growth stage (Abendroth et al., 2011).
‡ Numbers followed by different letters within rows for each main effect and the interaction of genotype and growth stage represent statistically significant differences at the $p \leq 0.10$.
* Statistically significant at 0.1 alpha level.

Table 3.3. Level of significance for N and P uptake and biomass accumulation for corn at different growth stages, grain yield and grain nutrient concentration in Ottawa.

Parameters	V6 growth stage			V10 growth stage			VT growth stage			Grain Yield	Grain Nutrient	
	DW†	N	P	DW	N	P	DW	N	P		N	P
	- - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	p > F	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -			
							2014					
Tillage (T)	0.224	0.660	0.999	0.552	0.519	0.251	0.071*	0.348	0.171	0.363	0.074*	0.505
Hybrid (H)	0.004*	0.004*	0.003*	0.284	0.698	0.284	0.006*	0.580	0.338	0.736	0.635	0.007*
T x H	0.210	0.350	0.338	0.217	0.240	0.174	0.299	0.944	0.861	0.374	0.235	0.261
Fertilizer (F)	<0.001*	<0.001*	<0.001*	0.002*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0.001*	<0.001*	0.007*
T x F	0.894	0.547	0.332	0.038*	0.055*	0.054*	0.002*	0.459	0.078*	0.057*	0.078*	0.265
F x H	0.880	0.895	0.607	0.223	0.215	0.088*	0.805	0.595	0.935	0.011*	0.027*	0.220
T x F x H	0.173	0.262	0.243	0.774	0.825	0.800	0.289	0.571	0.538	0.403	0.355	0.022*
							2015					
Tillage (T)	0.004*	0.002*	0.006*	0.011*	0.088*	0.036*	0.048*	0.113	0.124	0.128	0.923	0.648
Hybrid (H)	0.309	0.991	0.451	0.859	0.943	0.465	0.113	0.545	0.680	0.903	0.001*	0.194
T x H	0.826	0.548	0.732	0.151	0.078*	0.064*	0.973	0.909	0.770	0.162	0.465	0.577
Fertilizer (F)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0.031*	<0.001*
T x F	0.005*	0.010*	0.024*	0.739	0.258	0.451	0.633	0.521	0.352	0.935	0.029*	0.901
F x H	0.587	0.909	0.806	0.798	0.632	0.438	0.781	0.988	0.605	0.016*	0.033*	0.484
T x F x H	0.061*	0.200	0.075	0.280	0.636	0.705	0.549	0.756	0.513	0.806	0.297	0.134

† DW, dry weight; N, nitrogen; P, phosphorus; V6, V10, VT growth stage (Abendroth et al., 2011).
* Statistically significant at 0.1 alpha level.

Table 3.4. Interaction effect for tillage and fertilizer placement on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration in Ottawa.

		No-till			Strip-till		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
				2014			
DW (g plant^{-1})	V6†	5.5	5.8	4.4	5.6	6.1	4.7
	V10	71 a‡	66 ab	45 d	61 abc	59 bc	56 c
	VT	159 b	171 a	129 c	151 b	136 c	132 c
N (mg plant^{-1})	V6	238	278	182	229	266	190
	V10	2205 a	2145 a	1138 b	1897 a	1874 a	1478 b
	VT	3071	3167	1915	2814	2882	1987
P (mg plant^{-1})	V6	29	30	23	27	30	25
	V10	281 a	270 ab	159 c	231 b	236 b	190 c
	VT	414 a	409 a	294 c	365 b	369 b	314 c
Grain yield (Mg ha^{-1})		9.2 a	9.0 a	6.0 c	9.1 a	8.4 b	6.3 c
Grain N concentration (g kg^{-1})		12.0 a	12.1 a	9.9 c	11.1 b	11.6 ab	10.0 c
Grain P concentration (g kg^{-1})		2.5	2.5	2.5	2.4	2.5	2.6
				2015			
DW (g plant^{-1})	V6	16.1 a	13.2 b	10.5 c	11.1 c	11.6 bc	6.7 d
	V10	87	86	61	71	75	45
	VT	131	133	96	116	128	85
N (mg plant^{-1})	V6	473 a	391 b	251 d	304 c	345 bc	147 e
	V10	1648	1692	791	1252	1487	666
	VT	1466	1657	690	1144	1525	622
P (mg plant^{-1})	V6	57 a	46 b	38 c	39 c	41 bc	24 d
	V10	272	269	179	215	225	152
	VT	296	298	215	244	280	212
Grain yield (Mg ha^{-1})		9.5	9.5	4.0	9.1	9.1	3.5
Grain N concentration (g kg^{-1})		9.7 ab	9.4 ab	9.2 b	9.2 b	9.8 a	9.1 b
Grain P concentration (g kg^{-1})		2.5	2.5	2.8	2.5	2.5	2.8

† V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 3.5. Interaction effect for tillage and hybrid on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration in Ottawa.

		No-till		Strip-till	
		P1151 AM	P1105 AM	P1151 AM	P1105 AM
			2014		
DW (g $plant^{-1}$)	V6[†]	5.5	5.0	6.0	5.0
	V10	64.9	56.5	58.3	58.9
	VT	163.6	142.6	145.6	133.7
N (mg $plant^{-1}$)	V6	246	219	250	207
	V10	1928	1730	1698	1802
	VT	2751	2685	2603	2519
P (mg $plant^{-1}$)	V6	29	26	30	25
	V10	255	218	217	222
	VT	382	363	356	343
Grain yield (Mg ha^{-1})		8.0	8.1	8.0	7.9
Grain N concentration (g kg^{-1})		11.4	11.3	11.4	11.2
Grain P concentration (g kg^{-1})		2.6	2.4	2.5	2.5
			2015		
DW (g $plant^{-1}$)	V6	12.8	13.7	9.5	10.1
	V10	80.5	75.4	61.6	65.7
	VT	115.9	123.7	105.9	113.4
N (mg $plant^{-1}$)	V6	366	377	271	260
	V10	1451 a[‡]	1303 ab	1066 b	1204 ab
	VT	1235	1307	1071	1121
P (mg $plant^{-1}$)	V6	46	48	34	35
	V10	256 a	224 b	190 b	205 b
	VT	269	271	240	250
Grain yield (Mg ha^{-1})		7.9	7.5	7.1	7.4
Grain N concentration (g kg^{-1})		9.9	9.0	9.7	9.1
Grain P concentration (g kg^{-1})		2.6	2.5	2.6	2.6

† V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 3.6. Interaction effect for hybrid and fertilizer placement on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration in Ottawa.

		P1151AM			P1105AM		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
				2014			
DW (g plant^{-1})	V6†	5.9	6.3	4.9	5.2	5.6	4.1
	V10	72	63	50	60	62	51
	VT	164	163	137	146	144	124
N (mg plant^{-1})	V6	250	289	206	218	256	166
	V10	2223	1961	1255	1879	2058	1361
	VT	2911	3150	1969	2974	2898	1933
P (mg plant^{-1})	V6	30	32	27	26	28	21
	V10	287 a‡	252 ab	170 c	226 b	255 ab	179 c
	VT	394	398	314	385	380	295
Grain yield (Mg ha^{-1})		9.3 a	8.8 bc	5.8 e	9.0 ab	8.5 c	6.5 d
Grain N concentration (g kg^{-1})		11.9 a	12.1 a	10.2 b	11.9 a	12.1a	9.7 c
Grain P concentration (g kg^{-1})		2.5	2.5	2.7	2.4	2.5	2.5
				2015			
DW (g plant^{-1})	V6	12.9	12.1	8.5	14.2	12.7	8.8
	V10	78	82	53	80	79	53
	VT	122	126	85	125	135	95
N (mg plant^{-1})	V6	384	370	202	393	366	196
	V10	1477	1614	685	1424	1565	772
	VT	1273	1570	617	1335	1612	695
P (mg plant^{-1})	V6	46	43	31	49	44	32
	V10	256	248	164	231	246	167
	VT	275	277	211	265	301	216
Grain yield (Mg ha^{-1})		9.5 a	9.5 a	3.4 c	9.1 a	9.1 a	4.1 b
Grain N concentration (g kg^{-1})		9.7 ab	9.8 a	9.8 a	9.2 c	9.4 bc	8.5 d
Grain P concentration (g kg^{-1})		2.6	2.5	2.8	2.4	2.5	2.7

† V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 3.7. Corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration as affected by tillage, hybrid and fertilizer placement in Ottawa.

