EVALUATION OF CORN AND SOYBEAN RESPONSE TO PHOSPHORUS AND POTASSIUM FERTILIZATION

by

INGRID ARNS

B.S., Universidade Federal do Rio Grande do Sul, 2010

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2013

Approved by:

Major Professor
Dorivar Ruiz Diaz

Abstract

Corn (Zea mays) response to fertilization and placement methods has been studied extensively; however studies on soybean [Glycine max (L.) Merr.] response to placement have been limited. Three studies were completed to evaluate different aspects of crop response. The objective of the first study was to evaluate the effect of starter and broadcast fertilizer application on corn and soybean, in a typical corn-soybean rotation in Kansas. Treatments were unfertilized control, starter (N, P and K), broadcast P and K using mono ammonium phosphate (MAP) and potassium chloride (KCl) and the combination of starter and broadcast. Corn and soybean yield generally was not affected by starter and broadcast treatments. Thus fertilization may be recommended only under specific conditions. The objectives of the second study were (i) to evaluate the effect of residual and direct fertilization on soybeans after corn under a corn-soybean rotation system, and (ii) study the effect of fertilizer P and K application on soil test P (STP) and soil test K (STK) changes over time. Direct fertilization increased soybean yield while residual fertilizer did not. Therefore maintenance rates may be effective to improve soybean yield and likely maintain STP and STK levels. Application of P and K fertilizer generated significant increases in STP and STK after one year of application. The rate of P and K fertilizer required to increase 1 mg kg^{-1} yr^{-1} was between 2.8 - 5.1 kg ha^{-1} for P and between 1.0- 2.5 kg ha^{-1} for K, respectively. The objective of the third study evaluate both corn and soybean response to direct P fertilization including starter and broadcast. The treatments were a control, two starter fertilizers (with N-P and N only), five P rates (9.8, 19.6, 29.3, 39.1, 48.9 kg P ha-1) and one treatment with starter fertilizer in addition to the broadcast fertilizer application. Corn grain yield was not significantly affected by any broadcast or starter treatments. Broadcast application rates significantly increased soybean yield on low STP levels. Results of this study show that large

corn or soybean yield response to starter and broadcast P application are likely with low STP levels.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I am deeply grateful to Dr. Dorivar Ruiz Diaz for his commitment as my major advisor, whose expertise, understanding, and patience, added considerably to my graduate experience. I would like to thank the other members of my committee, Drs. David Mengel and Alan Schlegel for their assistance and feedback during my Master program. Appreciation also goes to Kansas State University for the opportunity and to the Department of Agronomy faculty and staff for supporting my research. I must also acknowledge the graduate and undergraduate students part of our soil fertility program for their help with the field and lab work: Dr. Nathan Mueller, Evan King, Aaron Widmar, Paulo de Oliveira Neto and Santiago Pac. Last but not the least I would also like to thank my parents Ulfried and Adriane, my brothers Rodolfo and Arthur, my partner Alvaro and my dear friends for supporting me in this journey.

Dedication

This thesis is dedicated to Rolf Derpsh, a wonderfully brilliant man who has given the most contribution to a more sustainable agriculture with the development of No-tillage technology in Brazil, Latin America and across the world. Rolf has been always a fighter and a leader, but more than that he is such a loving and giving man. Rolf encouraged and gave me the opportunity to reach my dreams and because of him I am achieving one of them, which is my master degree in the USA. I thank Rolf for changing my life and for bringing me so much happiness.

Chapter 1 - Introduction and Thesis Organization

Phosphorus and potassium fertilization on soybean and corn

Phosphorus and potassium fertilizer demand and price increased to a great extent during the past two decades (USDA, 2012). Therefore more efficient fertilizer management strategies are necessary, not only to increase farmer profitability but also to reduce water contamination problems. In Kansas the median values for P is 18 ppm Bray P-1 equivalent and approximately 55% is the relative frequency of soils found to be below critical level of 20 ppm (Fixen et al., 2010). The median P level for Kansas soils has declined compared to 2005, when the median was 21 ppm. This change is probably due to the cumulative effects of crop removal exceeding P use (Fixen, 2006; Fixen et al., 2010). Corn and soybean yield and producer's profit usually are increased by application of P fertilizer to soils in the very low or low categories (Mallarino, 1991). Yield increases from fertilizer follow a curve of diminishing returns (Troeh and Thompson, 2005). Small applications of needed fertilizer result in the greatest return per unit of nutrient applied, whereas additional amounts of fertilizer have a smaller increase in yield. Eventually a point is reached where the last increment of fertilizer added barely increases yield enough to pay the cost of application.

The critical value for phosphorus used in Kansas is 20 ppm for both corn and soybean (Leikam et al., 2003). Soil test values above this level have shown that P fertilization is rarely profitable for either of these crops (Mallarino, 1991; Webb et al., 1992). The effect of fertilization and placement methods on corn and soybean are usually observed in no till systems. Under this condition the surface residue can result in cooler and wetter soils compared to soils under conventional tillage systems (Fortin, 1993). Therefore in no-till systems starter fertilizer application can have a positive effect on early growth and grain yield, increasing the nutrient concentration and availability in the root zone when low soil temperature slow root growth and nutrient diffusion (Borkert and Barber, 1985). Overall, yield increases due to starter application are most frequently found on low testing soils, poorly drained soils, late planted crops, hybrids of long maturity groups, and conservations tillage systems (Bundy and Andraski, 2001; Randall and Hoeft, 1988).

Broadcast phosphorus fertilization frequently increases corn and soybean yield when soils has low to very low STP and rarely on soils with high STP (Bordoli and Mallarino, 1998; Borges a Mallarino, 2000). Dodd and Mallarino (2005) showed in a long term study that corn and soybean responded to annual P fertilization 50 to 70% of the time when soil test level was equal or less than 20 ppm and did not responded to higher test P. Similarly Mallarino (1991) indicated that yields of corn and soybean are not significantly affected by either P or K fertilization in high P and K testing soils. Therefore profitability of these crops can be significantly reduced by application of P and K fertilizers to increase soil test values above the medium range. Generally, the literature shows consistent early growth and nutrient uptake responses to fertilizer on high- testing soil sites but inconsistent yield responses (Bermudez and A.P. Mallarino, 2002; Mallarino et al., 1999; Randall and Hoeft, 1988)

Since most of the soils in Kansas have medium to high STP and high STK levels, it is important to evaluate how crops respond to fertilizers placement and rates under these soil test levels. Fertilizer application as starter or broadcast, both has been evaluated for corn. However, studies on soybean response and placement are limited in Kansas. The following three chapters evaluate the corn and soybean responses to starter and broadcast P and K.

Thesis Organization

This thesis is divided into five chapters. Following this introductory chapter, there are three chapters, each of them consisting of one research project. Titles of chapter 2, 3 and 4 are: "Corn and soybean response to starter and broadcast fertilization", "Evaluation of soybean response to direct and residual fertilization", and "Corn and soybean response to phosphorus fertilization and placement". The fifth chapter is the overall conclusion.

References

Bermudez M., and A.P. Mallarino. 2002. Yield and early growth responses to starter fertilizer in no-till corn assessed with precision agriculture technologies. Agron J. 94:1024-1033.

Dodd J.R., and A.P. Mallarino. 2005. Soil-test phosphorus and crop grain yield responses to long-term phosphorus fertilization for corn-soybean rotations. Soil Sci. Soc. Am. J.69:1118-1128.

Fixen P.E. 2006. Soil Test Levels in North America. Better Crop With Plant Food. 90(1) 4-7.

Fixen, P.E., T.W. Bruulsema, T.L. Jensen, R.M. Mikkelsen, S.T. Murrel, and S.B. Phillips et al. 2010. The fertility of North American soils. Better Crop With Plant Food. 94(4): 6-8.

Mallarino A.P., J.M. Bordoli, and R. Borges. 1999. Phosphorus and potassium placement effects on early growth and nutrient uptake of no-till corn and relationships with grain yield. Agron. J. 91:37-45.

Mallarino A.P., J.R. Webb, and A.M. Blackmer. 1991. Corn and Soybean yields during 11 years of phosphorus and potassium fertilization on a high-testing soil. J. Prod. Agr. 4:312-317.

Randall G.W., and R.G. Hoeft. 1988. Placement methods for improved efficiency of P and K fertilizers: a review. J. Prod. Agr. 1:70-79.

Troeh F.R., and L.M. Thompson. 2005. Soils and Soil Fertility. 6th ed. Blackwell. Ames, IA.

USDA- Economic Research Service. 2012. Published estimates data base (PEDB). Available at http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx (verified 25 Feb. 2013). USDA-NASS, Washington, DC.

Chapter 2 - Corn and soybean response to starter and broadcast fertilization

Abstract

Corn (Zea mays) response to fertilization and placement methods has been studied extensively; however studies on soybean [*Glycine max* (L.) Merr.] response have been limited. The objective of this study was to evaluate the effect of starter and broadcast fertilizer application on corn and soybean, in a typical corn-soybean rotation in Kansas. Early growth, nutrient concentration, uptake and yield, were evaluated at four locations for corn, and four locations for soybean during 2011 and 2012. Treatments were unfertilized control, starter (N, P and K), broadcast P and K using mono ammonium phosphate (MAP) and potassium chloride (KCl) and the combination of starter and broadcast. Soil samples and plant tissues were collected and analyzed for N, P and K concentration. Corn early growth was measured at the V6-V7 growth stage and yield determined at the end of the season. Corn early growth, P and K concentration and uptake in young corn plants were significantly increased across locations. Grain P or K removal was not affected by fertilization in corn. Individual locations showed no significant effect of starter and broadcast treatments on corn yield. However, across locations 1 and 3 yield was increased with the addition of starter fertilizer. Phosphorus concentration in soybean leaf was increased by broadcast application. Soybean yield was not affected with starter or broadcast fertilizer application; however seed P removal was increased with broadcast application. Corn and soybean yield was generally not affected by starter and broadcast treatments in our study.

Introduction

Fertilizer management and application method can substantially affect yield response and producer's profitability. Starter fertilizer is a common practice to increase crop growth, stand uniformity and enhance yield potential. Some studies evaluated the effects of placement and fertilization of P and K on different crops and have shown that starter fertilizer often increase corn yield compared to a control treatment with no fertilization (Bundy et al., 2005; Randall and Hoeft, 1988). This response can be frequent in soils with P and/or K deficiency. In Kansas according to Fixen et al. 2010, the median values for P are 18 ppm Bray P-1 equivalent and 274 ppm for exchangeable K (Carson, 1980). Also approximately 55% and 13% is the relative frequency of soils found to be below critical levels for P and K respectively (Fixen et al., 2010). The critical value for phosphorus used in Kansas is 20 ppm for both corn and soybean (Leikam et al., 2003). Below this level a significant probability of yield response can be expected when applying P fertilizer. Soils high in nutrient level do not always supply enough nutrients to the plant during the early part of the growing season given that certain conditions can limit the nutrient availability (Ketcheson, 1968). Low soil temperature for example, can reduce root growth (Ching and Barber, 1979; Havlin, 2005) and nutrient uptake by plant (Mackay and Barber, 1985). Under these conditions, starter fertilizer application can have a positive effect on early growth and grain yield, increasing the nutrient concentration and availability in the root zone when low soil temperature slow root growth and nutrient diffusion (Borkert and Barber, 1985). Overall, yield increases due to starter application are most frequently found on low testing soils, poorly drained soils, late planted crops, hybrids of long maturity groups, and conservations tillage systems (Bundy and Andraski, 2001; Randall and Hoeft, 1988).

Some studies evaluating yield response to starter fertilization have shown inconsistent results due to many factors (Kaiser et al., 2005). Rehm and Lamb (2009) found that starter fertilizer N, P or N, P, and K increased corn early growth under no tillage conditions and where P and K levels were optimum to high, but this increase did not necessarily resulted in increased grain yields. Likewise, other studies found significant corn early growth response to starter, however yield responses of no-till corn to starter are more likely when soil test P is below optimum and/or preplant or sidedress N rates are deficient (Bermudez and Mallarino, 2002; Kaiser et al., 2005). These studies indicate that corn early growth response to starter fertilizer is an unreliable indicator of grain yield. Vetsch and Randall (2002) however showed that starter fertilizer increased corn yields on high P and K soils in continuous corn and corn-soybean rotation and they suggest that starter fertilizer should be considered to optimize corn production across all tillage systems. Similarly, Touchton (1988) indicates that starter N and P frequently improved early growth and increased corn grain yield under soils high in P. Another study also showed corn yield response to starter fertilizer in no-till but not in conventional tillage system on a high-testing P and K silt loam soil (Wolkowski, 2000). According to Eckert and Johnson (1985) and Howard and Tyler (1987) banding fertilizer is preferable method for P applications to no-tillage corn. They concluded that starter under conservation systems has generally higher yield, and therefore increased fertilizer efficiency when compared with surface broadcasting at low to moderate soil test P levels. Conversely, Howard and Essington (2002) found that broadcast P rates increased no till corn yields at low STP and that yield responses to banding N-P were inconsistent over 11 years. Kaiser et al. (2005) on the other hand showed that starter P fertilization alone produced corn yield similar to large P broadcast rates on soils with STP in the responsive range.

Mallarino (1991) and Randall et al. (1997) showed that yields of corn and soybean were not significantly affected by either P or K broadcast fertilization in high P and K testing soils. Likewise, band application of P or K show no yield benefit in soybean when soil tests are in the optimum or high ranges (Buah et al., 2000; Rehm and Lamb, 2010). Soybean yield response to P fertilizer application is normally found when soil test P (Mehlich-3) is below 22 mg kg-1 and similar to corn, not related to early growth (Mallarino and Borges, 1997; Mallarino et al., 2009). In low P soils, soybean yield and P uptake are increased with P applied in a band near the seed (Rehm, 1988; Bullen et al., 1983). Ham (1973) showed that broadcast N, P, and starter N, P and K significantly increased soybean yields over the control when soils were low on P, however there was no difference between the placement methods. Moreover, when soils were high on P and K, no fertilizer treatment increased soybean yield. Differently, Mallarino and Borges (1997) found that potassium fertilization increased soybean yield under no-till when soil test K was optimum to high.

Fertilizer application as starter, broadcast, and the combination of both has been evaluated with emphasis on corn. However, studies on soybean response to placement under different tillage systems are limited. The objective of this study was to evaluate the effect of starter and broadcast fertilizer applications on corn and soybean in a typical corn-soybean rotation.