		Tillage		Hybrid		Fertilizer Placement		
		No-till	Strip-till	P1151 AM	P1105 AM	Broadcast	Sub-surface band	Control
					2014			
DW (g plant^{-1})	V6[†]	5.2	5.5	5.8 a[‡]	5 b	5.6 b	6 a	4.5 c
	V10	61	59	62	58	66 a	62 a	51 b
	VT	153 a	140 b	155 a	138 b	153 a	154 a	130 b
N (mg plant^{-1})	V6	233	228	248 a	213 b	234 b	272 a	186 c
	V10	1829	1750	1813	1766	2051 a	2009 a	1308 b
	VT	2718	2561	2677	2602	2942 a	3024 a	1951 b
P (mg plant^{-1})	V6	28	28	30 a	25 b	28 b	30 a	24 c
	V10	237	219	236	220	256 a	253 a	175 b
	VT	373	349	369	353	390 a	389 a	304 b
Grain yield (Mg ha^{-1})		8.1	7.9	8.0	8.1	9.2 a	8.7 b	6.2 c
Grain N concentration (g kg^{-1})		11.3 a	10.9 b	11.1	11.2	11.6 a	11.8 a	10.0 b
Grain P concentration (g kg^{-1})		2.5	2.5	2.6 a	2.5 b	2.4 b	2.5 a	2.6 a
					2015			
DW (g plant^{-1})	V6	13 a	10 b	11	12	14 a	12 b	9 c
	V10	78 a	64 b	71	71	79 a	80 a	53 b
	VT	120 a	110 b	111	119	124 a	131 a	90 b
N (mg plant^{-1})	V6	372 a	265 b	318	319	389 a	368 a	199 b
	V10	1377 a	1135 b	1259	1254	1450 a	1590 a	729 b
	VT	1271	1096	1153	1214	1304 b	1591 a	656 c
P (mg plant^{-1})	V6	47 a	35 b	40	42	48 a	43 b	31 c
	V10	240 a	197 b	223	215	244 a	247 a	165 b
	VT	270	245	255	261	270 a	289 a	214 b
Grain yield (Mg ha^{-1})		7.7	7.2	7.5	7.4	9.3 a	9.3 a	3.8 b
Grain N concentration (g kg^{-1})		9.4	9.4	9.8 a	9.0 b	9.4 ab	9.6 a	9.2 b
Grain P concentration (g kg^{-1})		2.6	2.6	2.6	2.6	2.5 b	2.5 b	2.8 a

[†] V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 3.8. Levels of significance for N and P uptake and biomass accumulation for corn at different growth stages, grain yield and grain nutrient concentration in Scandia.

Parameters	V6 growth stage			V10 growth stage			VT growth stage			Grain Yield	Grain Nutrient Concentration	
	DW[†]	N	P	DW	N	P	DW	N	P		N	P
	p > F											
	2014											
Tillage (T)	0.350	0.482	0.238	0.351	0.325	0.240	0.169	0.815	0.638	0.649	0.630	0.943
Hybrid (H)	0.013*	0.024*	0.111	0.171	0.158	0.082*	0.928	0.816	0.458	0.973	0.050*	0.902
T x H	0.263	0.320	0.460	0.071*	0.126	0.221	0.465	0.341	0.251	0.471	0.889	0.719
Fertilizer (F)	0.003*	<0.001*	<0.001*	0.186	0.440	0.128	0.041*	0.297	0.084*	0.047*	0.525	0.042*
T x F	0.361	0.801	0.870	0.830	0.614	0.724	0.637	0.685	0.393	0.255	0.410	0.546
F x H	0.331	0.510	0.428	0.379	0.571	0.748	0.412	0.780	0.756	0.569	0.830	0.694
T x F x H	0.575	0.792	0.980	0.035*	0.035*	0.016*	0.415	0.619	0.771	0.145	0.531	0.375
	2015											
Tillage (T)	0.162	0.715	0.749	0.591	0.931	0.824	0.56	0.342	0.736	0.351	0.671	0.226
Hybrid (H)	0.815	0.664	0.285	0.521	0.464	0.868	0.207	0.516	0.747	0.836	0.009*	0.026
T x H	0.287	0.413	0.128	0.401	0.522	0.438	0.561	0.390	0.480	0.232	0.366	0.989
Fertilizer (F)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0.103	0.293	0.334	<0.001*	0.013*	<0.001*
T x F	0.397	0.622	0.983	0.837	0.804	0.754	0.463	0.848	0.886	0.054*	0.758	0.128
F x H	0.945	0.973	0.281	0.613	0.611	0.459	0.271	0.290	0.247	0.119	0.448	0.963
T x F x H	0.066*	0.063*	0.029*	0.477	0.671	0.480	0.428	0.832	0.542	0.074*	0.014*	0.571

[†] DW, dry weight; N, nitrogen; P, phosphorus; V6, V10, VT growth stage (Abendroth et al., 2011).
* Statistically significant at 0.1 alpha level.

Table 3.9. Interaction effect for tillage and fertilizer placement on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration in Scandia.

		No-till			Strip-till		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
				2014			
DW (g plant^{-1})	V6†	21.3	20.8	17.4	18.8	21.4	16.6
	V10	115.1	113.9	106.6	120.8	125.4	110.9
	VT	151.9	157.9	136.2	145.0	143.5	133.7
N (mg plant^{-1})	V6	712	729	544	657	725	528
	V10	3262	3284	3209	3633	3895	3323
	VT	3049	3314	2785	3258	3125	2933
P (mg plant^{-1})	V6	72	75	44	68	67	41
	V10	353	355	310	417	375	336
	VT	324	339	265	338	285	274
Grain yield (Mg ha^{-1})		14.0	12.5	11.7	12.5	13.4	11.6
Grain N concentration (g kg^{-1})		12.4	12.4	12.1	12.1	12.4	12.3
Grain P concentration (g kg^{-1})		2.3	2.2	2.0	2.2	2.2	2.1
				2015			
DW (g plant^{-1})	V6	12.5	11.4	9.4	12.2	10.1	8.2
	V10	69.6	60.7	48.3	70.4	57.9	45.9
	VT	125.4	135.5	120.0	139.4	133.3	120.3
N (mg plant^{-1})	V6	311	291	241	313	289	219
	V10	1417	1073	849	1412	1154	796
	VT	1306	1466	1303	1491	1771	1407
P (mg plant^{-1})	V6	41	36	27	40	36	26
	V10	198	135	106	193	148	105
	VT	249	255	224	274	257	225
Grain yield (Mg ha^{-1})		12.6 a‡	11.5 b	9.7 c	12.1 a	12.4 a	10.0 c
Grain N concentration (g kg^{-1})		8.7	9.1	8.6	8.7	9.1	8.4
Grain P concentration (g kg^{-1})		2.6	2.4	2.2	2.5	2.2	2.3

† V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 3.10. Interaction effect for tillage and hybrid on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration in Scandia.

		No-till		Strip-till	
		P1151 AM	P1105 AM	P1151 AM	P1105 AM
			2014		
DW (g plant^{-1})	V6[†]	20.8	18.8	21.0	16.9
	V10	121.4 a[‡]	102.3 b	117.4 ab	120.7 a
	VT	150.9	146.5	139.0	142.5
N (mg plant^{-1})	V6	693	630	704	570
	V10	3638	2866	3598	3635
	VT	3126	2972	2981	3230
P (mg plant^{-1})	V6	66	62	64	53
	V10	388	290	386	366
	VT	315	304	276	321
Grain yield (Mg ha^{-1})		12.9	12.5	12.4	12.6
Grain N concentration (g kg^{-1})		12.5	12.2	12.4	12.1
Grain P concentration (g kg^{-1})		2.2	2.2	2.2	2.2
			2015		
DW (g plant^{-1})	V6	11.4	10.9	10.0	10.3
	V10	59.9	59.3	56.0	60.2
	VT	124.7	129.2	125.3	136.7
N (mg plant^{-1})	V6	283	279	266	281
	V10	1109	1117	1059	1183
	VT	1375	1342	1441	1672
P (mg plant^{-1})	V6	37	33	34	34
	V10	151	141	146	152
	VT	254	231	248	257
Grain yield (Mg ha^{-1})		11.1	11.4	11.6	11.4
Grain N concentration (g kg^{-1})		9.0	8.6	9.1	8.4
Grain P concentration (g kg^{-1})		2.5	2.3	2.4	2.3

† V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 3.11. Interaction effect for hybrid and fertilizer placement on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration in Scandia.

		P1151AM			P1105AM		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
				2014			
DW (g plant^{-1})	V6[†]	21.2	23.4	18.1	19.0	18.8	16.0
	V10	118	126	109	116	107	106
	VT	144	155	133	154	146	134
N (mg plant^{-1})	V6	720	802	577	645	650	501
	V10	3511	3768	3227	3246	3087	3105
	VT	3140	3265	2702	3066	3217	2973
P (mg plant^{-1})	V6	72	79	44	68	64	41
	V10	403	404	333	356	311	294
	VT	327	317	246	320	323	290
Grain yield (Mg ha^{-1})		13.6	12.6	11.5	12.8	13.2	11.7
Grain N concentration (g kg^{-1})		12.4	12.5	12.4	12.1	12.2	12.0
Grain P concentration (g kg^{-1})		2.3	2.2	2.1	2.2	2.2	2.0
				2015			
DW (g plant^{-1})	V6	12.3	10.8	8.9	12.4	10.7	8.7
	V10	70	60	44	70	59	50
	VT	130	135	110	135	134	131
N (mg plant^{-1})	V6	308	288	228	316	292	231
	V10	1424	1095	732	1405	1131	913
	VT	1478	1593	1154	1320	1644	1557
P (mg plant^{-1})	V6	40	38	27	41	34	26
	V10	201	147	98	191	135	114
	VT	285	266	202	239	246	246
Grain yield (Mg ha^{-1})		12.6	11.8	9.6	12.1	12.0	10.1
Grain N concentration (g kg^{-1})		9.0	9.2	8.9	8.4	8.9	8.1
Grain P concentration (g kg^{-1})		2.7	2.4	2.4	2.5	2.2	2.2

[†] V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.

[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 3.12. Corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration as affected by tillage, hybrid and fertilizer placement in Scandia.

		Tillage		Hybrid		Fertilizer Placement		
		No-till	Strip-till	P1151 AM	P1105 AM	Broadcast	Sub-surface band	Control
				2014				
DW (g plant^{-1})	V6[†]	20	19	21 a[‡]	18 b	20 a	21 a	17 b
	V10	112	119	119	112	118 ab	120 a	109 b
	VT	149	141	145	145	149 a	151 a	135 b
N (mg plant^{-1})	V6	661	637	698 a	600 b	685 a	727 a	536 b
	V10	3252	3617	3618	3251	3448	3590	3266
	VT	3049	3105	3054	3101	3154	3219	2859
P (mg plant^{-1})	V6	64	59	65	58	70 a	71 a	42 b
	V10	339	376	387 a	328 b	385 a	365 ab	323 b
	VT	309	299	295	313	331 a	312 ab	270 b
Grain yield (Mg ha^{-1})		12.7	12.5	12.6	12.7	13.3 a	12.9 a	11.7 b
Grain N concentration (g kg^{-1})		12.3	12.2	12.4 a	12.1 b	12.3	12.4	12.2
Grain P concentration (g kg^{-1})		2.2	2.2	2.2	2.2	2.3 a	2.2 ab	2.1 b
				2015				
DW (g plant^{-1})	V6	11	10	11	11	12 a	11 b	9 c
	V10	60	58	58	60	70 a	59 b	47 c
	VT	127	131	125	133	132 a	134 a	120 b
N (mg plant^{-1})	V6	281	274	275	280	312 a	290 a	230 b
	V10	1113	1121	1084	1150	1415 a	1113 b	823 c
	VT	1358	1557	1408	1507	1399	1618	1355
P (mg plant^{-1})	V6	35	34	35	34	41 a	36 b	27 c
	V10	147	149	149	147	196 a	141 b	106 c
	VT	243	252	251	244	262	256	224
Grain yield (Mg ha^{-1})		11.3	11.5	11.4	11.5	12.4 a	11.9 a	9.9 b
Grain N concentration (g kg^{-1})		8.8	8.7	9.0 a	8.5 b	8.7 b	9.1 a	8.5 b
Grain P concentration (g kg^{-1})		2.4	2.3	2.5 a	2.3 b	2.6 a	2.3 b	2.3 b

[†] V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Chapter 4 - Soybean Cultivar Response to No-till and Strip-till with Surface and Subsurface Fertilization

Abstract

Soybean (*Glycine max* (L.) Merr.) response to fertilization can be variable according to the method of application method and tillage, and has not evaluated extensively. The objective of this study was to evaluate the effects of P fertilizer placement, tillage system on soybean production with different genotypes. The study was established at four site-years in Kansas. The experimental design was a split-plot in a randomized complete block design with four replications. Three P fertilizer treatments and two different tillage operations were combined with two soybean genotypes selected based on contrasting root systems. The three fertilizer placements were sub-surface band, broadcast, and control. The two soybean varieties were included, one intended for poor drainage (PD) and another for good drainage (GD). The two tillage operations were no-till (NT) and strip-till (ST). Treatments rates were calculated based on nutrient sufficiency recommendation. Roots and plant tissue samples were collected during the vegetative and reproductive growth stage to evaluate above ground biomass and nutrient uptake. Seed yield was recorded at harvest and analyzed for nutrient concentration. Root biomass accumulation among varieties was different and varies by site. Sub-surface band treatment favored early growth (V3 growth stage) biomass and P uptake but it did not turn into yield gains. Soybean seed yield did not respond to P fertilization in this study. Yield differences were affected by variety selection and vary by site.

Abbreviations: PD, poor drainage variety; GD, good drainage variety; NT, no-till; ST, strip-till.

Introduction

No-till (NT) maintains crop residue on the soil surface reducing temperature as well as increase in water storage in the soil. The yield response of soybean to P fertilization can be affected by water availability in the soil. The lack of moisture in the surface layers of soil may limit plant nutrient uptake (Kaspar et al., 1989). According to Marais and Wiersma (1975), the lack of water in the soil leads to reduced P uptake by roots due the decreasing rate of P diffusion in the soil. Soybeans are usually planted later in the spring, when soils are warmer and dryer, compared to conditions faced by corn in early spring. Thus, strip-till (ST) is not a common practice prior soybean. Strip-till can reduce the soil nutrient stratification in the surface layer by disturbing the first 15 cm of soil, and also allow the fertilizer band application. Past studies, though, found that reduced tillage do not prejudice soybean yield gain (Bharati et al., 1986). Erbach, D.C. (1982) conducted a study in Iowa testing different tillage systems and found no response of soybean to any tillage.

Response to P fertilization in soybeans is unlikely when the soil P levels are high and very high (deMooy et al., 1973; Mallarino and Borges, 2005). At a low soil P level, Cihacek et al. (1991) found little yield response to P fertilization and attributed less importance to the method of P application but rather to whether or not P was applied. Kalra and Soper (1968) suggested that soybeans might be less responsive to P compared to other crops due to its greater nutrient absorption efficiency. Even though, Bullen et al. (1983) reported that band application of P near soybean seeds yielded more than broadcast treatment. In Mississippi, Hairston et al. (1990) showed greater soybean seed yield at deep band of P and K treatment over broadcast in a low soil test P and K. In contrast, a study made by Lutz and Jones (1974) found broadcast P application with greater soybean yields when compared to deep band application. Iowa research with NT soybean (Borges and Mallarino, 2000; Buah et al., 1999) showed that P fertilization often increased yield in low-testing soils but band or broadcast placement methods did not differ.

Nutrient acquisition is highly dependent of the root systems, more specifically to characteristics that can identify the root architecture of the plant (Gregory, 2011). Therefore, different rooting systems can show a significant interaction with fertilizer application method as well as with tillage.

The objective of this study was to evaluate the effects of fertilizer placement and tillage system on soybean aboveground dry matter, nutrient concentration in tissue, nutrient uptake, seed yield and seed nutrient concentration using two different varieties. In addition, this study aims to find possible differences in root characteristics among those varieties in the field.

Materials and Methods

Four soybean sites were established in 2014 and 2015. Sites 1 and 2 were in Ottawa, Kansas (38°32´19″N; 95°15´11″W) on a Woodsen silt loam soil (fine, smectitic, thermic Abruptic Argiaquolls) with poor drainage conditions. Sites 3 and 4 were in Scandia, Kansas (39°46´23″N; 97°47´19″W) on a Crete silt loam soil (fine, smectitic, mesic Pachic Argiustolls) with good drainage conditions. Description of each site is presented in Table 4.1. Row spacing was 76 cm; plot size was 12.2 m in length and 3 m in width (36.6 m^2) – in all sites.