Material and Methods

Four corn and four soybean locations were established in 2011 and 2012. Fields with history of corn-soybean rotation were selected to represent a common system in the region of study. Description of each location is presented in Table 2.1. The experimental design consisted of a factorial arrangement in a randomized complete block design with four treatments and four replications. The plot size was 15 m long, 4-6 rows width with row spacing of 76 cm for both crops. Starter fertilizer was a mixture of commercial formula 3-8-8 (N-P-K) [3-18-18 ($N-P_2O_5-K_2O$)] and urea ammonium nitrate (UAN) 28% N for a total application of 17 kg ha^{-1} of N and 10.5 kg ha^{-1} of P (24 kg ha^{-1} P_2O_5) and 20 kg ha^{-1} of K (24 kg $ha^{-1}$of K_2O). Broadcast fertilizer was a combination of mono ammonium phosphate (MAP) [23-52-0 (N-P-K)] [11-52-0 ($N-P_2O_5-K_2O$)] and KCl [0-0-52 (N-P-K)] [0-0-62 ($N-P_2O_5-K_2O$)] for a total application rate of 49 kg ha^{-1} of P (112 kg ha^{-1} P_2O_5) and 93 kg ha^{-1} of K (112 kg ha^{-1} K_2O). The broadcast application rates can be considered commonly used rates by producers before corn in a corn-soybean rotation and intended for both crops in the rotation (Leikam et al., 2003). Broadcast fertilizer was applied 1-4 weeks before planting at all locations. Broadcast fertilizer was incorporated at the locations under conventional tillage (locations 2 and 4 for both corn and soybean) before planting and non-incorporated at the no-till locations (1 and 3). Nitrogen fertilizer for corn was applied in spring one month prior to planting injecting anhydrous ammonium at 168 kg N ha^{-1} for locations 2 and 4. At locations 1 and 3, N application rate was 180 kg N ha^{-1} applied as side-dress at V5 corn growth stage (Abendroth et al., 2011) using urea. Locations 2 and 4 were irrigated for both corn and soybean, with center pivot sprinkler irrigation systems and irrigation was applied as needed during the growing season.

Soil samples were collected from each small plot before fertilizer application. Each sample was a composite of 10-12 cores collected from the 0-15 cm depth. Samples were analyzed for P by the Mehlich-3 method (Frank et al., 1998) and K with the ammonium acetate method (Warncke and Brown, 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson and Brown, 1998), and soil organic matter (OM) was determined by Walkley–Black method (Combs and Nathan, 1998).

Plant population was measured in a 7.6-m section of two central rows of each plot, for both crops. Corn early growth, nutrient content and nutrient uptake was evaluated. Aboveground parts of 10 corn plants were collected from each location at V6-V7 growth stage (Abendroth et al., 2011). Corn ear leaves were collected at the R1 growth stage and soybean leaf samples consisting of the most recently developed fully expanded trifoliate leaf (petiole excluded) between early bloom (R1) and full bloom (R2) stages (Pedersen, 2009). Both corn and soybean leaf samples were analyzed for N, P and K. Plant samples were dried at 60^{o}C in a forced-air oven, weighted (only for corn), and ground to pass a 2-mm screen. Ground samples were digested using sulfuric acid and hydrogen peroxide in a Digesdahl Analysis System (Hach Co., 1991). Nitrogen and P were measured by colorimetry and K was measured by flame photometry (Murphy and Riley, 1962). Corn N, P and K uptake was calculated using nutrient concentrations and oven-dried weights. After corn and soybean reached physiological maturity, yield was determined by harvesting the center two rows of each plot. Harvested was completed with a small plot combine at all locations, except corn locations 1 and 3, where corn ears were hand-harvested. Grain yield was adjusted to a moisture content of 155g kg^{-1} for corn and 130g kg^{-1} for soybean. Statistical analysis was completed using the generalized linear mixed model (GLIMMIX) procedure of SAS (SAS., 2006) assuming block and locations as random factors in the model. When significant, plant population was used as covariate in the analysis. Statistical analysis was completed by location and across locations. In addition, analysis was completed by groups of location because of different management practices and contrasting yield levels. Corn locations 1 and 3 were no-till, non-irrigated and had sidedress urea as N source at V5. Differently locations 2 and 4 were conventional tillage, irrigated and had pre-plant anhydrous ammonium as N source. Soybean locations 1 and 3 were no-till and non-irrigated whereas locations 2 and 4 were conventional tillage and irrigated. Statistical significance was determined at the $P \leq 0.10$ level.

Results and Discussion

Corn

Corn early growth was increased with fertilization at locations 1, 2 and 4 (Tables 2.2 and 2.4). Although broadcast P-K rate was almost 10 fold the starter rate, biomass results shows the same response between starter and broadcast applied alone at all locations and across locations. This suggests no advantage of placement for corn early growth. This result agrees with those of Mallarino et al. (2011) who found that increased early growth with starter fertilizer was similar to those of broadcast applications at higher rates. At location 1, only the combination of starter and broadcast increased biomass over the control (Table 2.4); with similar results across locations 1 and 3 (Figure 2.1a). At location 2, broadcast and starter alone significantly increased early growth over the control; however no additional increase in early growth with the combined broadcast and starter application. At location 4, across locations 2 and 4 and across all locations, starter and broadcast alone increased significantly biomass over the control (Figure 2.1a). Furthermore, there was an added affect when they were applied in combination showing an increase on biomass over the starter or broadcast alone. This result differs from those of Kaiser and Mallarino (2005) where they found that the combination of both placements didn't contribute to additional increase in early growth over either placement alone.

Fertilization affected P concentration of young corn plants at three locations (1, 2, and 4) (Table 2.2). At location 1 the combination of starter and broadcast increased P concentration over starter and broadcast alone but not when compared to the control (Table 2.5). At location 2, only treatments with broadcast significantly increased P concentration. Starter alone decreased P concentration over the control at location 4, however when applied after broadcast there was no treatment effect. Across locations 1 and 3, fertilization had no significant effect in early plant P concentration (Figure 2.2a). Across locations 2 and 4 and across all locations there was an increase in P concentration when broadcast with starter was applied. However, starter alone showed a decreased P concentration over other treatments (Figure 2.2a). With the increased early growth resulted from starter fertilizer alone, a possible nutrient dilution effect may explain the generally lower P concentration with the starter alone treatment. The dilution effect was found in previous studies (Plenet and Lemaire, 1999; Ziadi et al., 2007). Broadcast showed no difference in P concentration compared to the unfertilized control (Table 2.5 and Figure 2.2a). However, the combination of starter and broadcast show an increased P concentration, which suggest that a higher P fertilizer rate may help to compensate the dilution effect.

Early P uptake was increased at three locations by fertilization (Table 2.2 and 2.5), including the location where starter decreased P concentration (location 4). Broadcast was statistically different and had a higher uptake than starter only at location 2 (Table 2.5). At location 1, only the combination of starter and broadcast increased P uptake over the control. Similar results were found when analyzing across locations 1 and 3 (Figure 2.2b). At locations 2 and 4, P uptake was increased significantly by both starter and broadcast. Nevertheless the combination of both placements increased P uptake more than starter or broadcast alone (Table 2.5). The result was similar when analyzing across locations 2 and 4 and across all locations. Thereby early plant P uptake seems to reflect fertilization effects on early growth more closely than plant P concentration. These results agree with those of Kaiser et al. (2005) who found significant increase in early growth and inconsistent or lower plant P concentration with fertilizer application. Broadcast increased early K concentration at locations 2 and 4, whereas starter had no effect on K concentration at any location. The combination of starter and broadcast increased K concentration at three locations (1, 2 and 4). Analysis across locations 1 and 3, show increased early K concentration with all fertilization treatments. Whereas across locations 2 and 4 and across all locations only treatments with broadcast fertilization increased K concentration (Figure 2.2c). This agrees with previous studies showing that broadcast K frequently increased early plant K concentration in corn (Clover and Mallarino, 2012). Starter and broadcast alone enhanced K uptake at locations 2 and 4 (Table 2.5). At location 1 and across locations 1 and 3, only the combination of starter and broadcast increased K uptake. Across locations 2 and 4 and across all locations starter and broadcast alone increased K uptake over the control however the combination of both placements had a statistically higher K uptake compare to other treatments (Figure 2.2d).

Early plant N concentration was inconsistent between locations. Starter alone or in combination with broadcast increased N concentration only at location 1 (Table 2.5). Fertilizer treatments decreased N concentration at location 4, similar to early P concentration at this location. Nevertheless analysis across locations 1 and 3, 2 and 4, and all locations show no effect of any fertilizer treatment on early N concentration (Figure 2.2e). According to Buah et al. (1999) starter N-P-K fertilizer increases plant K concentration much more frequent than plant N and P concentration, this explain the lack of response of early N and P concentration to starter application in this study. Starter alone or in combination with broadcast increased plant N uptake at three locations (locations 1, 2 and 4) (Table 2.5). Across locations 1 and 3, only the combination of starter and broadcast increased N uptake over the control (Figure 2.2f). Starter and broadcast alone increased N uptake over the control across locations 2 and 4 and all locations, however the combination of both had a significant higher uptake compare to the other treatments.

Fertilization treatments increased ear leaf P concentration at the R2 growth stage only at location 1 (Table 2.2 and 2.5). Across locations 1 and 3 however, all fertilizer treatments increased P concentration over the control (Figure 2.3a). Broadcast application increased ear leaf P across locations 2 and 4 (Figure 2.3a). Across all locations broadcast alone and with starter significantly increased ear leaf P. These results are similar to those of Howard and Mullen (1991) who found increased ear leaf P concentration with high broadcast P applied prior planting. This suggest that higher rates applied with broadcast fertilization affect plant P concentration longer in the season compare to starter application.

Potassium concentration in the ear leaf was not increased by any treatment at any location or across locations (Table 2.2, Figure 2.3b). Other studies found similar results with no response to of leaf K concentration to starter (Mengel et al. 1988). Conversely, in some other work the broadcast application has shown that leaf K concentration is consistently increased with broadcast K application (Randall et al. 1997; Clover and Mallarino 2012).

Starter or broadcast alone decreased ear leaf N concentration compare to the control at location 2, whereas the combination of both placement showed no change on ear leaf N concentration (Table 2.2). At location 4, starter after broadcast decreased N concentration over the control. Analysis across locations 2 and 4 suggest that broadcast treatments decrease N concentration in the ear leaf (Figure 2.3c). These results are similar to N concentration at early growth V6-V7 stage. Analysis across locations shows similar results for ear leaf N concentration with no significant differences between treatments. This result agrees with those of Touchton (1988) that shows N concentrations in the ear leaf were not affected by any starter N-P treatment.

Yield level at dryland locations (1 and 3) was low compared to the irrigated locations (2 and 4) during 2011 and 2012. None of the individual locations showed a significant effect of starter or broadcast treatments (Table 2.3 and 2.4). Nevertheless, analysis across locations 1 and 3 showed a significant yield response to starter (Figure 2.1b). Soil test P at these locations was at the optimum level or above, and these results are in agreement with those of Buah and Polito (1999) and Bundy and Andraski (2001). They reported positive grain yield response to the addition of fertilizers applied as starter under no tillage conditions on soils medium to high in P and K. Although starter alone increased yield, when in combination with broadcast there was no yield response. This lack of response could be explained when we look into grain moisture analysis across locations (data not shown). Grain moisture from starter treatment was 110 g kg-1, same as the control. Broadcast in combination with starter had a significant higher moisture of 138 g kg-1. Thus broadcast may have delayed plant development compare to plants with starter treatment, and therefore plants were affected by the dry condition in different growth stages. Across locations 2 and 4 there was no significant effect on yield with fertilizer treatments. These results are similar to those of Bullock et al. (1993), who found no increase in grain yields with starter fertilizer under conventional tillage and medium to high soil test levels. Analysis across all locations also showed no significant yield difference between treatments.

Treatments with broadcast fertilization increased corn grain P concentration over the control only at location 2 (Table 2.3 and 2.5). None of the other locations was affected by fertilization. Across locations 1 and 3, fertilization did not increase grain P concentration, which can be explained by high soil test P levels at these two locations (Heckman et al., 2003). Across locations 2 and 4 and across all locations broadcast alone or with starter increased P concentration on the grain whereas starter alone did not change grain P concentration (Figure

2.4a). Although grain P concentration was increased at location 2, grain P removal was not affected by fertilization (Table 2.3). None of the other locations showed any effect of fertilization on P removal. Across locations 2 and 4 only broadcast increased P removal by the grain (Figure 2.4c). This higher removal was due primarily to increased P concentration in the grain. Across all locations, there was no significant treatment effect on P removal showing that higher nutrient concentration in the grain does not necessarily generate higher P removal.

Grain K concentration was affected by fertilization at three locations (1, 2 and 4) (Table 2.3). At location 1, broadcast application decreased K concentration in the grain compare to the control and starter alone (Table 2.5). On the other hand at locations 2 and 4 grain K concentration was increased by fertilization. Across locations 1 and 3, the response is similar to location 1 (Figure 2.4b). Across locations 2 and 4, broadcast treatments significantly increased grain K concentration over the control. Analysis across all locations, however, shows no effect of fertilization on grain K concentration. Only location 1 had grain K removal affected by fertilization. Similarly to grain K concentration, broadcast fertilization decreased grain K removal at location 1 and across locations 1 and 3 (Figure 2.4d). Analysis across locations 2 and 4 and all locations showed no significant differences between the treatments on grain K removal. These results agree with those of Clover and Mallarino (2012), where they found that potassium fertilization seldom increased grain K concentration or K removal.

Soybean

Broadcast application alone increased P leaf concentration over the control at two locations (1 and 3) (Tables 2.6 and 2.7). Starter after broadcast increased P concentration at all locations (Table 2.7). Across locations 1 and 3, only treatments with broadcast fertilization increased P concentration in soybean leaf (Figure 2.5a). Across locations 2 and 4 and across all locations, the combination of starter and broadcast seems to further increase P concentration than broadcast applied alone. Starter applied alone had no significant effect on leaf P concentration. According to Buah at al. (2000), broadcast application with high rates of P generally increases leaf P concentration more often than starter applied alone.

Fertilization treatments did not significantly increase soybean leaf K concentration at any location compare to the control (Table 2.6 and 2.7). At location 1 fertilization treatments decreased K concentration. Similarly at location 2, starter alone decreased K concentration compare to the control, broadcast treatments showed no significant change on K concentration. Across locations 1 and 3, there was no effect of fertilization on K concentration. Analysis across locations 2 and 4, starter alone decreased leaf K concentration whereas broadcast alone and with starter was not statistically different than the control (Figure 2.5b). Across all locations, both broadcast and starter applied alone decreased leaf K concentration, while the combination of both did not. The lack of response of K leaf concentration to fertilization might be because soils in the study had high- to very high K levels (Yin and Vyn, 2002). Trifoliate nitrogen concentration was not affected by fertilization at any location (Table 2.6). Across locations 1 and 3 however, broadcast application significantly increased N concentration over the control (Figure 2.5c). Across locations 2 and 4 and all locations, there was no treatment effect on nitrogen concentration.

Soybean yield was not significantly affected by fertilization at any location or across locations (Table 2.6 and Figure 2.5d). At location 3, there was a trend of increase on seed yield, where the combination of starter and broadcast or broadcast alone increased yield by 350 kg ha^{-1} over the control (Table 2.7). At locations 1, 2 and 4 soil test P was classified as low (<20 mg kg-1) for corn and soybean (Leikam et al., 2003). However research in other regions of the U.S.

suggests a lower soil test P critical level for soybean between 12 and 18 mg kg^{-1} (Dodd and Mallarino, 2005). It is likely that the critical soil test P level for soybean is lower than 20 mg kg^{-1} which might explain the lack of response of soybean to fertilization. These results agree with Buah et al., (2000) and Rehm and Lamb (2010), who found that there is no soybean seed yield advantage of P or K starter or broadcast when soil tests are in the optimum or higher ranges.

Soybean seed P concentration was significantly increased with broadcast application only at location 1 (Table 2.6 and 2.7). Analysis across locations 1 and 3, 2 and 4 and across all locations shows that the combination of starter and broadcast increased seed P concentration over the control or starter alone (Figure 2.6a). According to Farmaha et al. (2012), phosphorus fertilization may increase not only aboveground tissue concentration but also seed P concentration. Seed P removal was not affected by any treatment within each location (Table 2.6 and 2.7). However, across locations 1 and 3 and all locations, P removed by the seed was increased with fertilization (Figure 2.6c). Across location 1 and 3 any of the fertilizer placement methods increased seed P removal over the control, whereas across all locations, only broadcast alone was statistically different than the control. Seed K concentration was increased by broadcast alone or in combination with starter only at location 1 (Table 2.7). Similarly to location 1, across locations 1 and 3 seed K concentration was increased only by broadcast treatments (Figure 2.6b). Analysis across locations 2 and 4 and across all locations, fertilization did not significantly affected seed K concentration. Potassium removal through seed was not affected by fertilizer application within each location and across locations (Figure 2.6d). This result agrees with Farmaha et al. (2011), who found that K fertilization can increase aboveground tissue accumulation but not K removal in the seed, indicating that K fertilization can increase K cycling from the soil to the plant which is later returned to the soil in the form of crop residue.

Conclusion

Fertilization frequently increased corn early growth. Starter and broadcast applied alone generated similar biomass response over the control at all locations, showing no advantage of one placement over the other. However there was a benefit of applying starter after broadcast, since the combination increased early growth over starter and broadcast alone. Early plant P and K concentration, early N, P and K uptake, and ear leaf P was generally increased with fertilization and more frequently to broadcast alone or in combination with starter. Corn grain yield was increased by starter fertilizer across locations under dryland, no tillage conditions, and with sidedress N fertilizer. This increase is possible due to a nitrogen deficient early corn plant, considering that soils may have low available nitrogen for the roots and urea was applied only at V5 growth stage. Therefore starter fertilizer should be recommended for producers using no-till system and also for those using sidedress nitrogen after planting. Analyses across locations with irrigation, conventional tillage, and pre-plant N application, there was no corn yield response. Starter could be used by farmers, however under these conditions and soils high on P and K, yield response to starter would seldom occur. Corn grain P concentration is frequently increased when applying broadcast fertilization; however it does not always translate in higher grain P removal. Grain K concentration response to fertilization was inconsistent and grain K removal was not affected by any treatment. Therefore fertilization generally does not cause luxury uptake by the corn grain and may increase nutrient P and K cycling, since the excess nutrient absorbed by the plant would later be returned to the soil with the crop residue.

Broadcast alone or in combination with starter frequently increased trifoliate P concentration on soybean. On the other hand, trifoliate K concentration did not increase with any fertilization treatment. Soybean yield was not significantly affected by fertilization at any location or across locations. Thus broadcast or starter fertilizer would not be recommended to increase yield for the soil test P and K levels found in this study. Soybean seed P concentration and removal was increased by broadcast application even with no soybean yield response to fertilization, whereas seed K concentration and removal was not affected by treatments. Broadcast P fertilization resulted in phosphorus luxury uptake by soybean seeds and therefore, in order to increase fertilizer use efficiency, broadcast P application on soybeans should be used only on soils testing below the optimal level.

References

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn Growth and Development. PMR 1009. Iowa State Univ. Ext., Ames.

Bermudez, M., and A.P. Mallarino. 2002. Yield and early growth responses to starter fertilizer in no-till corn assessed with precision agriculture technologies. Agron J. 94:1024-1033.

Borkert, C.M., and S.A. Barber 1985. Predicting the most eficient phosphorus placement for soybeans. Soil Sci. Soc. Am. J. 49:901-904.

Buah, S.S.J., T.A. Polito, and R. Killorn. 1999. No-tillage corn hybrids response to starter fertilizer. J. Prod. Agr. 12:676-680.

Buah, S.S.J., T.A. Polito, and R. Killorn. 2000. No-tillage soybean response to banded and broadcast and direct and residual fertilizer phosphorus and potassium applications. Agron. J. 92:657-662.

Bullen, C. W., R.J Soper, and L.D. Bailey. 1983. Phosphorus nutrition of soybeans by placement of fertilizer phosphorus. Crop Sci. 63:199-210.

Bullock, D.G., F.W. Simmons, I.M. Chung, and G.I. Johnson. 1993. Growth analysis of corn grown with or without starter fertilizer. Crop Sci. 33:112-117.

Bundy, L.G., and T.W. Andraski. 2001. Starter fertilizer response on high and very high testing soils. Better Crops with Plant Food. 85:3-5.

Bundy, L.G., H. Tunney, and A.D. Halvorson. 2005. Agronomic aspects of phosphorus management. p. 685-727. *In* J. T. Sims and A. N. Sharpley, (ed.). Phosphorus: agriculture and the environment. ASA, CSSA and SSSA, Madison, WI.

Carson, P.L. 1980. Recommended potassium test. p.12-13. *In* W. C. Dahnke, (ed.). Recommended chemical coil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). N.D. Agric. Exp. Stn., Fargo, ND.

Ching, P.C., and S.A. Barber. 1979. Evaluation of temperature effects on K uptake by corn. Agron. J. 71:1040-1044.

Hach Co. 1991. Intructional manual. Digesdahl digestion apparatus model 23130-20. Boulder, Co.

Combs, S.M. and M.V. Nathan.1998. Soil organic matter. p.53-57. *In* J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.

Dodd, J.R. and A.P. Mallarino. 2005. Soil test phosphorus and crop grain yield responses to long-term phosphorus fertilization for corn-soybean rotations. Soil Sci. Soc. Am. J. 69:1118-1128.

Eckert, D.J., and J.W. Johnson. 1985. Phosphorus fertilization in no-tillage corn production. Agron. J. 77:789-792.

Farmaha, B.S., F.G., Fernandez, and E.D. Nafziger. 2011. No-till and strip-till soybean production with surface and subsurface phosphorus and potassium fertilization. Agron. J. 103:1862-1869.

Farmaha, B.S., F.G., Fernandez, and E.D. Nafziger. 2012. Soybean seed composition, aboveground growth, and nutrient accumulation with phosphorus and potassium fertilization in no-till and strip-till. Agron. J. 104:1006-1015.

Fixen, P.E., T.W. Bruulsema, T.L. Jensen, R.M. Mikkelsen, S.T. Murrel, and S.B. Phillips et al. 2010. The fertility of North American soils. Better Crop With Plant Food. 94(4): 6-8.

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. p.21-30. *In* J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.), Missouri Agric. Exp. Stn., Columbia.

Ham, G.E., W.W. Nelson, S.D. Evans, and R.D. Frazier. 1973. Influence of fertilizer placement on yield response of soybeans. Agron J. 65:81-84.

Havlin, J.L., S.L. Tisdale, J.D., Beaton, and W.L. Nelson. 2005. Soil Fertility and Fertilizers. 7th ed. Pearson Education.

Heckman, J.R., J.T. Sims, D.B. Beegle., F.J. Coale, S.J. Herbert., and T.W. Bruulsema et al. 2003. Nutrient removal by corn grain harvest. Agron. J. 95:587-591.

Howard, D.D., M.E. Essington, and J. Logan. 2002. Long-term broadcast and banded phosphorus fertilization of corn produced using two tillage systems. Agron. J.94:51-56.

Howard, D.D., and D.D. Tyler. 1987. Comparison of surface applied phosphorus and potassium rates and in-furrow fertilizer combinations for no-till corn. J. Fert. Issues. 4:48-52.

Howard, D.D., and M.D. Mullen. 1991. Evaluationof in-furrow and banded starter N P K nutrient combinations for no-tillage corn production. J. Fert. Issues. 8:34-39.

Kaiser, D.E., A.P. Mallarino, and M. Bermudez. 2005. Corn grain yield, early growth, and early nutrient uptake as affected by broadcast and in-furrow starter fertilization. Agron. J. 97:620-626.

Ketcheson, J.W. 1968. Effect of controlled air and soil temperature and starter fertilizer on growth and nutrient composition of corn (*Zea may*s L.) Soil Sci. Soc. Am. J. 32:531-534.

Leikam, D.F., R.E Lamond, and D.B. Mengel. 2003. Soil test interpretation and fertilizer recommendation. MF 2586. Kansas State Univ. Ext., Manhattan.

Mackay, A.D., and S.A. Barber. 1985. Soil moisture effects on root growth and phosphorus uptake by corn. Agron. J. 77:519-523.

Mallarino, A.P., and R. Borges. 1997. Deep banding phosphorus and potassium for no-till corn and soybeans. p. 129-135. *In* Proc. Conf. North Central Extension-Industry Soil Fertility, 27th, St. Louis, MO. 19-20 Nov. 1997. Univ. of Nebraska-Lincoln, Lincoln, NE.

Mallarino, A.P., N. Bergmann, and D.E. Kaiser. 2011. Corn responses to in-furrow phosphorus and potassium starter fertilizer applications. Agron. J. 103:685-694.

Mallarino, A.P., S.R. Barcos, J.R. Prater, and D.J. Wittry. 2009. Timing of Broadcast Phosphorus Fertilization for No-Till Corn and Soybean. Soil Sci. Soc. Am. J. 73:2143-2150.

Mallarino, A.P., J.R. Webb, and A.M. Blackmer. 1991. Corn and soybean yields during 11 years of phosphorus and potassium fertilization on a high-testing soil. J. Prod. Agr. 4:312-317.

Mengel, D.B., S.E. Hawkins., and P. Walker. 1988. Phosphorus and Potassium placement for no-till and spring plowed corn. J. Fert. Issues. 5:31-36.

Murphy, J., and J.P. Riley. 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta 26:31-36.

Pedersen, P. 2009. Soybean growth and development. PM 1945. Iowa State Univ. Ext., Ames.

Plenet, D., and G. Lemaire. 1999. Relationships between dynamics of nitrogen uptake and dry matter accumulation in maize crops. Determination of critical N concentration. Plant Soil. 216:65-82.

Randall, G.W., and R.G. Hoeft. 1988. Placement methods for improved efficiency of P and K fertilizers: a review. J. Prod. Agr. 1:70-79.

Randall, G.W., S.D. Evans, and T.K. Iragavarapu. 1997. Long-term P and K applications: II. Effect on corn and soybean yields and plant P and K concentrations. J. Prod.Agr. 10:572-580.

Rehm, G.W., and J.A. Lamb. 2009. Corn response to fluid fertilizers placed near the seed at planting. Soil Sci. Soc. Am. J. 73:1427-1434.

Rehm, G.W., and J. A. Lamb. 2010. Soybean response to fluid fertilizers placed near the seed at planting. Soil Sci. Soc.Am. J. 74:2223-2229.

Rehm, G.W., S.D. Evans, W.W. Nelson, and G.W. Randall. 1988. Influence of placement of phosphorus and potassium on yield of corn and soybeans. J. Fert. Issues. 5:6-13.

SAS Institute. 2006. The SAS system for Windows. Version 9.1. SAS Inst., Cary, CN.

Touchton, J.T. 1988. Starter fertilizer combinations for corn grown on soils high in residual-P. J. Fert. Issues 5:126-130.

Vetsch, J.A., and G.W. Randall. 2002. Corn production as affected by tillage system and starter fertilizer. Agron. J. 94:532-540.

Sawyer, J.C., A.P. Mallarino, R. Killorn., and S.K Barnhart. 2002. General guide for crop nutrient recommendation in Iowa. PM 1688. Iowa State Univ. Ext., Ames.

Warncke, D., and J.R. Brown 1998. Potassium and other basic cations. p.31-34. *In* J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.

Watson, M.E., and J.R. Brown 1998. pH and lime requirement. p.13-16. *In* J. R. Brown (Ed.) Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn, Columbia.

Wolkowski, R.P. 2000. Row-placed fertilizer for maize grown with an in-row crop residue management system in southern Wisconsin. Soil Tillage Res. 54:55-62.

Yin, X., and T.J. Vyn. 2002. Soybean responses to potassium placement and tillage alternatives following no-till. Agron. J. 94:1367-1374.

Ziadi, N., G. Belanger, A.N. Cambouris, N. Tremblay, M.C. Nolin, and A. Claessens. 2007. Relationship between P and N concentrations in corn. Agron. J. 99:833-841.

Figures and Tables

Table 2.1 Location description, soil classification, preliminary soil analysis, hybrids, varieties, tillage, and planting date for 2011 and 2012.