Experimental design was a split-plot in a randomized complete block design, where tillage and variety were whole plots and fertilizer placement was split-plot, with four replications. Fertilizer treatments consisted of a control, sub-surface band only and broadcast only. These three fertilizer treatments were combined with two different varieties selected based on contrasting root systems and two different tillage operations. Three genotypes of soybeans were selected based on possible differences in environment response, being Pioneer 94Y40 (Pioneer Hi-Bred, Johnston, IA) and Pioneer 93Y20 (Pioneer Hi-Bred, Johnston, IA) considered highly suitable in poor drained areas (PD) and Pioneer P44T63R (Pioneer Hi-Bred, Johnston, IA), which perform better in good drainage conditions (GD). The two tillage operations were no-till (NT) and strip-till (ST). Sub-surface band fertilizer was applied 15 cm deep in the soil, 2-3 weeks before planting using the ST applicator Yetter (Yetter Mfg., Colchester, IL) pull caddy with Maverick Generation 2 openers and residue managers (model 2984) and a 5 cm mole knife, equipped with a Gandy Orbit Air model 623016 box and metering system (Gandy Co, Owatanna, MN). For NT was applied starter (5 cm deep and 5 cm to the side of the seed) with the planter. Broadcast treatments were applied at planting. At Scandia and Ottawa, sub-surface band treatment rate was 23 kg ha^{-1} N as UAN (28-0-0, N-P2O5-K2O respectively) and 45 kg ha^{-1} P_2O_5 as ammonium polyphosphate (10-34-0). Broadcast and starter treatment rates were the same as sub-surface band. Broadcast sources were Urea (45-0-0) and MAP (11-52-0). Treatments rates can be considered commonly used by producers in a corn-soybean rotation based on nutrient sufficiency recommendation.

A composite soil sample of 20 cores was collected from each replication (block). Extractable P was determined by the Mehlich-3 method (Frank, 1998) and extracts analyzed using inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia). Extractable K was determined by the ammonium acetate method (Warncke, 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson, 1998), and soil organic matter (OM) was determined by Walkley–Black method (Combs, 1998).

Plant tissue samples were taken during the vegetative and reproductive growth stage. Whole plant samples were taken at V3-V5 growth stage (Pedersen, 2003). This was accomplished by removing ten soybean plants at random from non-harvest rows of each plot. Thirty uppermost trifoliate (without the petiole) were collected from the middle two rows at the R3 growth stage (Pedersen, 2003). Plants were weighted and dried in a forced air oven at 70 °C for a minimum of 6 days and weighted for biomass calculation. Once dry and weighted, plants were ground then analyzed for total nitrogen (N) and P. Total N and P were analyzed by sulfuric peroxide digest as described by Lindner and Harley (1942). Nitrogen digest was analyzed by an indophenol blue colorimetric procedure using the Rapid Flow Analyzer (Model RFA-300; Alpkem Corporation, Clackamas, Oregon, USA). Phosphorus was determined using inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia). Biomass weight and concentration in tissue were used to calculate N and P uptake. Root samples were collected from the control plots, with no treatment application, to evaluate possible differences in rooting system among genotypes. Ten root samples of each variety were dug from the soil using a shovel at V3 and R3 growth stages. Root samples were collected at 20 cm deep and 40 cm diameter around the stem giving the total root biomass per volume of soil. Soil was removed by hand in the field as much as possible with minimum root loss. Later, roots collected were washed with water, dried at 65°C for six days and weighted to get the total dry weight.

The two central rows of each plot were machine harvested. Seed weight was recorded and adjusted for 130 g kg^{-1} moisture. Seed was dried at 60°C for a minimum of four days, ground to a powder and digested with a sulfuric acid and hydrogen peroxide digest (Thomas, 1967). Samples were then analyzed as previously described for leaf samples.

Data was analyzed by site using PROC GLIMMIX in SAS 9.2 (SAS, 2011) assuming block as a random factor in the model. The starter treatment was analyzed as part of the sub-surface band treatment. Separation of means at a significant level of $p \leq 0.10$ was completed using the LINES option in PROC GLIMMIX.

Results and Discussion

Root System Analysis

Root characteristics showed significant differences in soybean (Table 4.2). The interaction of variety by growth stage showed significant differences in Ottawa 2014 where PD variety showed greater root biomass at the R3 growth stage. This result suggests a possible advantage in nutrient and water uptake (Mengel, 1995) towards the end of the season (Mengel, 1995).

Root dry weight accumulation in the soybean varieties showed different results by site. In 2015, the PD variety was found to have 75% more root dry weight in Scandia, but had 23% less root biomass than GD variety in Ottawa for the same year (Table 4.2). The PD variety likely was stimulated by the lower soil P test from Scandia (11 mg kg^{-1}), increasing root growth. Similar results in root growth stimulated by low P availability were found by Lynch and Brown (2008). On the other hand, in Ottawa, the GD variety probably induced root growth trying to adapt to a wet, poorly drained soil. On average, root dry weight increased 225% in Ottawa and 290% in Scandia from V3 to R3 growth stage for both years of study (Table 4.2).

Dry Weight Accumulation

Above ground dry weight accumulation responded to the tillage by fertilizer placement interaction in Ottawa 2014 (Table 4.3), but did not show a significant difference in Scandia (Table 4.4). Strip-till combined with sub-surface band increased soybean dry weight compared to

NT under sub-surface band fertilization (Table 4.5). In addition, the other combinations of ST had greater g plant^{-1} than NT with any fertilizer placement for Ottawa 2014. Strip-till probably contributed for the early growth of soybean by breaking any possible soil compaction and increased nitrogen mineralization, potentially beneficial at this early growth stage (Ritchie et al., 1985). No significant differences were found for tillage by variety at any site-year (Table 4.6).

Differences in total biomass accumulation were mostly due to fertilizer placement treatments. In 2 out of 4 site-years (Ottawa 2014 and Scandia 2015), sub-surface band was found to have significantly increased dry weight when compared to broadcast and control at V3 growth stage (Table 4.7). The sub-surface band fertilization places the fertilizer in closer proximity to the soybean root, providing nutrients for soybean development. Previous studies also report advantages of banded applications for early growth in soybean (Mallarino and Haden, 2004). In Ottawa 2015, sub-surface band and broadcast showed similar dry weight accumulation at V3 growth stage, and both were greater compared to control (Table 4.7). In Scandia 2014 no differences were found in soybean dry weight response to fertilizer placement treatments (Table 4.7).

Strip-till was found to increase soybean dry weight at the V3 growth stage in Ottawa 2014, but not at the other sites (Table 4.7). These results are similar to previous studies showing the lack of soybean response to tillage (Randall et al., 2001a).

Ottawa 2015 was the only site that showed statistical differences in dry weight for soybean varieties, where the PD variety showed 3.2 g plant^{-1} versus 3.0 g plant^{-1} from the GD variety at V3 growth stage (Table 4.7). This result can be due to the suitability of the PD variety to poorly drained soils which applied to conditions found in Ottawa.

Nutrient Concentration in Tissue and Uptake

Nutrient uptake at V3 growth stage and nutrient concentration in tissue at R3 growth stage showed significant differences for the main factors evaluated in Ottawa (Table 4.3) and Scandia (Table 4.4). No interaction effect was found regarding tillage by fertilizer or tillage by variety at any site for nutrient uptake in soybean (Table 4.5 and 4.6). On the other hand, the interaction tillage by fertilizer was found to be significant for nutrient concentration at R3 in Ottawa 2015, where NT by sub-surface band accumulated more P in tissue compared to ST by sub-surface band (Table 4.5).

Regarding nutrient uptake at V3 growth stage, the fertilizer placement factor showed significant differences at Ottawa and at Scandia. Sub-surface band treatment had greater effects on uptake compared to broadcast at both sites (Table 4.7). This result can be explained by the proximity of the fertilizer band to the root system, and agrees with Borges and Mallarino (2000) where banded P applications increased P uptake compared to broadcast. Both fertilizer treatments increased P uptake compared to the control. Nitrogen and P tissue concentration at R3 growth stage were found to be in the sufficiency range (42.5 to 55.0 g kg^{-1} for N; 2.5 to 5.0 g kg^{-1} for P) (Mengel, 2015) in all site-years regardless of fertilizer placement used (Table 4.7). Nevertheless, two out of four site-years showed differences in nutrient concentration according to fertilizer placement. In Ottawa 2015 the control treatment showed greater N concentration in the tissue compared to broadcast, but similar to sub-surface band (Table 4.7). The reduced rainfall amount towards the reproductive stage of soybean probably contributed for the lack of response of fertilization in Ottawa, especially for P. According to Hanway and Weber (1971), 75% of total P uptake by soybeans is done in the reproductive stages. In Scandia 2015 the broadcast treatment increased the P concentration in tissue when compared to sub-surface band

and control (Table 4.7). This result can be explained by the fact that Scandia site showed P levels in the soil below the critical level (Table 4.1) for response to fertilization in Kansas which is 20 mg kg^{-1} (Leikam, 2003).

Strip-till treatment resulted in greater N and P uptake than NT only in Ottawa 2014 (Table 4.7). This result can be attributed to soil mineralization due the tillage enhancing the organic matter mineralization and breaking a possible stratification layer in the surface increasing nutrient availability.

Varieties did not show significant differences at any site for nutrient uptake at V3 growth stage (Table 4.7). Increased root biomass at R3 stage of PD variety probably helped to reach greater N and P concentration in tissue over the GD variety at Ottawa 2014 and Scandia 2015 (Table 4.7). Mengel (1995) explained that the ability of the plant to produce more roots increases nutrient uptake sites and consequently the nutrient absorption.