			Soil classification		Soil-test values						
Year	Location	County	Series†	Subgroup‡	STP	STK	pH	OM	Variety§/ Hybrid¶	Tillage system#	Planting date
					mg kg^{-1}			g kg^{-1}			
					Corn						
2011	1	Riley	Eudora SL	F. Hapludolls	24	449	6.2	2.5	DK-6342	NT	29 Apr. 2011
2011	2	Shawnee	Eudora SL	F. Hapludolls	17	228	6.8	1.6	DK-6449 VT3	CT	28 Apr. 2011
2012	3	Riley	Eudora SL	F. Hapludolls	26	370	5.8	2.4	DK C63-49	NT	18 Apr. 2012
2012	4	Shawnee	Eudora L	F. Hapludolls	16	249	6.5	1.7	DK-6323	CT	19 Apr. 2012
					Soybean						
2011	1	Riley	Rossville SL	C. Hapludolls	12	306	6.7	2.2	KS 3406RR	NT	11 May 2011
2011	2	Shawnee	Eudora SL	F. Hapludolls	16	161	6.2	1.6	LG C3616RR	CT	16 May 2011
2012	3	Riley	Eudora SL	F. Hapludolls	24	458	6.3	2.8	KS 3406RR	NT	10 May 2012
2012	4	Shawnee	Eudora SL	F. Hapludolls	18	135	6.8	1.3	Asgrow 3282	CT	14 May 2012

† SL, Silt Loam; S, Loam

‡ F, Fluventic; C, Cumulic;

§ LG, LG SEEDS; KS, Kansas Agricultural Experiment Station.

¶ Corn Hybrid: DK, DeKalb.

CT, Conventional tillage. Locations 2, 6 and 8 were chisel plowed in the spring and turbo-tilled in the fall; Location 4 was subsoiled in the winter and field cultivated in spring. NT, no tillage

Table 2.2. Significance of *F* values for treatment effects on corn early growth, N, P and K concentration and uptake at the V6 growth stage, ear leaf N, P and K concentration at the R2 growth stage, and grain yield for each location and across locations.

Location	Fixed effects									
	Early growth	Early nutrient concentration			Early nutrient uptake			Ear leaf nutrient concentration		
		P	K	N	P	K	N	P	K	N
	P > F									
1	0.029	0.067	0.003	< 0.001	0.001	0.003	< 0.001	0.040	0.235	0.381
2	< 0.001	< 0.001	0.007	0.328	< 0.001	< 0.001	< 0.001	0.017	0.766	0.051
3	0.762	0.635	0.105	0.955	0.903	0.503	0.751	0.223	0.948	0.964
4	< 0.001	0.010	0.034	0.019	< 0.001	< 0.001	< 0.001	0.212	0.172	0.034
Across locations 1&3†	0.099	0.555	< 0.001	0.155	0.038	0.007	0.022	0.006	0.264	0.942
Across locations 2&4‡	< 0.001	< 0.001	0.002	0.101	< 0.001	< 0.001	< 0.001	0.045	0.424	0.033
Across all locations	< 0.001	< 0.001	< 0.001	0.291	< 0.001	< 0.001	< 0.001	0.001	0.072	0.160

† Locations 1 and 2 were no-till, non-irrigated and had broadcast urea as N source;

‡ Locations 3 and 4 were conventional tillage, irrigated and was used anhydrous ammonia as N source;

Table 2.3. Significance of F values for treatment effects on corn yield, and on N, P and K grain concentration and removal.

Location	Fixed effects						
	Grain Yield	Grain concentration			Grain removal		
		P	K	N	P	K	N
	- P > F -						
1	0.206	0.609	0.005	0.995	0.529	0.001	0.107
2	0.299	0.062	0.090	0.214	0.105	0.391	0.182
3	0.142	0.490	0.268	0.676	0.357	0.276	0.180
4	0.279	0.329	0.069	0.762	0.534	0.438	0.426
Across locations 1&3†	0.026	0.915	0.002	0.953	0.129	< 0.001	0.016
Across locations 2&4‡	0.929	0.017	0.015	0.180	0.092	0.224	0.766
Across all locations	0.901	0.051	0.177	0.738	0.329	0.871	0.764

† Locations 1 and 3 were no-till and non-irrigated.

‡ Locations 2 and 4 were conventional tillage and irrigated.

Table 2.4. Corn yield and early growth at V6 growth stage as affected by starter and broadcast fertilizations.

	Treatments							
			Broadcast				Broadcast	
Location	Control	Starter	No starter	Starter	Control	Starter	No starter	Starter
	- - - - - - - plant dry weight, g $plant^{-1}$ - - - - - - -				- - - - - - - - - - - yield, Mg ha^{-1} - - - - - - - - - - -			
1	8.4b†	8.1b	8.3b	9.5a	3.70	3.96	3.83	3.58
2	6.5b	10.4a	10.1a	11.3a	9.16	8.98	9.54	8.91
3	8.2	7.8	8.6	8.7	2.70	3.14	2.70	2.76
4	3.3c	6.1b	5.3b	8.8a	15.32	15.13	14.94	15.76

† Numbers followed by different letters between columns for each variable represent statistically significant differences at the $P \leq 0.10$.

Table 2.5. Placement effects on early plant N, P and K concentration and uptake in corn at V6 growth stage and on ear leaf N, P and K concentration at R2 growth stage, and N, P and K grain concentration and removal.

	Treatments											
			Broadcast				Broadcast				Broadcast	
Location	Control	Starter	No starter	Starter	Control	Starter	No starter	Starter	Control	Starter	No starter	Starter
	- - - plant P concentration, g kg^{-1} - - -				- - - - plant K concentration, g kg^{-1} - - -				- - - plant N concentration, g kg^{-1} - - -			
1	4.0ab†	3.9b	3.9b	4.2a	51.1b	52.7b	52.9b	55.7a	25.0b	27.8a	24.9b	28.6a
2	2.8c	2.7c	3.3b	3.7a	45.2b	43.2b	50.5a	48.9a	31.0	30.6	29.8	31.3
3	3.7	3.7	3.6	3.5	49.8	52.6	54.1	53.7	30.0	30.1	30.1	29.2
4	3.0a	2.5b	2.8a	2.9a	47.1c	50.2bc	50.6ab	53.5a	35.8a	33.0b	33.4b	32.6b
	- - - - plant P uptake, mg plant^{-1} - - - -				- - - - plant K uptake, mg plant^{-1} - - - -				- - - - plant N uptake, mg plant^{-1} - - - -			
1	33.5b	33.6b	32.2b	39.5a	427b	454b	439b	530a	209c	240b	206c	272a
2	18.9d	27.9c	33.4b	41.5a	301c	452b	511ab	556a	200c	320ab	301b	355a
3	30.2	28.3	30.7	30	408	409	464	471	243	233	257	253
4	10.0c	15.0b	15.0b	26.0a	158c	308b	272b	471a	116c	203b	179b	287a
	- - - - leaf P concentration, g kg^{-1} - - - -				- - - - leaf K concentration, g kg^{-1} - - -				- - - leaf N concentration, g kg^{-1} - - - -			
1	2.3b	2.4a	2.4a	2.6a	22.8	22.6	24.1	23.5	22.1	21.7	21.3	21.5
2	2.6ab	2.5b	2.6ab	2.7a	20.5	20.4	20.6	20.4	25.0a	23.8bc	23.1c	54.1ab
3	2.1	2.2	2.3	2.4	17.4	16.9	17.5	17.2	24.0	23.7	24.0	24.5
4	2.6	2.7	2.9	3.1	16.6	15.9	16.9	16.7	25.6ab	26.0a	24.3bc	23.5c
	- - - grain P concentration., g kg^{-1} - - -				- - - K grain concentration, g kg^{-1} - - -				- - - N grain concentration g kg^{-1} - - -			
1	2.9	2.9	2.9	3.0	4.2a	4.0a	3.4b	3.7b	14.1	14.1	14.2	14.1
2	2.4c†	2.5bc	2.6ab	2.7a	3.2b	3.3a	3.3a	3.4a	11.5	11.5	11.9	11.5
3	2.9	2.9	3.0	2.9	5.2	5.0	4.9	4.8	15.1	15.2	14.9	15.0
4	2.5	2.5	2.8	2.6	3.4b	3.4b	3.5ab	3.6a	11.5	11.7	11.7	11.6
	- - - - - - - P removal kg ha^{-1} - - - - - - -				- - - - - - K removal kg ha^{-1} - - - - - - -				- - - - - - - N removal kg ha^{-1} - - - - - -			
1	10.8	11.4	10.8	10.8	15.0a	15.5a	13.0b	13.3b	52.3	55.4	54.0	50.4
2	21.8	22.4	25.0	22.8	29.0	29.5	31.5	29.6	105	103	115	103
3	8.0	9.0	8.0	7.8	14.3	15.5	13.5	13.0	41.5	47.3	40.5	40.5
4	37.8	37.8	41.0	40.8	51.5	50.8	53.5	54.3	177	177	174	183

† Numbers followed by different letters between columns represent statistically significant differences at the $P \leq 0.10$.

Table 2.6. Significance of *F* values for treatment effects on N, P and K trifoliate concentration at R1 growth stage, on seed yield and on N, P and K grain concentration and removal.

	Fixed effects									
	Leaf concentration			Grain concentration			Grain removal			
Location	P	K	N	P	K	N	P	K	N	Yield
	- -				P > F		- -			
1	0.001	0.048	0.311	0.018	0.010	0.930	0.390	0.849	0.734	0.886
2	0.010	0.093	0.864	0.123	0.254	0.301	0.921	0.997	0.257	0.955
3	0.016	0.539	0.129	0.253	0.612	0.866	0.181	0.212	0.514	0.250
4	0.034	0.163	0.599	0.316	0.947	0.849	0.626	0.840	0.969	0.896
Across locations 1&3†	< 0.001	0.116	0.048	0.005	0.037	0.897	0.083	0.200	0.257	0.326
Across locations 2&4‡	< 0.001	0.014	0.778	0.092	0.552	0.509	0.716	0.910	0.673	0.967
Across all locations	< 0.001	0.045	0.147	0.001	0.153	0.791	0.073	0.243	0.158	0.414

† Locations 1 and 3 were no-till and non-irrigated.

‡ Locations 2 and 4 were conventional tillage and irrigated.

Table 2.7. Soybean leaf P and K concentration at R1 growth stage, seed yield, and seed P and K concentration and removal as affected by starter and broadcast fertilizations.

			Broadcast	
Location	Control	Starter	No starter	Starter
	- - - - - - leaf P concentration, g kg - - - - - -			
1	3.6b†	3.5b	3.9a	4.0a
2	3.9b	3.9b	4.0ab	4.2a
3	3.9b	4.0b	4.3a	4.4a
4	4.1b	4.1b	4.2b	4.5a
	- - - - - - leaf K concentration, g kg^{-1} - - - - - -			
1	25.3a	24.0b	23.6b	23.6b
2	23.7a	22.3b	22.9ab	23.5a
3	20.9	21.0	19.9	21.1
4	16.4	16.2	16.9	17.7
	- - - - - - - - - - - yield, kg ha^{-1} - - - - - - - - - - -			
1	2090	2150	2220	2020
2	3300	3430	3360	3360
3	2010	2310	2350	2360
4	4900	4880	4980	4890
	- - - - - - seed P concentration, g kg^{-1} - - - - -			
1	5.7c†	6.0bc	6.2a	6.3ab
2	5.3	5.5	5.6	5.6
3	5.7	5.6	5.8	5.8
4	5.4	5.2	5.5	5.8
	- - - - - seed K concentration, g kg^{-1} - - - - -			
1	19.0b	19.2b	19.8a	19.9a
2	18.5	18.1	18.9	18.3
3	18.2	17.9	18.2	18.3
4	18.0	18.1	18.1	18.2
	- - - - - - - seed P removal, kg ha^{-1} - - - - - - -			
1	11.7	12.5	14.3	12.6
2	17.8	18.8	18.5	18.6
3	8.8	12.8	13.0	14.0
4	26.0	25.5	27.8	28.0
	- - - - - - - seed K removal, kg ha^{-1} - - - - - - -			
1	39.3	41.0	43.8	41.0
2	61.5	61.6	62.0	61.0
3	28.8	41.3	41.5	43.3
4	85.7	89.3	90.8	88.8

† Numbers followed by different letters between columns represent statistically significant differences at the $P \leq 0.10$.

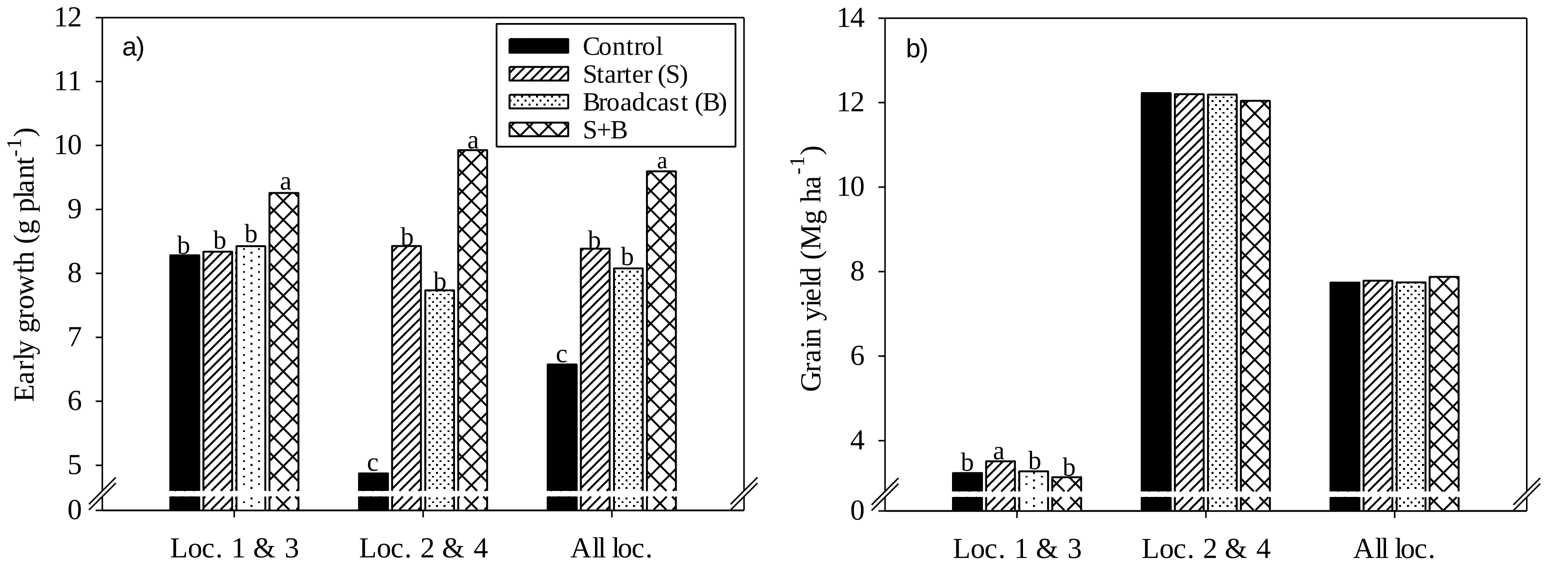

Figure 2.1. Placement effects on corn early growth at V6 growth stage (a) and grain yield (b) across locations 1 and 3, locations 2 and 4 and across all locations. Locations 1 and 3 were no-till, non-irrigated and had broadcast urea as N source; locations 2 and 4 were conventional tillage, irrigated and anhydrous ammonia was used as N source. Different letters for each bar group indicate statistically significant differences at the $P < 0.10$.

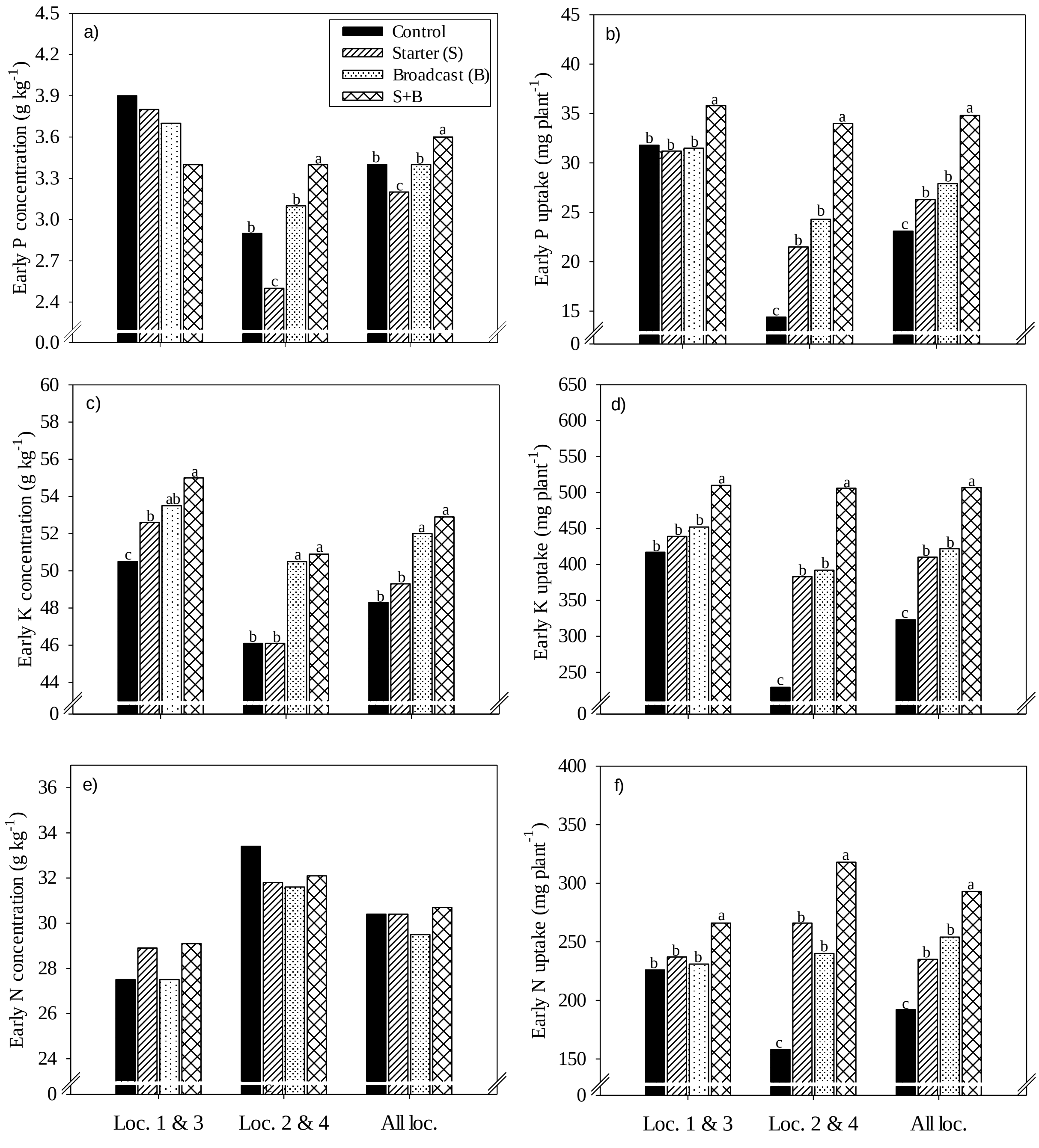

Figure 2.2. Placement effects on early plant P (a), K (c) and N (e) concentration and P (b), K (d) and N (f) uptake in corn at the V6 growth stage across locations 1 and 3, 2 and 4 and across all locations. Locations 1 and 3 were no-till, non-irrigated and had broadcast urea as N source; locations 2 and 4 were conventional tillage, irrigated and anhydrous ammonia was used as N source**.** Different letters for each bar group indicate statistically significant differences at the $P < 0.10$.

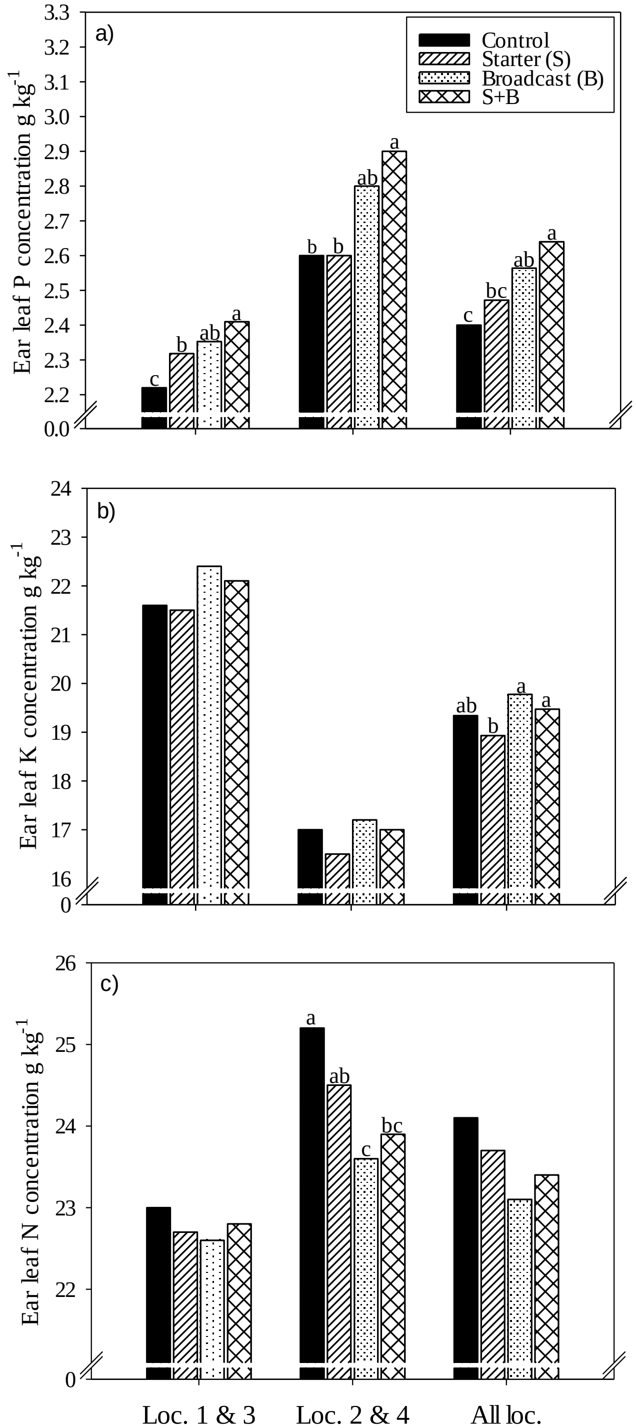

Figure 2.3. Placement effects on ear leaf P (a), K (b) and N (c) concentration on corn at R2 growth stage across locations 1 and 3, 2 and 4 and across all locations. Locations 1 and 3 were no-till, non-irrigated and had broadcast urea as N source; locations 2 and 4 were conventional tillage, irrigated and anhydrous ammonia was used as N source. Different letters for each bar group indicate statistically significant differences at the $P < 0.10$.

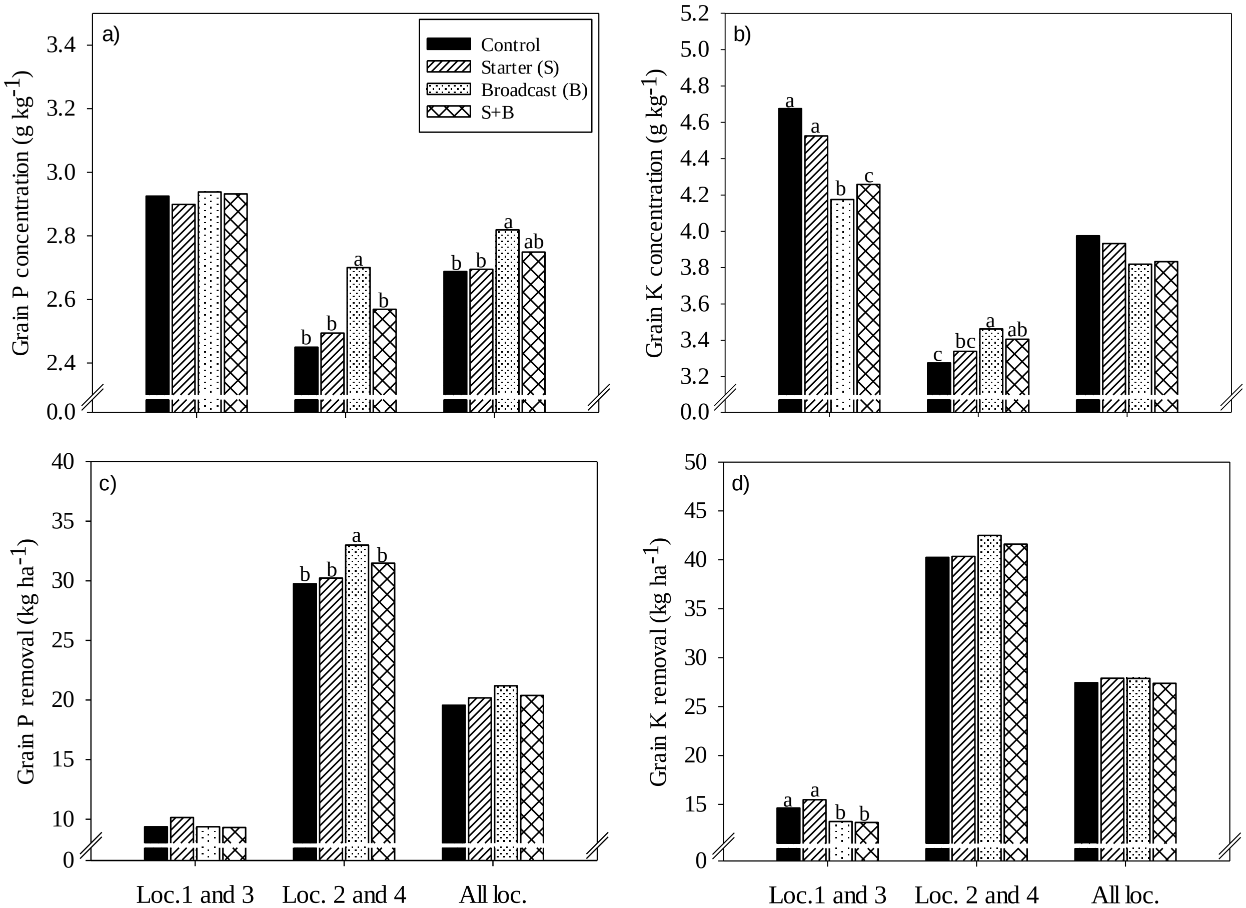

Figure 2.4. Placement effects grain P (a) and K(b) concentration and P (c) and K (d) removal on corn across locations 1 and 3, 2 and 4 and across all locations. Locations 1 and 3 were no-till, non-irrigated and had broadcast urea as N source; locations 2 and 4 were conventional tillage, irrigated and anhydrous ammonia was used as N source. Different letters for each bar group indicate statistically significant differences at the $P < 0.10$.

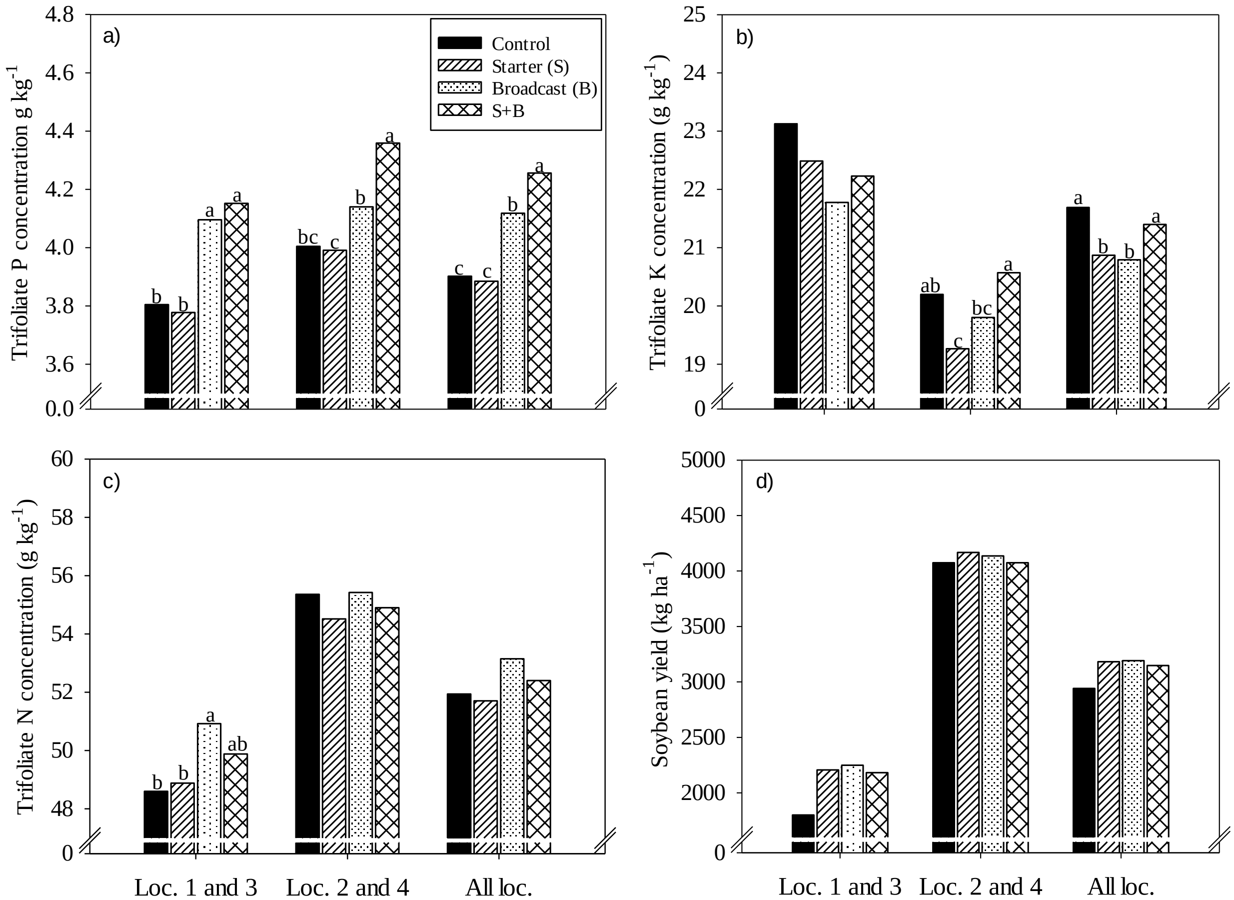

Figure 2.5. Placement effects on soybean trifoliate P (a), K (b) and N (c) concentration at R1 growth stage, and on seed yield (d) across locations 1 and 3, locations 2 and 4 and across all locations. Locations 1 and 3 were no-till and non-irrigated; locations 2 and 4 were conventional tillage and irrigated. Different letters for each bar group indicate statistically significant differences at the $P < 0.10$.