Seed Yield

Soybean seed yield showed few differences among the treatments in this study (Table 4.3 and 4.4). No interaction effect of tillage by fertilizer (Table 4.5) or tillage by variety (Table 4.6) was found for soybean yield.

No significant differences were found for fertilizer placement at any site-year (Table 4.7). Those results agree with past studies where band applications of P were similar to broadcast for soybeans (Borges and Mallarino, 2000; Buah et al., 1999). This study reinforces previous research reporting a likely lower critical level for soil test P for soybean compared to other crops (Arns and Ruiz Diaz, 2012). It is important to mention, though, that when P is not applied, the soil P levels will drop and yield reduction happen due to insufficient P (Randall et al., 1997).

Supporting the soil characteristics of Scandia, results regarding tillage showed greater yields under NT system only in 2014 (Table 4.7). The water retention under NT system probably contributed for late growth stages, especially during seed filling when rainfall decreases considerably in Kansas. Although NT showed response in one site year, the tillage factor influence in soybean yields was not consistent. This result agrees with Elmore (1987) and Randall et al. (2001a) who conducted studies finding no significant response of soybean yields to different tillage systems.

Poor drainage variety yielded 27% more than GD variety in Ottawa 2014 (Table 4.7). A different result was found in Scandia where the GD variety had greater seed yield in both years (Table 4.7). These results can be explained by the suitability of each variety associated with soil characteristics of each site of study where Scandia is a silt-loam soil with a good drainage system and Ottawa is a silt loam soil with bad drainage conditions.

Seed Nutrient Concentration

The interaction NT by sub-surface band increased seed P concentration when compared to ST by sub-surface band in Scandia 2015 (Table 4.5). No significant differences were found in the interaction tillage by variety regarding seed nutrient concentration (Table 4.6).

Soybean seed nutrient concentration showed differences in 3 out of 4 site-years for fertilizer placement (Table 4.7). In Ottawa 2015, fertilizer placement influenced soybean seed P concentration. Broadcast was found to contribute for greater seed P concentration over sub-surface band and control treatments (Table 4.7). This result agrees with Farmaha et al. (2012) who found responses to P fertilization not only in tissue but also in seed concentration. Similar result was found in Scandia 2014. Assuming that 2015 registered greater amounts of precipitation than 2014 (Scandia had supplemental irrigation), broadcast probably help the soybean in late uptake since roots closer to soil surface could benefit from this sort of application. Scandia 2015 registered significantly greater seed P concentration under broadcast or sub-surface band treatments over the control, but no significant differences were found among fertilized treatments (Table 4.7).

Tillage, as a main factor, did not have any influence in the soybean seed N and P concentration. Varieties of soybean showed differences in seed nutrient concentration. In Ottawa 2015 and Scandia 2015 PD variety showed greater N seed concentration than the GD variety (Table 4.7). In Ottawa 2015 GD variety showed greater P seed concentration compared to PD variety (Table 4.7). This result can be explained by the greater root dry weight found for GD variety at Ottawa 2015. Since P is an immobile nutrient, the increased root biomass probably induced the greater absorption of P by GD variety.

Conclusions

Differences in soybean root dry weight among genotypes were not consistent. The interaction of variety by growth stage showed greater root biomass for PD variety at R3 growth stage compared to GD variety only in one site. Root biomass accumulation among varieties was different and varies by site.

Sub-surface band treatment increased soybean above ground biomass accumulation at early growth stage in 2 out of 4 sites. It also contributed for greater P uptake by soybean compared to broadcast and control at V3-V5 growth stage. However, trifoliate concentrations revealed that at reproductive stage soybean N and P uptake were similar among fertilizer treatments.

Although sub-surface band treatment increased most of the characteristics evaluated in this study, soybean seed yields were not significantly affected by fertilization at any site. Thus, the soil testing levels probably were sufficient to meet N and P requirements for soybeans. Even with this lack of fertilization response, if the producer chooses for not fertilize before soybean production, in a long term management, the fertility levels tend to decrease due crop removal.

Soybean yields were influenced by varieties according to the site where they were established. Poor drainage variety performed better at Ottawa while GD variety was found to have better results at Scandia site.

Tillage did not show a consistent response in soybean at any site. Thus, this result is important for farmers considering switching to conservation tillage. In case choosing NT, money and time can be saved since no operational tillage is necessary. Besides, a reduced tillage system improves soil quality and conservation.

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Table 4.1. Average soil test values, total precipitation, average temperature and planting date by site.

Site	Year	Soil test values				Precipitation‡	Average temperature§	Planting date
		STP†	STK	pH	OM			
		mg kg^{-1}			g kg^{-1}	mm	°C	
1	2014	23	150	6.5	28	481	21.7	16-May
2	2015	21	124	6.6	26	276	23.3	10-Jun
3	2014	13	504	6.6	32	538	21.2	21-May
4	2015	11	481	6.6	31	467	21.5	9-Jun

† STP, soil test for phosphorus (Mehlich-3 method); STK, soil test for potassium (Ammonium acetate method); pH (1:1 soil:water ratio); OM, organic matter (Walkley-Black method).
‡ Total precipitation during May to October in 2014 and May to October in 2015 growing season. Sites 3 and 4 received supplemental irrigation.
§Average temperature during May to October in 2014 and May to October in 2015 growing season.

Table 4.2. Soybean root dry weight by variety and growth stage in Ottawa and Scandia. Samples collected from the control treatment only.

Variety/ growth stages		Ottawa		Scandia	
		2014	2015	2014	2015
		- - - - - - - - - - - - - - - g - - - - - - - - - - - - - - -			
		Variety			
PD†		0.8	0.23 b‡	0.72	0.70 a
GD		0.51	0.30 a	0.67	0.40 b
		Growth stage			
V3		0.24 b	0.17 b	0.48 b	0.16 b
R3		1.07 a	0.35 a	0.92 a	0.94 a
		Variety by Growth stage			
PD	V3	0.15 c	0.13	0.39	0.2
GD	V3	0.32 bc	0.22	0.56	0.12
PD	R3	1.45 a	0.33	1.05	1.21
GD	R3	0.69 b	0.37	0.78	0.68
		- - - - - - level of significance ($p > F$) - - - - - - -			
Variety (V)		0.131	0.067*	0.738	0.094*
Growth stage (GS)		0.001*	0.001*	0.008*	0.001*
V x GS		0.025*	0.483	0.143	0.197

† PD, poor drainage variety; GD, good drainage variety; V3, R3 growth stage (Pedersen, 2003).

‡ Numbers followed by different letters within rows for each main effect and the interaction of genotype and growth stage represent statistically significant differences at the $p \leq 0.10$.

* Statistically significant at 0.1 alpha level.

Table 4.3. Levels of significance for biomass accumulation, N and P uptake at V3 growth stage; and N and P concentration at R3 growth stage and in the seed, as well as yield for soybean in Ottawa.

	V3 growth stage			R3 growth stage		Seed Yield	Seed Nutrient	
Parameters	DW[†]	N uptake	P uptake	N	P		N	P
				p > F				
				2014				
Tillage (T)	*0.008	0.070	*0.011	0.293	0.822	0.203	0.732	0.907
Variety (V)	0.795	0.953	0.739	*0.002	*0.059	*<0.001	0.230	0.784
T x V	0.481	0.374	0.944	0.629	0.117	0.404	0.282	0.687
Fertilizer (F)	*0.007	*<0.001	*<0.001	0.759	0.538	0.415	0.151	0.142
T x F	*0.084	0.337	0.690	0.506	0.544	0.902	0.514	0.205
F x V	0.118	0.174	*0.024	0.529	0.969	0.225	0.777	0.346
T x F x V	0.297	0.857	0.628	0.540	0.642	0.287	0.924	0.192
				2015				
Tillage (T)	0.433	0.388	0.934	0.779	0.548	0.869	0.338	0.789
Variety (V)	*0.078	0.181	0.214	0.974	0.771	0.877	*0.091	*<0.001
T x V	0.455	0.181	0.219	0.351	0.336	0.554	0.807	0.658
Fertilizer (F)	*0.053	*0.056	*0.002	*0.098	0.967	0.886	0.603	*0.004
T x F	0.499	0.562	0.866	0.149	*0.030	0.515	0.570	0.155
F x V	*0.081	*0.033	*0.055	0.714	0.750	0.456	0.363	0.328
T x F x V	0.196	0.230	0.215	0.710	0.847	0.106	0.139	0.347

[†] V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus;

* Statistically significant at 0.1 alpha level.

Table 4.4. Levels of significance for biomass accumulation, N and P uptake at V3; N and P concentration at R3 growth stage, seed yield and seed nutrient concentration for soybean in Scandia.