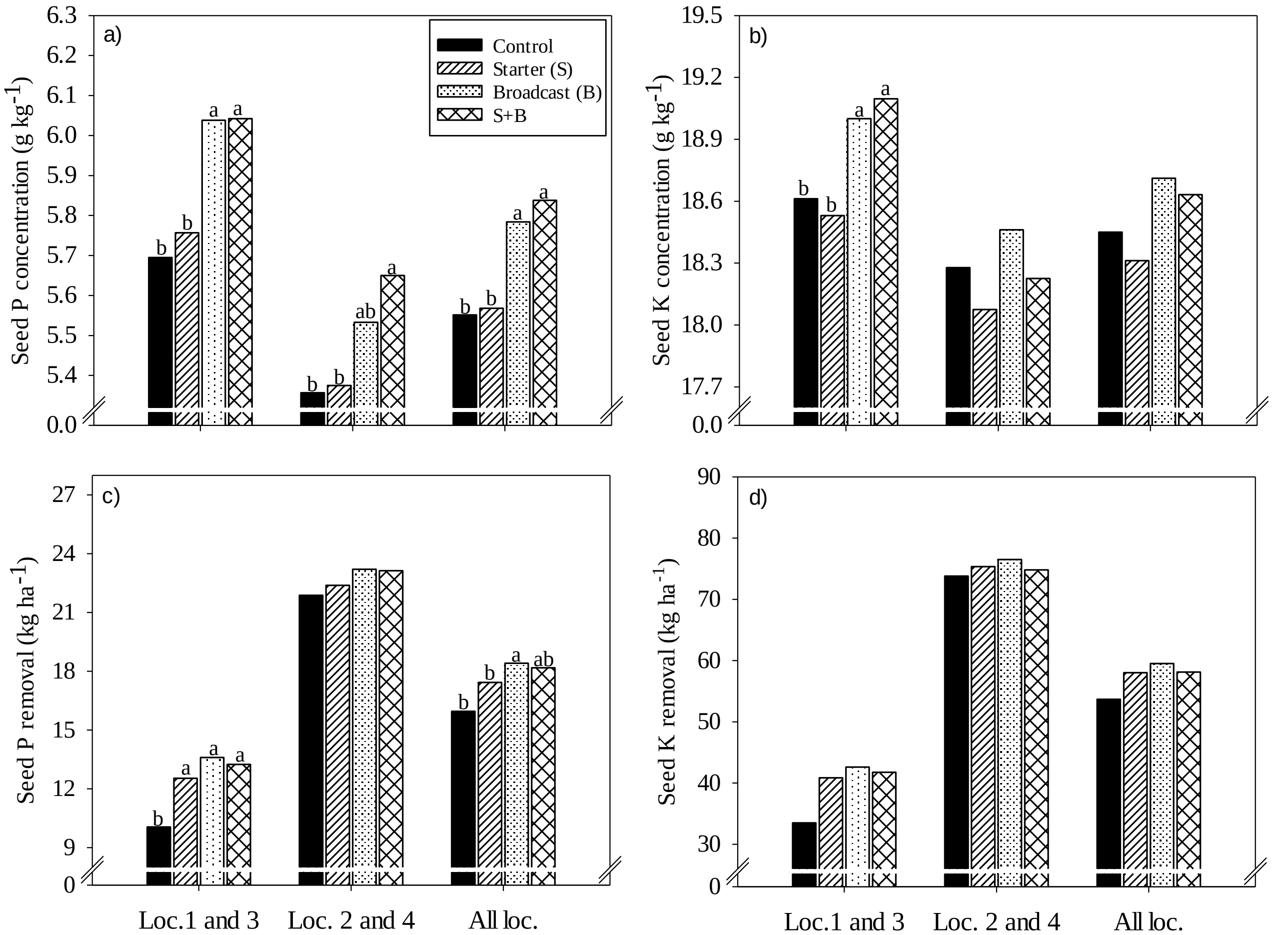

Figure 2.6. Placement effects on soybean seed P (a) and K (b) concentration, and on P (c) and K (d) seed removal across locations 1 and 3, locations 2 and 4 and across all locations. Locations 1 and 3 were no-till and non-irrigated; locations 2 and 4 were conventional tillage and irrigated. Different letters for each bar group indicate statistically significant differences at the $P < 0.10$.

Chapter 3 - Evaluation of soybean response to direct and residual fertilization

Abstract

Fertilizer application is traditionally applied before corn (Zea Mays) and intended for both corn and soybean [Glycine max (L.) Merr.]. However, studies evaluating the need for direct soybean fertilization and response to residual fertilizer are limited. The objectives of this study were (i) to evaluate the effect of residual and direct fertilization on soybeans after corn under a corn-soybean rotation system, and (ii) study the effect of fertilizer P and K application on soil test P (STP) and soil test K (STK) changes over time. Soybean trials were conducted in 2012 at two locations in Kansas. In 2011 a study was established to evaluate the effect of P and K fertilization on corn. The followed year soybean was planted on the same plots to evaluate the effect of residual and direct fertilization on soybean. Soil samples were collected in 2011 and 2012. Soybean leaf was analyzed for P and K, and yield was determined after physiological maturity. Application of P and K fertilizer generated significant increases in STP and STK after one year of application. The rate of P and K fertilizer required to increase 1 mg kg^{-1} yr^{-1} of the respective nutrients was between 2.8 - 5.1 kg ha^{-1} for P and between 1.0- 2.5 kg ha^{-1} for K, respectively. These values are lower than current guidelines, suggesting that some farmers in Kansas may be over applying P and K fertilizer. Direct fertilization increased soybean yield while residual fertilizer did not. Therefore maintenance rates may be affective not only to sustain STP and STK levels but also to improve soybean yield.

Introduction

Phosphorus and potassium are essential nutrients for soybean production; however excess application of these nutrients and soil degradation can cause several environmental issues. In order to develop a long term P and K fertilization management strategy, is essential to adjust application rates to maintain soil test P (STP) and soil test K (STK) at levels that guarantee optimal crop profitability and prevent water pollution. Some studies indicate that to maintain STP and STK the required rates of P and K are dependent on the initial soil test level, and that greater rates of fertilizer P and K are needed to maintain levels when initial soil test values are higher (Dodd and Mallarino, 2005; McCallister et al., 1987; McCollum, 1991; Webb et al., 1992). The amount of fertilizer needed to maintain certain soil test level and crop yield also depends on several factors, such as soil type and mineralogy, subsoil available nutrient content and nutrient removal through harvested products (McCallister, 1987).

Critical levels for STP and STK is the target soil test level for optimum crop yield. Below this level crop yield may be restricted by nutrient availability in the soil. Kansas State University has estimated a critical level of 20 mg P kg-1 by Mehlich-3 (Frank et al., 1998) and 130 mg K kg^{-1} by ammonium acetate (Warncke and Brown, 1998) methods (Leikam et al., 2003). Moreover on the latter study, the amount of P and K required to increase STP and STK by 1 mg kg^{-1} is 9 kg P ha^{-1} yr^{-1} and 9 kg K ha^{-1} yr^{-1}, respectively. According to Rehm et al. (1984), soil test value for P on loamy fine sand soils was increased by 1 mg P kg^{-1} for each 9.3 kg ha^{-1} of P applied. Dodd and Mallarino (2005) found on fine loamy-soils that the amount of P needed to increase STP by 1 mg P kg^{-1} was between 17 and 28 kg P ha^{-1} yr^{-1}. Similarly Randall et al. (1997) found on clay loam soils under corn-soybean rotation that the amount of P necessary to increase 1 mg kg^{-1} of P was between 19 and 35 kg P ha^{-1} yr^{-1} and to increase 1 mg kg^{-1} of K was needed approximately 20 kg K ha-1 yr-1. Soils with high clay content or fine textured soils exhibit higher buffer capacity and adsorption than coarse-textured soils and then higher adsorbed P and K, therefore more fertilizer P and K will be needed in clay soils compare to sandy soils (Havlin et al. 2005).

Dodd and Mallarino (2005) showed in a long term study that corn and soybean respond 50 to 70% of the time to annual P fertilization when soil test level was equal or less than 20 mg kg-1 and no response under higher soil test P. Similarly, Mallarino and Barcos (2009) also found that yield responses to P broadcast fertilization applied before corn and soybean normally occurred when soils were equal or lower than 22 mg kg-1.

Most producers in Kansas do not apply direct fertilizer P or K on soybean; instead they generally rely on residual effects of corn fertilization from the previous year. Soybean is normally the second crop and is normally less responsive to fertilizer in the year of application than corn (deMooy et al., 1973). According to the latter study, soybean perhaps is relatively more efficient in recovering residual fertilizer from the soil as compared to other crops. According to Randall et al. (2001), under low STP level substantial soybean yield increase may occur from residual P application from corn, either with broadcast or band applied. Buah et al. (2000) in the other hand found that soybean responded to P fertilization in the year of application more frequently than to residual P fertilizer application, especially under low STP. According to their study, application of smaller annual P applications may be more effective than larger semiannual application for increasing soybean yields. Differently, deMooy et al. (1973), found no statistical differences on soybean yield increase between direct and residual response to P and K under soils with STP and STK between medium and high range.

Although several studies evaluated the effect of fertilization and placement on soybean and corn, limited information is available on the residual effects of previous crop fertilization on soybean. Moreover there is limited information on how STP and STK change over time given certain initial soil test level and soil type. The objectives of this study were (i) to evaluate the effect of residual fertilization on soybeans after corn under a corn-soybean rotation system, and (ii) study the effect of fertilizer P and K application on STP and STK changes over time.

Material and Methods

This study was conducted in 2011 and 2012 at two locations in Kansas. Description of each location is presented in Table 3.1. In 2011 a study was established to evaluate the effect of P and K fertilization on corn. The following year soybean was planted over corn residue plots to evaluate the effect of corn broadcast fertilization on soybean. Broadcast fertilizer in 2011 was a combination of mono ammonium phosphate (MAP) [23-52-0 (N-P-K)] [11-52-0 (N-P2O5-K2O)] and KCl [0-0-52 (N-P-K)] [0-0-62 (N-P2O5-K2O)] for a total application rate of 49 kg ha^{-1} of P (112 kg ha-1 P2O5) and 93 kg ha^{-1} of K (112 kg ha-1 K2O). The broadcast application rates can be considered commonly used rates by producers before corn in a corn-soybean rotation and intended for both crops in the rotation (Leikam et al., 2003). Soybean treatments are described on Table 3.2. Broadcast application on soybean was a combination of MAP [11-23-00 (N-P-K)] [11-52-00 (N-P2O5-K2O)] and KCl [0-0-50 (N-P-K)] [00-00-62 (N-P2O5-K2O)] for a total application rate of 20 kg ha^{-1} of P (45 kg ha^{-1} P2O5) and 65 kg ha^{-1} of K (75 kg ha^{-1} K2O). The fertilizer application rates were determined by total nutrient removal for soybeans estimated base on yield potential. Broadcast was applied 3-4 weeks before planting soybeans, and incorporated at Topeka before planting and non-incorporated at Ashland. Topeka was irrigated as needed with center pivot sprinkler irrigation systems while Ashland was non-irrigated. The experimental design consisted of a randomized complete block design with four treatments and four replications. The plot size was 15 m long with 4 rows and row spacing was 76 cm.

Soil samples were collected from each small plot before fertilizer application in 2011 prior planting corn. In 2012 soil samples were collected only from one treatment plots that received both broadcast (49 kg P ha^{-1} and 93 kg K ha^{-1}) and starter (10 kg P ha^{-1} and 19 kg K ha^{-1}) application in 2011. Sampling was completed before fertilizer was applied on soybean. Composite soil samples of 10-12 cores were collected from 0 to 15 cm depth in the row and between rows with a ratio of 1:3, i.e. every four cores, one core was taken in the row and 3 cores was taken between the rows (Fernandez and Schaefer, 2011). Samples were analyzed for P by the Mehlich-3 method (Frank et al., 1998) and K with the ammonium acetate method (Warncke and Brown, 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson and Brown, 1998), and soil organic matter (OM) was determined by Walkley–Black method (Combs and Nathan, 1998).

Plant population was measured in a 7.6 m section of two central rows of each plot. Soybean leaf samples were collected consisting of the most recently developed fully expanded trifoliate leaf (petiole excluded) between early bloom (R1) and full bloom (R2) stages (Pedersen, 2009). Plant samples were dried at $60^{o}C$ in a forced-air oven and ground to pass a 2-mm screen. Ground samples were digested using sulfuric acid and hydrogen peroxide in a Digesdahl Analysis System (Hach Co., 1991). Nitrogen and P were measured by colorimetry and K was measured by flame photometry (Murphy and Riley, 1962). After soybean reached physiological maturity, yield was determined by harvesting the center two rows of each plot. Harvest was completed with a small plot combine at both locations and seed yield was adjusted to a moisture content of 130g kg^{-1}. Statistical analysis was completed using the generalized linear mixed model

(GLIMMIX) procedure of SAS (SAS., 2006) assuming block and locations as random factors in the model. Statistical significance was determined at the $P \leq 0.10$ level. When significant, plant population was used as covariate in the analysis. Statistical analysis was completed by location and across locations.