Parameters	V3 growth stage			R3 growth stage		Seed Yield	Seed Nutrient	
	DW†	N uptake	P uptake	N	P		N	P
				- - - p > F - - -				
				2014				
Tillage (T)	0.464	0.516	0.960	0.506	0.342	*0.069	0.547	0.833
Variety (V)	0.249	0.280	*0.060	0.495	0.943	*0.003	0.213	0.328
T x V	0.423	0.364	0.351	0.152	0.313	0.429	0.566	0.195
Fertilizer (F)	0.239	*0.083	*0.041	*0.086	*<0.001	0.265	0.476	*<0.001
T x F	0.897	0.765	0.957	0.970	0.517	0.681	0.463	0.451
F x V	0.245	0.195	0.160	0.644	0.961	0.306	0.399	*0.015
T x F x V	0.677	0.540	0.494	0.458	0.141	0.502	0.221	0.284
				2015				
Tillage (T)	0.327	0.209	0.322	0.451	0.201	0.512	0.864	0.581
Variety (V)	0.854	0.600	0.555	*0.038	0.635	*0.040	*0.017	0.719
T x V	0.554	0.561	0.468	0.734	0.529	0.660	0.939	0.947
Fertilizer (F)	*0.005	*<0.001	*<0.001	0.546	*<0.001	0.218	0.392	*<0.001
T x F	0.534	0.588	0.383	0.233	0.189	0.259	0.243	*0.019
F x V	0.659	0.512	0.720	0.539	0.672	0.509	0.277	0.812
T x F x V	0.742	0.791	0.748	0.830	0.928	0.554	0.945	0.688

† V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus;

* Statistically significant at 0.1 alpha level.

Table 4.5. Interaction effect for tillage and fertilizer placement on soybean biomass accumulation, nutrient uptake and nutrient concentration in tissue at different growth stages, seed yield and seed nutrient concentration.

		No-till			Strip-till		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
				Ottawa 2014			
DW (g $plant^{-1}$)	V3[†]	1.06 d[‡]	1.11 cd	1.06 d	1.28 b	1.50 a	1.22 bc
N (mg $plant^{-1}$)	V3	30	32	27	35	39	29
N (g kg^{-1})	R3	48	48	47	48	48	49
P (mg $plant^{-1}$)	V3	2.8	3.6	2.4	3.4	4.0	2.9
P (g kg^{-1})	R3	2.9	3.0	2.9	3.0	3.0	3.0
Seed yield (Mg ha^{-1})		1.5	1.6	1.5	1.6	1.7	1.6
Seed N concentration (g kg^{-1})		59.2	60.2	58.1	58.8	60.2	59.4
Seed P concentration (g kg^{-1})		5.7	5.7	5.7	5.7	5.8	5.6
				Ottawa 2015			
DW (g $plant^{-1}$)	V3	3.2	3.3	2.9	3.2	3.1	2.9
N (mg $plant^{-1}$)	V3	89	86	72	82	79	75
N (g kg^{-1})	R3	56	57	59	57	58	58
P (mg $plant^{-1}$)	V3	8.5	9.1	7.5	8.5	8.9	7.7
P (g kg^{-1})	R3	4.2 bc	4.4 a	4.3 abc	4.4 ab	4.2 c	4.3 abc
Seed yield (Mg ha^{-1})		3.7	3.6	3.7	3.6	3.6	3.6
Seed N concentration (g kg^{-1})		59.1	59.4	60.0	59.3	58.7	59.4
Seed P concentration (g kg^{-1})		5.1	5.0	5.1	5.2	5.1	5.0
				Scandia 2014			
DW (g $plant^{-1}$)	V3	2.7	2.9	2.7	2.8	3.2	2.8
N (mg $plant^{-1}$)	V3	132	143	128	134	157	130
N (g kg^{-1})	R3	58	57	55	57	56	54
P (mg $plant^{-1}$)	V3	9.9	10.8	9.0	9.7	11.1	9.0
P (g kg^{-1})	R3	3.8	3.5	3.3	3.6	3.4	3.0
Seed yield (Mg ha^{-1})		4.2	4.1	4.1	4.0	3.9	3.8
Seed N concentration (g kg^{-1})		58.5	57.8	58.2	58.2	58.3	55.6
Seed P concentration (g kg^{-1})		4.8	4.4	4.1	4.7	4.4	4.2
				Scandia 2015			
DW (g $plant^{-1}$)	V3	1.4	1.4	1.2	1.1	1.3	1.1
N (mg $plant^{-1}$)	V3	61	70	50	52	60	47
N (g kg^{-1})	R3	51	52	52	53	53	56
P (mg $plant^{-1}$)	V3	5.7	6.0	4.4	4.5	5.6	4.0
P (g kg^{-1})	R3	4.2	4.2	3.7	4.2	4.0	3.8
Seed yield (Mg ha^{-1})		4.9	4.7	4.5	4.5	4.8	4.5
Seed N concentration (g kg^{-1})		55.1	54.9	54.0	55.0	54.4	54.9
Seed P concentration (g kg^{-1})		4.9 a	5.0 a	4.2 c	4.9 a	4.6 b	4.3 c

[†] V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus;
[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 4.6. Interaction effect for tillage and variety on soybean biomass accumulation, nutrient uptake and nutrient concentration in tissue at different growth stages, seed yield and seed nutrient concentration.

		No-till		Strip-till	
		Poor Drainage Variety	Good Drainage Variety	Poor Drainage Variety	Good Drainage Variety
			Ottawa 2014		
DW (g plant^{-1})	V3†	1.1	1.1	1.4	1.3
N (mg plant^{-1})	V3	29	30	35	33
N (g kg^{-1})	R3	49	46	50	47
P (mg plant^{-1})	V3	3.0	2.9	3.5	3.4
P (g kg^{-1})	R3	3.0	2.9	3.0	2.9
Seed yield (Mg ha^{-1})		1.8	1.3	1.9	1.4
Seed N concentration (g kg^{-1})		60	58.4	59.5	59.4
Seed P concentration (g kg^{-1})		5.7	5.7	5.7	5.7
			Ottawa 2015		
DW (g plant^{-1})	V3	3.2	3.1	3.2	2.9
N (mg plant^{-1})	V3	82	82	85	73
N (g kg^{-1})	R3	58	57	58	58
P (mg plant^{-1})	V3	8.4	8.4	8.8	8.0
P (g kg^{-1})	R3	4.3	4.3	4.2	4.3
Seed yield (Mg ha^{-1})		3.7	3.6	3.6	3.6
Seed N concentration (g kg^{-1})		60.1	58.9	59.5	58.7
Seed P concentration (g kg^{-1})		4.9	5.2	4.9	5.2
			Scandia 2014		
DW (g plant^{-1})	V3	2.6	3.0	2.9	3.0
N (mg plant^{-1})	V3	126	143	139	141
N (g kg^{-1})	R3	58	55	55	56
P (mg plant^{-1})	V3	8.9	10.9	9.6	10.3
P (g kg^{-1})	R3	3.5	3.6	3.4	3.3
Seed yield (Mg ha^{-1})		4.0	4.3	3.8	3.4
Seed N concentration (g kg^{-1})		59.2	57.1	57.8	57.0
Seed P concentration (g kg^{-1})		4.4	4.5	4.5	4.3
			Scandia 2015		
DW (g plant^{-1})	V3	1.3	1.5	1.2	1.1
N (mg plant^{-1})	V3	57	64	53	52
N (g kg^{-1})	R3	53	51	54	52
P (mg plant^{-1})	V3	5.1	6.2	4.9	4.6
P (g kg^{-1})	R3	4.0	4.1	4.0	3.9
Seed yield (Mg ha^{-1})		4.5	4.9	4.5	4.7
Seed N concentration (g kg^{-1})		55.5	53.8	55.7	54.0
Seed P concentration (g kg^{-1})		4.7	4.7	4.6	4.6

† V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Table 4.7. Soybean biomass accumulation, nutrient uptake and nutrient concentration in tissue at different growth stages, seed yield and seed nutrient concentration as affected by the main effects of tillage, variety and fertilizer placement.

		Tillage		Variety		Fertilizer Placement		
		No-till	Strip-till	PD	GD	Broadcast	Sub-surface band	Control
						Ottawa 2014		
DW (g plant^{-1})	V3[†]	1.1 b[‡]	1.3 a	1.2	1.2	1.2 b	1.3 a	1.1 b
N (mg plant^{-1})	V3	30 b	34 a	32	32	33 b	36 a	28 c
N (g kg^{-1})	R3	47.8	48.4	49.7 a	46.6 b	47.9	48.4	48.0
P (mg plant^{-1})	V3	2.9 b	3.5 a	3.2	3.2	3.1 b	3.8 a	2.7 c
P (g kg^{-1})	R3	2.9	3.0	3.0 a	2.9 b	2.9	3.0	2.9
Seed yield (Mg ha^{-1})		1.6	1.7	1.9 a	1.3 b	1.6	1.7	1.6
Seed N concentration (g kg^{-1})		59.2	59.5	59.7	58.9	59.0	60.2	58.7
Seed P concentration (g kg^{-1})		5.7	5.7	5.7	5.7	5.7	5.7	5.6
						Ottawa 2015		
DW (g plant^{-1})	V3	3.1	3.1	3.2 a	3.0 b	3.2 a	3.2 a	2.9 b
N (mg plant^{-1})	V3	82.4	78.7	83.6	77.5	85.8 a	82.1 a	73.6 b
N (g kg^{-1})	R3	57.5	57.8	57.7	57.7	56.9 b	57.5 ab	58.6 a
P (mg plant^{-1})	V3	8.4	8.4	8.6	8.2	8.6 a	9.0 a	7.6 b
P (g kg^{-1})	R3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Seed yield (Mg ha^{-1})		3.6	3.6	3.6	3.6	3.6	3.6	3.6
Seed N concentration (g kg^{-1})		59.6	59.1	59.8 a	58.9 b	59.2	59.2	59.7
Seed P concentration (g kg^{-1})		5.0	5.1	4.9 b	5.2 a	5.1 a	5.0 b	5.0 b
						Scandia 2014		
DW (g plant^{-1})	V3	2.8	3.0	2.8	3.0	2.8	3.1	2.8
N (mg plant^{-1})	V3	135	140	133	142	133 b	150 a	129 b
N (g kg^{-1})	R3	56.8	55.8	56.7	55.8	57.7 a	56.7 ab	54.4 b
P (mg plant^{-1})	V3	9.9	9.9	9.2 b	10.6 a	9.8 ab	11.0 a	9.0 b
P (g kg^{-1})	R3	3.5	3.3	3.4	3.4	3.7 a	3.5 b	3.1 c
Seed yield (Mg ha^{-1})		4.2 a	3.9 b	3.9 b	4.2 a	4.1	4.0	4.0
Seed N concentration (g kg^{-1})		58.6	57.4	58.5	57.0	58.3	58.1	56.9
Seed P concentration (g kg^{-1})		4.4	4.4	4.5	4.4	4.8 a	4.4 b	4.1 c
						Scandia 2015		
DW (g plant^{-1})	V3	1.3	1.2	1.2	1.3	1.2 b	1.4 a	1.1 c
N (mg plant^{-1})	V3	61	53	55	58	56 b	65 a	49 c
N (g kg^{-1})	R3	51.8	52.6	53.1 a	51.3 b	52.3	52.5	51.8
P (mg plant^{-1})	V3	5.4	4.7	4.9	5.2	5.1 b	5.8 a	4.2 c
P (g kg^{-1})	R3	4.0	4.0	4.0	4.0	4.2 a	4.1 b	3.7 c
Seed yield (Mg ha^{-1})		4.7	4.6	4.5 b	4.8 a	4.7	4.7	4.5
Seed N concentration (g kg^{-1})		54.7	54.8	55.6 a	53.9 b	55.1	54.6	54.5
Seed P concentration (g kg^{-1})		4.7	4.6	4.7	4.6	4.9 a	4.8 a	4.3 b

[†] V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus; PD, poor drainage variety; GD, good drainage variety.

[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Chapter 5 - General Conclusions

The adoption of either sub-surface band or broadcast fertilization may change the distribution of nutrients in the soil. While sub-surface band create bands of greater nutrient concentration, broadcast induce to stratification or, in other words, accumulation of certain nutrient in the soil surface. Both methods showed to increase yields in corn, but not in soybeans. It is important to notice that even with low or no response showed by soybean, the farmer has to consider building the soil fertility or at least supplying what is being removed from the system with the grain harvester. In this study, Scandia site was diagnosed with low soil test P levels (below critical level for Kansas) under irrigation and Ottawa site with medium soil test P levels (above critical level for Kansas) under rainfed conditions. This condition is very important since the P diffusion depends not only of moisture but the P concentration in the soil solution. Soybean yields did not respond to fertilization even in Scandia where the soil test levels for P were under the critical level for Kansas. The fact that Scandia has supplemental irrigation probably contributed for P diffusion in soil, minimizing the lower P levels in soil.

Tillage as a single factor has not shown consistent results. The exception was in Ottawa 2015 where most of the variables tested (biomass, nutrient uptake and grain nutrient concentration) showed greater values under NT. However, most of the significant interactions of this study were with fertilizer placement by tillage, and again, NT has shown greater response when compared to ST. It is important to remember that the NT in this study was not a long term system. Nevertheless, NT system applied here was considerable with more residues from past crops when compared to ST, besides the fact of no soil disturbance. Future increments in this research topic would include a long term NT area to access a more representative data regarding tillage.

Based on the greenhouse study and field measurements done with roots, we conclude that in corn, the two hybrids tested are different in characteristics evaluated such as dry weight, root length and surface area. It will be very useful to test those hybrids under the fertilizer placements to see possible response based on the genotype potential under certain situation specifically for those sites. Soybean varieties showed a more site specific response depending mainly on the soil texture. Since the uptake is related to a soil-root mechanism, the correct genotype choice made by the producer is an important management practice to reach greater yields.

Appendix A - Across Location Analysis for Chapters 3 and 4

Appendix A.1. Levels of significance for N and P uptake and biomass accumulation for corn at different growth stages, grain yield and grain nutrient concentration across locations.

Parameters	V6 growth stage			V10 growth stage			VT growth stage			Grain Yield	Grain Nutrient Concentration	
	DW†	N	P	DW	N	P	DW	N	P		N	P
	- - - - - - - - - -	- - - -	- - - -	- - - -	- - - -	- - - -	p > F	- - - -	- - - -	- - - -	- - - -	- - - -
Tillage (T)	<0.001*	0.009*	0.001*	0.140	0.842	0.641	0.010*	0.956	0.267	0.437	0.641	0.593
Hybrid (H)	0.013*	0.002*	0.025*	0.173	0.232	0.012*	0.983	0.646	0.938	0.912	<0.001*	0.003*
T x H	0.431	0.329	0.680	0.005*	0.011*	0.012*	0.319	0.225	0.109	0.627	0.930	0.759
Fertilizer (F)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0.110
T x F	0.153	0.314	0.703	0.643	0.578	0.405	0.110	0.727	0.339	0.238	0.282	0.280
F x H	0.564	0.642	0.396	0.306	0.338	0.272	0.288	0.368	0.231	0.085*	0.068*	0.603
T x F x H	0.310	0.542	0.597	0.350	0.197	0.227	0.780	0.917	0.722	0.232	0.149	0.092*

† DW, dry weight; N, nitrogen; P, phosphorus; V6, V10, VT growth stage (Abendroth et al., 2011).

* Statistically significant at 0.1 alpha level.

Appendix A.2. Interaction effect for tillage and fertilizer placement on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration across locations.

		No-till			Strip-till		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
DW (g plant^{-1})	V6†	13.8	12.8	10.4	11.9	12.3	9.0
	V10	85	82	65	81	77	64
	VT	142	149	119	138	135	118
N (mg plant^{-1})	V6	149	139	108	126	137	95
	V10	2098	2048	1447	2049	2022	1566
	VT	2198	2401	1663	2176	2336	1737
P (mg plant^{-1})	V6	34	30	24	29	28	21
	V10	273	257	184	264	242	196
	VT	317	325	249	305	302	256
Grain yield (Mg ha^{-1})		11.3	10.6	7.9	10.7	10.8	7.8
Grain N concentration (g kg^{-1})		10.7	10.7	9.9	10.5	10.8	9.9
Grain P concentration (g kg^{-1})		2.5	2.4	2.4	2.4	2.3	2.4

† V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Appendix A.3. Interaction effect for tillage and hybrid on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration across locations.

		No-till		Strip-till	
		P1151 AM	P1105 AM	P1151 AM	P1105 AM
DW (g $plant^{-1}$)	V6†	12.6	12.1	12.0	10.6
	V10	81 a‡	73 b	73 b	76 b
	VT	138	136	129	131
N (mg $plant^{-1}$)	V6	138	126	128	110
	V10	1998 a	1731 c	1831 bc	1927 ab
	VT	2115	2060	2022	2144
P (mg $plant^{-1}$)	V6	30	28	28	24
	V10	260 a	217 b	234 b	234 b
	VT	304	290	281	294
Grain yield (Mg ha^{-1})		9.9	9.9	9.7	9.8
Grain N concentration (g kg^{-1})		10.7	10.2	10.6	10.2
Grain P concentration (g kg^{-1})		2.5	2.4	2.5	2.4

† V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Appendix A.4. Interaction effect for hybrid and fertilizer placement on corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration across locations.