Results and Discussion

Soil test values

Fertilizer application significantly increased soil test P and K at both locations (Figure 2.1). The 60 kg P ha^{-1} rate applied in Ashland in 2011 on corn increased the soil test P by 18 mg P kg^{-1}, i.e. from 24 to 42 mg P kg^{-1} in one year. Topeka received the same rate of P as Ashland and the STP increased 14 mg P kg^{-1}, from 14 to 28 mg P kg^{-1}. Therefore the rate of P fertilizer required to increase 1 mg kg^{-1} yr^{-1} of P was between 2.8 to 3.6 kg P ha^{-1} in Ashland and between 3.7 to 5.1 kg P ha^{-1} in Topeka (Figure 3.2). Rehm et al. (1984) found similar rate of P (5.6 kg P ha^{-1}) necessary to increase STP by 1 mg kg-^{1} yr^{-1}, however their work was conducted under sandier soils (loamy fine sand). STK was increased in Ashland by 89 mg K kg^{-1}, i.e. from 450 to 539 mg K kg^{-1}, and in Topeka by 53 mg K kg^{-1}, i.e. 232 to 285 mg K kg^{-1} in after one year of 110 kg K ha^{-1} rate application (Figure 2.1). The amount of K fertilizer needed to increase STK by 1 mg kg^{-1} yr^{-1} was between 1.0 to 1.7 kg K ha^{-1} in Ashland and between 1.8 to 2.5 kg K ha^{-1} in Topeka. Phosphorus and K removal by soybeans seeds in 2012 was not considered, and therefore the amount of fertilizer required to increase soil test P and K may be overestimated. Although the results shown are only from one year, the difference between the amounts of fertilizer needed to increase soils test levels are much lower than Leikam et al. (2003) work, probably because our study was conducted only on silt loam soils with lower buffer capacity.

Crop response

Fertilization significantly increased leaf P concentration in Ashland (Figure 3.3). Either residual, direct fertilization or the combination of both was effective on increasing leaf P concentration. None of the treatments that received fertilizer affected leaf P concentration in Topeka. Results across locations showed a significant effect of fertilizer treatments and as at Ashland all of them were effective on increasing leaf P concentration (Figure 3.3). According to Buah et al. (2000) residual or direct P fertilization frequently increased leaf P concentration on soybean.

Soybean yield was significantly increased with residual fertilizer in combination with direct broadcast application in Ashland (Figure 3.3). Residual fertilization or direct application alone did not affect yield when compared to the control. In Topeka, there was a slight increase in yield when direct fertilization was applied, the response being very similar to Ashland; however fertilization was not significantly different than the control (Figure 3.3). According to Dodd and Mallarino (2005) soybean does not always respond to annual P fertilization when soil test level is equal or greater than 20 mg kg^{-1}, which may explain the lack of yield response to fertilization in Topeka. Across both locations residual treatment had no effect on yield. The combination of residual and direct fertilization and the direct application only significantly increased yield over the control and the residual treatment. The lack of response of the residual fertilization agrees with Buah et al. (2000), where he found that application of smaller annual P applications may be more effective than larger semiannual application for increasing soybean yields.

Conclusion

Application of P and K fertilizer generated significant increases in soil test levels for the respective nutrients after one year of application. The rate of P and K fertilizer required to increase 1 mg kg^{-1} yr^{-1} of the respective nutrients was between 2.8 - 5.1 kg ha^{-1} for P and between 1.0 - 2.5 kg ha^{-1} for K, respectively. These values are lower than current guidelines, suggesting that producers may be over applying P and K fertilizer.

Soybean yield was increased by residual fertilizer in combination with direct broadcast application in Ashland, where soil test level was above the critical level of 20 mg kg-1. Residual fertilizer only was ineffective in increasing yields. In Topeka where soil test P was considered low, there was an increase on yield over the control at this location, however it was not statistically significant. Across locations direct fertilization significantly increased soybean yield, about 250 kg ha^{-1}. Therefore maintenance rates may be affective not only to sustain STP and STK levels but also to improve soybean yield.

Overall part of this study provided some information about soil test P and K and yield response to fertilization; however more research is needed involving more locations and soils types across Kansas to get more representative results.

References

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn Growth and Development. PMR 1009. Iowa State Univ. Ext., Ames.

Buah, S.S.J., T.A. Polito, and R. Killorn. 2000. No-tillage soybean response to banded and broadcast and direct and residual fertilizer phosphorus and potassium applications. Agron. J. 92:657-662.

Bundy, L.G., and T.W. Andraski. 2001. Starter fertilizer response on high and very high testing soils. Better Crops with Plant Food. 85(2):3-5.

Bundy, L.G., H. Tunney, and A.D. Halvorson. 2005. Agronomic aspects of phosphorus management. p. 685-727. *In* J. T. Sims and A. N. Sharpley, (ed.). Phosphorus: agriculture and the environment. ASA, CSSA and SSSA, Madison, WI.

Carson, P.L. 1980. Recommended potassium test. p.12-13. *In* W. C. Dahnke, (ed.). Recommended chemical coil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). N.D. Agric. Exp. Stn., Fargo, ND.

Combs, S.M. and M.V. Nathan.1998. Soil organic matter. p.53-57. *In* J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.

deMooy C.J., J.L. Young, and J.D. Kaap. 1973. Comparative response of soybean and corn to phosphorus and potassium. Agron. J. 65:851-855.

Dodd J.R., and A.P. Mallarino. 2005. Soil-test phosphorus and crop grain yield responses to long-term phosphorus fertilization for corn-soybean rotations. Soil Sci. Soc. Am. J. 69:1118-1128.

Fixen, P.E., T.W. Bruulsema, T.L. Jensen, R.M. Mikkelsen, S.T. Murrel, and S.B. Phillips et al. 2010. The fertility of North American soils. Better Crop With Plant Food. 94(4): 6-8.

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. p.21-30. *In* J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.), Missouri Agric. Exp. Stn., Columbia.

Hach Co. 1991. Intructional manual. Digesdahl digestion apparatus model 23130-20. Boulder, Co.

Havlin, J. L., S.L. Tisdale, J. D. James, and L.N. Nelson. 2005. Soil Fertility and fertilizers. 7th ed. Pearson Education, Inc. Upper Saddle River, NJ.

Leikam, D.F., R.E Lamond, and D.B. Mengel. 2003. Soil test interpretation and fertilizer recommendation. MF 2586. Kansas State Univ. Ext., Manhattan.

Mallarino, A.P., S.R. Barcos, J.R. Prater, and D.J. Wittry. 2009. Timing of Broadcast Phosphorus Fertilization for No-Till Corn and Soybean. Soil Sci. Soc. Am. J. 73:2143-2150.

McCallister D.L., Shapiro C.A., Raun W.R., Anderson F.N., Rehm G.W., Engelstad O.P., Russelle M.P., Olson R.A. (1987) Rate of Phosphorus and Potassium Buildup/Decline with Fertilization for Corn and Wheat on Nebraska Mollisols1. Soil Sci. Soc. Am. J. 51:1646-1652.

McCollum R.E. (1991) Buildup and Decline in Soil Phosphorus: 30-Year Trends on a Typic Umprabuult. Agron. J. 83:77-85.

USDA- Natural resources conservation service .1987. History of Kansas soil survey. Available at http://www.ks.nrcs.usda.gov/about/ks_history/soil_survey.html (verified 25 Feb. 2013). USDA-NRCS, Washington, DC

Pedersen, P. 2009. Soybean growth and development. PM 1945. Iowa State Univ. Ext., Ames.

Randall G.W., J.A. Vetsch, and T.S. Murrell. 2001. Soybean response to residual phosphorus for various placements and tillage practices. Better Crops with Plant Food. 85(4):12-15.

Rehm G.W., R.C. Sorensen, and R.A Wiese. 1984. Soil test values for phosphorus, potassium, and zinc as affected by rate applied to corn. Soil Sci. Soc. Am. J. 48:814-818.

SAS Institute. 2006. The SAS system for Windows. Version 9.1. SAS Inst., Cary, CN.

Warncke, D., and J.R. Brown. 1998. Potassium and other basic cations. p.31-34. *In* J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.

Watson, M.E., and J.R. Brown. 1998. pH and lime requirement. p.13-16. *In* J. R. Brown (Ed.) Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn, Columbia.

Webb J.R., A.P. Mallarino, and A.M. Blackmer. 1992. Effects of residual and annually applied phosphorus on soil test values and yields of corn and soybean. J. Prod. Agr. 5:148-152.

Figures and Tables

Table 3.1. Location description, soil classification, soil analysis, varieties, tillage, and planting date for soybean.

Year	Location	County	Soil classification: Series†	Soil classification: Subgroup‡	pH	OM	Variety ¶	Tillage system §	Planting date
						g kg^{-1}			
2011	1	Riley	Eudora SL	F. Hapludolls	6.2	25	KS 3406RR	NT	10/05/2012
2011	2	Shawnee	Eudora SL	F. Hapludolls	6.8	16	Asgrow 3282	CT	14/05/2012

† SL, Silt Loam;

‡ F, Fluventic;

¶ KS, Kansas Agricultural Experiment Station.

§ CT, Conventional tillage. Location 2 was chisel plowed in the spring and turbo-tilled in the fall; NT, no tillage.

Table 3.2. Description of soybean P and K broadcast rates applied on year 1 as residual fertilization from corn and the following year 2 as direct fertilization applied on soybean.

Treatment	Year 1 (corn)		Year 2 (soybean)	
	------------------------------ kg ha^{-1} ------------------------------			
	P	K	P	K
Control without fertilization	0	0	0	0
Residual broadcast	49	93	0	0
Direct broadcast	0	0	18	65
Residual + Direct broadcast	49	93	18	65

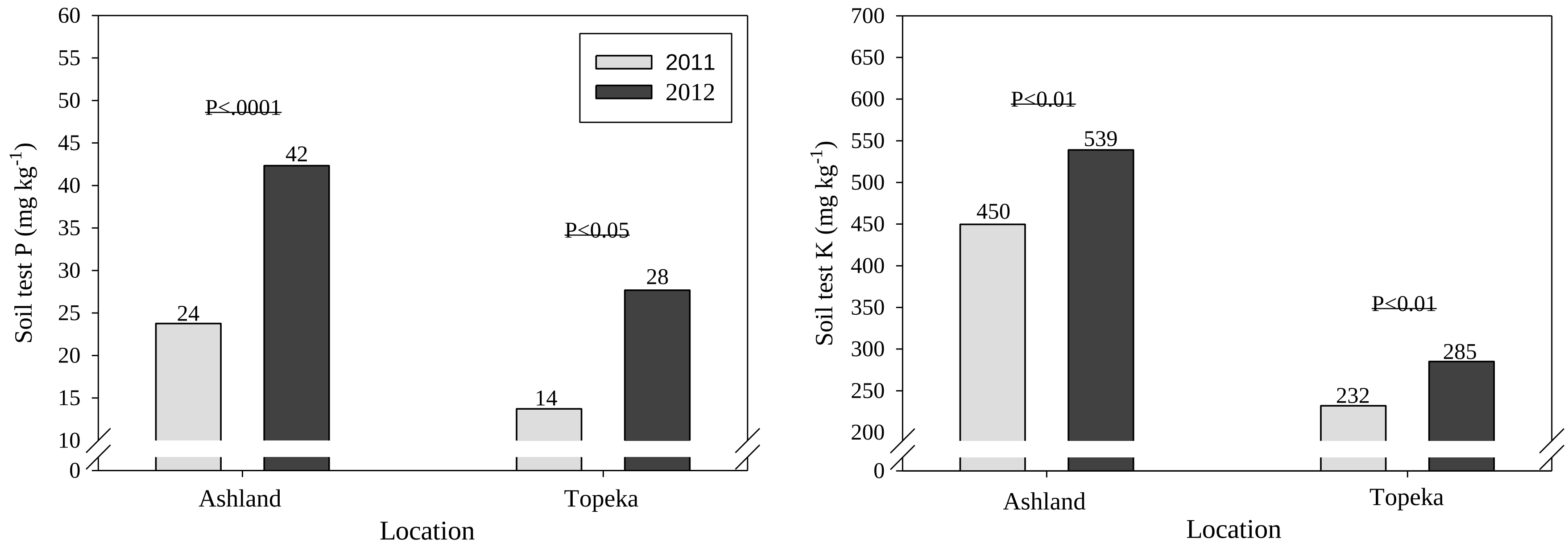

Figure 3.1. Soil test P (Mehlich-3) and K (Ammonium acetate) levels as affected by fertilizer application of 59 kg P ha^{-1} (10 k P ha^{-1} as starter and 49 kg P ha^{-1} as broadcast) and 110 kg K ha^{-1} (18 kg K ha^{-1} as starter and 92 kg K ha^{-1} as broadcast) in 2012 after one year of fertilizer application on non-fertilized plots from 2011.

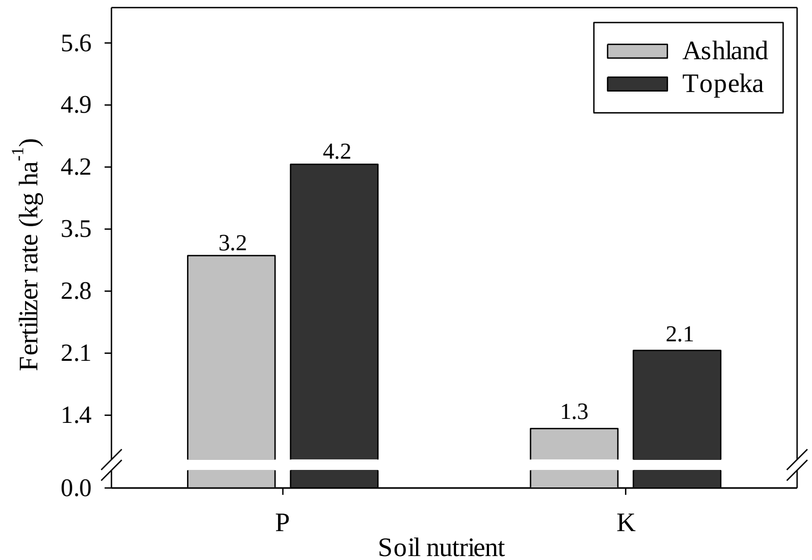

Figure 3.2. Rate of P and K fertilizer required to increase 1 mg kg^{-1} yr^{-1} of P and K in Ashland and Topeka. Soils were first sampled before fertilization on March 2011 and were then sampled again one year after fertilizer application (March 2012).