		P1151AM			P1105AM		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
DW ($g\ plant^{-1}$)	V6[†]	13.1	13.2	10.1	12.7	12.0	9.4
	V10	85	83	64	81	77	65
	VT	140	145	116	140	140	121
N ($mg\ plant^{-1}$)	V6	143	147	109	132	128	94
	V10	2159	2110	1475	1988	1960	1538
	VT	2200	2394	1611	2174	2343	1789
P ($mg\ plant^{-1}$)	V6	32	31	24	30	28	21
	V10	287	263	191	251	237	188
	VT	320	315	243	302	313	262
Grain yield ($Mg\ ha^{-1}$)		11.3 a[‡]	10.6 b	7.6 c	10.7 ab	10.7 ab	8.1 c
Grain N concentration ($g\ kg^{-1}$)		10.8 ab	10.9 a	10.3 d	10.4 cd	10.6 bc	9.6 e
Grain P concentration ($g\ kg^{-1}$)		2.5	2.4	2.5	2.4	2.3	2.4

[†] V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Appendix A.5. Corn biomass accumulation and nutrient uptake at different growth stages, grain yield and grain nutrient concentration as affected by tillage, hybrid and fertilizer placement across locations.

		Tillage		Hybrid		Fertilizer Placement		
		No-till	Strip-till	P1151 AM	P1105 AM	Broadcast	Sub-surface band	Control
DW (g plant^{-1})	V6[†]	12.4 a[‡]	11.1 b	12.1 a	11.3 b	12.9 a	12.6 a	9.7 b
	V10	77	74	77	74	83 a	80 a	65 b
	VT	137 a	130 b	134	134	140 a	142 a	119 b
N (mg plant^{-1})	V6	387 a	351 b	385 a	352 b	404 a	414 a	288 b
	V10	1865	1879	1914	1829	2074 a	2035 a	1506 b
	VT	2087	2083	2068	2102	2187 b	2369 a	1700 c
P (mg plant^{-1})	V6	43 a	39 b	43 a	40 b	47 a	45 a	31 b
	V10	238	234	247 a	225 b	269 a	250 b	190 c
	VT	297	288	293	292	311 a	314 a	253 b
Grain yield (Mg ha^{-1})		158.02	155.70	156.70	157.03	175.25 a	170.41 a	124.93 b
Grain N concentration (g kg^{-1})		10.5	10.4	10.7 a	10.2 b	10.6 b	10.8 a	9.9 c
Grain P concentration (g kg^{-1})		2.4	2.4	2.5 a	2.4 b	2.44 a	2.37 b	2.42 ab

[†] V6, V10, VT growth stage (Abendroth et al., 2011); DW, dry weight; N, nitrogen; P, phosphorus.
[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Appendix A.6. Levels of significance for biomass accumulation, N and P uptake at V3; N and P concentration at R3 growth stage, seed yield and seed nutrient concentration for soybean across locations.

	V3 growth stage			R3 growth stage			Seed Nutrient	
Parameters	DW[†]	N uptake	P uptake	N	P	Seed Yield	N	P
				- - - - - - - - - - - - p > F - - - - - - - - - - - -				
Tillage (T)	0.535	0.691	0.831	0.695	0.032*	0.143	0.605	0.807
Variety (V)	0.925	0.530	0.118	0.001*	0.540	0.414	0.002*	0.360
T x V	0.107	0.196	0.044*	0.143	0.958	0.514	0.159	0.686
Fertilizer (F)	0.001*	<0.001*	<0.001*	0.416	<0.001*	0.312	0.344	<0.001*
T x F	0.927	0.853	0.884	0.584	0.458	0.578	0.951	0.709
F x V	0.883	0.492	0.489	0.879	0.825	0.552	0.152	0.100
T x F x V	0.510	0.515	0.427	0.929	0.452	0.688	0.594	0.540

[†] V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus;

* Statistically significant at 0.1 alpha level.

Appendix A.7. Interaction effect for tillage and fertilizer placement on soybean biomass accumulation, nutrient uptake and nutrient concentration in tissue at different growth stages, seed yield and seed nutrient concentration across locations.

		No-till			Strip-till		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
DW (g plant^{-1})	V3[†]	2.1	2.2	2.0	2.1	2.2	2.0
N (mg plant^{-1})	V3	121	128	114	122	130	117
N (g kg^{-1})	R3	5.3	5.4	5.3	5.4	5.4	5.3
P (mg plant^{-1})	V3	10.5	10.8	9.2	10.6	11.0	9.5
P (g kg^{-1})	R3	0.4	0.4	0.4	0.4	0.4	0.4
Seed yield (Mg ha^{-1})		3.6	3.5	3.5	3.4	3.5	3.4
Seed N concentration (g kg^{-1})		57.9	58	57.5	57.8	57.8	57.3
Seed P concentration (g kg^{-1})		5.1	5.0	4.8	5.1	5.0	4.8

[†] V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus;
[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Appendix A.8. Interaction effect for tillage and variety on soybean biomass accumulation, nutrient uptake and nutrient concentration in tissue at different growth stages, seed yield and seed nutrient concentration across locations.

		No-till		Strip-till	
		Poor Drainage Variety	Good Drainage Variety	Poor Drainage Variety	Good Drainage Variety
DW (g $plant^{-1}$)	V3†	2.0	2.1	2.2	2.1
N (mg $plant^{-1}$)	V3	120	122	127	119
N (g kg^{-1})	R3	5.4	5.2	5.4	5.3
P (mg $plant^{-1}$)	V3	9.9 b‡	10.4 ab	10.6 a	10.2 ab
P (g kg^{-1})	R3	0.4	0.4	0.4	0.4
Seed yield (Mg ha^{-1})		3.5	3.5	3.4	3.4
Seed N concentration (g kg^{-1})		58.6	56.9	58	57.2
Seed P concentration (g kg^{-1})		4.9	5.0	4.9	5.0

† V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus.
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Appendix A.9. Interaction effect for variety and fertilizer placement on soybean biomass accumulation, nutrient uptake and nutrient concentration in tissue at different growth stages, seed yield and seed nutrient concentration across locations.

		Poor Drainage Variety			Good Drainage Variety		
		Broadcast	Sub-surface band	Control	Broadcast	Sub-surface band	Control
DW (g $plant^{-1}$)	V3†	2.1	2.2	2.0	2.1	2.2	2.0
N (mg $plant^{-1}$)	V3	125	130	116	118	128	115
N (g kg^{-1})	R3	5.5	5.4	5.4	5.3	5.3	5.3
P (mg $plant^{-1}$)	V3	9.4	10.6	10.6	10.5	11.1	9.3
P (g kg^{-1})	R3	0.4	0.4	0.4	0.4	0.4	0.4
Seed yield (Mg ha^{-1})		3.5	3.5	3.4	3.5	3.5	3.4
Seed N concentration (g kg^{-1})		58.8	58.6	57.6	57.0	57.2	57.2
Seed P concentration (g kg^{-1})		5.1	4.9	4.8	5.1	5.1	4.8

† V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus;
‡ Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.

Appendix A.10. Soybean biomass accumulation, nutrient uptake and nutrient concentration in tissue at different growth stages, seed yield and seed nutrient concentration as affected by the main effects of tillage, variety and fertilizer placement across locations.

		Tillage		Variety		Fertilizer Placement		
		No-till	Strip-till	PD	GD	Broadcast	Sub-surface band	Control
DW (g $plant^{-1}$)	V3[†]	2.1	2.1	2.1	2.1	2.1 b	2.2 a	1.9 b
N (mg $plant^{-1}$)	V3	77	76	76	77	77 b	82 a	70 c
N (g kg^{-1})	R3	5.34	5.36	5.43 a	5.28 b	5.37	5.37	5.31
P (mg $plant^{-1}$)	V3	6.65	6.61	6.49	6.77	6.63 b	7.36 a	5.89 c
P (g kg^{-1})	R3	0.37 a	0.36 b	0.37	0.37	0.38 a	0.37 b	0.35 c
Seed yield (Mg ha^{-1})		3.5	3.4	3.5	3.5	3.5	3.5	3.4
Seed N concentration (g kg^{-1})		57.8	57.6	58.3 a	57.1 b	57.8	57.9	57.4
Seed P concentration (g kg^{-1})		0.5	0.5	0.49	0.5	0.51 a	0.5 b	0.48 c

[†] V3, R3 growth stage (Pedersen, 2003); DW, dry weight; N, nitrogen; P, phosphorus; PD, poor drainage variety; GD, good drainage variety.

[‡] Numbers followed by different letters between columns, within each main factor, represent statistically significant differences at $p \leq 0.10$.