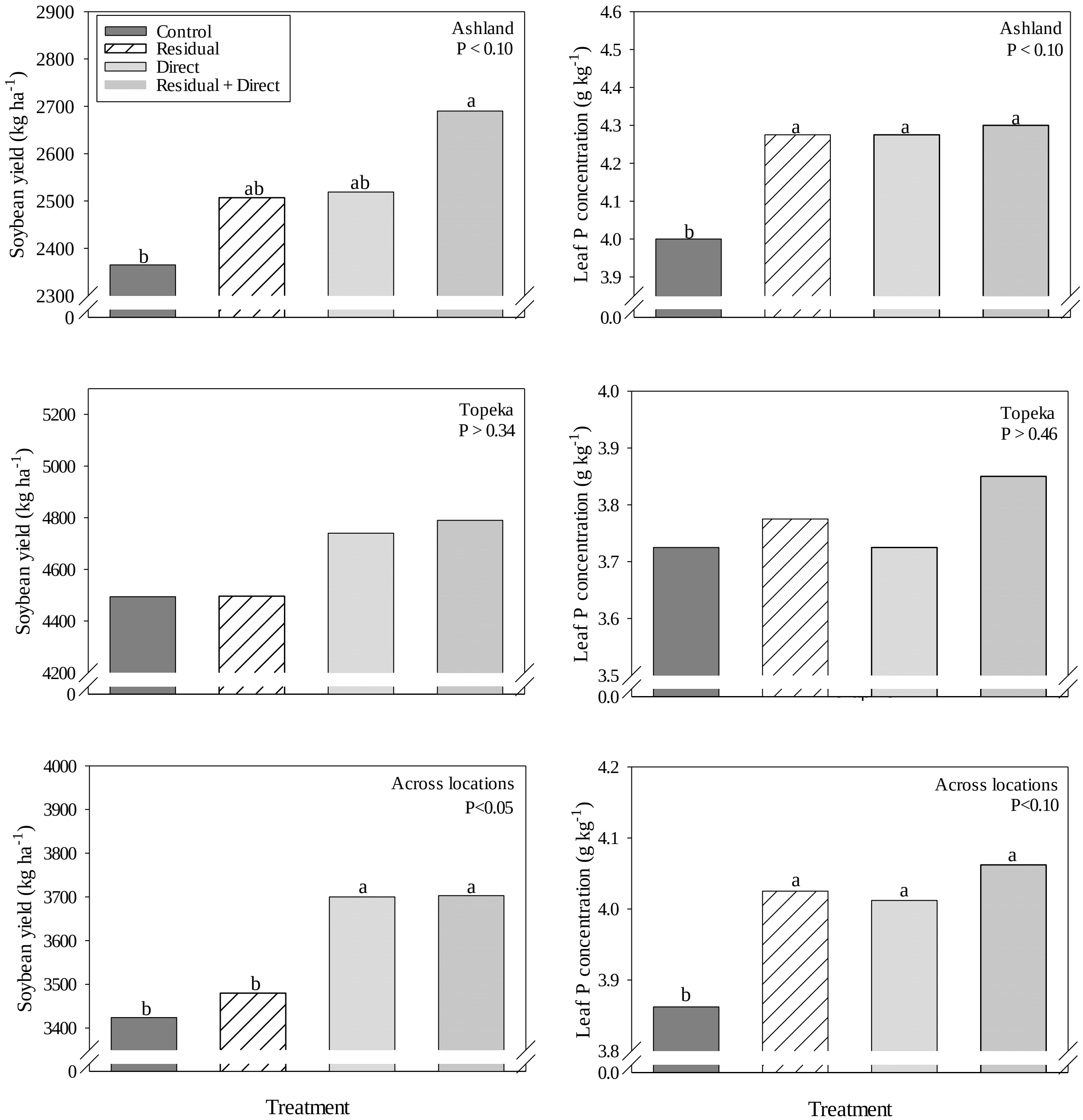

Figure 3.3. Direct and residual broadcast fertilization effects on soybean yield and leaf P concentration (R2 growth state) for each location and across locations in 2012. Direct fertilization consisted of 20 kg P ha^{-1} and 65 kg K ha^{-1} and residual of 49 kg P ha^{-1} and 93 kg K ha^{-1}. Soybean was planted over the corn residue plots trials from 2011. Ashland was no-till and non-irrigated and Topeka was conventional tillage and irrigated. Different letters indicate statistically significant differences at the P < 0.10.

Chapter 4 - Corn and soybean response to phosphorus fertilization and placement

Abstract

Evaluation of phosphorus fertilization has been conducted in the past with emphases on corn (Zea mays L.), and limited research on soybean [Glycine max (L.) Merr.]. The objective of this study is to evaluate both corn and soybean response to direct P fertilization including starter and broadcast application. This study was established at three locations for corn and three locations for soybean in 2012. The experimental design consisted of nine treatments in a randomized complete block design with four replications. The treatments were a control, two starter fertilizers (with N-P and N only), five broadcast P rates (10, 20, 30, 40, 50 kg P ha-1) and one treatment with starter fertilizer in addition to the broadcast fertilizer application of 40 kg ha-1 of P. Soil samples and plant tissue samples were collected and analyzed for P concentration. Corn early growth was measured at the V6-V7 growth stage and yield was determined after maturity. Corn early growth, P uptake, and ear leaf P concentration were frequently increased by broadcast fertilization. Nevertheless corn grain yield was not significantly affected by any broadcast or starter treatments. Soybean trifoliate P concentration was increased by all fertilizer treatments except for starter N-only. Broadcast application significantly increased soybean yield on low STP levels. Results of the study show that large corn or soybean yield response to starter and broadcast P application are likely with low STP levels.

Introduction

Phosphorus fertilizer demand and price increased significantly in the past two decades (USDA-NASS, 2011). Consequently, more efficient fertilizer management strategies are necessary, not only to increase profitability but also to reduce water contamination. Corn and soybean yield profitability are usually increased by application of P fertilizer to soils with soil test levels in the very low or low categories (Mallarino, 1991). In Kansas the median values for P is 18 ppm Bray P-1 equivalent and the relative frequency of soils found to be below critical levels is approximately 55% (Fixen, 2010). Soil test values above 20 mg kg^{-1} have shown that P fertilization is rarely profitable for either corn or soybean in the year of application (Mallarino, 1991; Webb et al., 1992). The effect of fertilization and especially placement methods on corn and soybean can be particularly important under no till systems. Under this condition the surface residue can cause cooler and wetter soils compared to soils under conventional tillage systems (Fortin, 1993). Soils with low temperature reduce root growth (Ching et al.,1979; Havlin, 2005) and nutrient uptake by plant (Mackay et al., 1985). Consequently, decreasing early growth and, in some cases, grain yield (Fortin,1993; Mallarino et al., 1998). Several researchers have reported increased early growth and less frequently yield responses to starter on soils with STP above the optimum level (Scharf, 1999; Bundy et al., 2001). Vetsch (2002) showed that starter fertilizer N-P increased corn yields on high P and K soils in continuous corn and corn-soybean rotation and he suggests that starter fertilizer should be considered to optimize corn production across all tillage systems. Mallarino (2009) and Vetsch (2000) indicate that N as starter can be a more critical element responsible for early growth and yield than P. Therefore, the starter effect in no-till corn production may be the result of N rather than P in fields with high P soil test (Vetsch et al., 2000). Reeves and Touchton (1986) found that N is more important than P in the starter on sandy soils with low CEC, low organic matter, and high P levels. Touchton (1988) indicated that starter P improved corn yields under strip still on high testing P soils, but his work also shows that significantly higher yields was obtained when starter had N besides P in the mixture. Conversely, Rehm et al. (2010) showed no corn yield response to any starter mixture that varied in N and P content. According to Bermudez and Mallarino (2002) early growth response to starter are usually significant, however large yield responses of no-till corn to starter are more likely when soil test P is below optimum and/or preplant or sidedress N rates are deficient.

Previous studies suggested that starter containing N would stimulate early growth and may increase soybean yield (Sij et al. 1979). Starling et al. (2000) found that N applied at planting increased early soybean vegetative growth and soybean yield. Similarly, Osborne and Riedell (2006) in the northern Great Plains also found an increase in soybean yield with starter N, and they attribute this increase to possible higher plant N concentration and early plant biomass. Differently, Touchton and Rickerl (1986) found that the greatest soybean yield improvement occurred with P, N-K and P-K starters over the control whereas the N containing starters such as N-only, N-P or NPK did not increase yields. Rehm et al. (2010) evaluated different starter mixtures with varying N:P ratios and found no soybean yield increase on soils ranging from medium to high P level.

Broadcast phosphorus fertilization frequently increases corn and soybean yield when soils have low to very low STP (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000). Dodd and Mallarino (2005) showed in a long term study that corn and soybean respond 50 to 70% of the time to annual P fertilization when soil test level was equal or less than 20 mg kg^{-1} and no response under higher soil test P. Similarly, Mallarino and Barcos (2009) also found that yield responses to P broadcast fertilization on corn and soybean normally occurred when soils were equal or lower than 22 mg kg^{-1}. In the same study, yield was maximized with 27 and 35 kg P ha^{-1} for corn and soybeans, respectively. Moreover, according to Buah et al. (2000), 19 kg ha^{-1} and 39 kg ha^{-1} of P as broadcast significantly increased soybean yield with STP of 19 mg kg^{-1} and 6 mg kg^{-1}, respectively. Rehm (1985) study showed that application of fertilizer with increasing P rates affected soybean yield at only locations with STP below 10 mg kg^{-1}, and maximum yield was attained with 33 kg ha^{-1} P. McCallister et al. (1987) found that positive corn yield response to applied P fertilizer resulted when soil test P was below 15 mg kg^{-1} and yields did not increase further with P rates higher than 22 kg ha^{-1}.

Corn or soybean yield response to starter or broadcast fertilization on soils with moderate to high P level has been inconsistent and results are often not well understood (Randall et al., 1988; Mallarino et al., 2011). Crop yield response to placement methods seems to vary substantially with environmental factors, since they affect primarily crop growth and development (Ham 1973). Phosphorus fertilizer is typically applied before corn and intended for both crops in a corn-soybean rotation. Therefore most studies emphasize corn response to P fertilization and placement methods. However, questions remain about the need of direct fertilization for soybean especially under a sufficiency management approach where fertilizer rates are determined primarily by grain removal with yield. The objective of this study was to evaluate corn and soybean response to P fertilization including starter fertilizers in a typical corn-soybean rotation.

Material and Methods

This study was initiated in 2012 with three locations for corn and three locations for soybean. Fields with history of corn-soybean rotation were selected to represent the common crop rotation in the region of study. Location 3 was irrigated with center pivot sprinkler irrigation systems and irrigation was applied as needed during the growing season (Table 4.1). The experimental design consisted of nine treatments in a randomized complete block design with four replications. The plot length varied among locations from 14 to 15 m and plot width varied from four to six rows. Row spacing was 76 cm at all locations for both crops. The treatments were control with no fertilization; starter 20 kg ha^{-1} N; starter 20 kg ha^{-1} N plus 9.8 kg ha^{-1} P; five broadcast phosphorus rates (9.8, 19.6, 29.3, 39.1, 48.9 kg ha^{-1} of P) (22.4, 44.8, 67.2, 89.6, 112 kg ha^{-1} P_2O_5), and a combination of 39 kg ha^{-1} of P as broadcast and starter (20 kg ha^{-1} N and 9.8 kg ha^{-1} P). Starter fertilizer was applied dribbled over the row and using urea ammonium nitrate (UAN 28% N) as N source, and 10-15-0 (N-P-K) [10-34-0 (N-P2O5-K2O)] as source of P. The broadcast fertilizer source was mono ammonium phosphate (MAP) and applied within three weeks before planting at all locations. Calcium nitrate was mixed with MAP for the broadcast P treatments to balance the N contribution of MAP. Nitrogen fertilizer was applied in spring one month prior to planting using anhydrous ammonium at a rate of 202 kg N ha^{-1} for location 3 and 80 kg N ha^{-1} at location 2. Additional rate of 100 kg N ha^{-1} was applied as side dress urea for a total of 180 kg N ha^{-1} at location 2. At Location 1, 179 kg N ha^{-1} as UAN 28% was injected with the corn planter between the corn rows.

Soil samples were collected from each small plot before fertilizer application. Each sample was a composite of 12 cores collected from the 0-15 cm depth. All soil samples were analyzed for P by the Mehlich-3 procedure (Frank et al., 1998) and for K with the ammonium acetate method (Warncke et al., 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson et al., 1998), and soil organic matter (OM) was determined by Walkley–Black method (Combs et al., 1998).

Plant population was measured in an 11.34 m section of two central rows in each plot for corn. The aboveground parts of 10 corn plants were collected from the middle two rows of each plot. The plants were collected for each location at the V6 to V7 growth stage (Abendroth et al., 2011) to evaluate early growth, N and P content and uptake. Corn ear leaves were collected at the R1 growth stage and analyzed for N and P concentration, except for location 1 where plants were too dry because of severe drought. Soybean leaf samples consisting of the most recently developed, fully expanded trifoliolate leaf (petiole excluded) were collected between the R1 and R2 growth stage (Pedersen, 2009) and analyzed for P concentration. Plant samples were dried at 65^{o}C in a forced-air oven, weighted (only for corn), and ground to pass a 2-mm screen. Ground samples were digested using sulfuric acid and hydrogen peroxide in a Digesdahl Analysis System (Hach Co. 1991) and phosphorus was measured by colorimetry (Murphy et al. 1962). Corn P uptake was calculated from nutrient concentrations and oven-dried weights. After corn and soybean reached physiological maturity, grain yield was determined by harvesting the center two rows of each plot. All locations were harvested with a small research combine, except corn at location 2, where corn ears were hand-harvested. Grain yield was adjusted to a moisture content of 155g kg^{-1} for corn and 130g kg^{-1} for soybean. Statistical analysis was completed using the generalized linear mixed model (GLIMMIX) for ANOVA (SAS Institute, 2006). Analysis considered block and location as random effects in the model. The nonlinear regression procedure NLIN (SAS Institute, 2006) was used to fit the regression equations and it is only illustrated when there was a significant regression fit. The procedure REG was used for the simplest equation model which was selected based on higher adjusted R^2. Statistically significant differences were established at the 0.10 probability level.

Results and Discussion

Corn

Early growth biomass was increased at two locations (1 and 3) with fertilization (Table 4.2). At these locations, starter N or NP had no effect on biomass. Only broadcast with 48.9 kg P ha^{-1} and the combination of starter and broadcast enhanced early growth over the control, except for location 3 where 9.8 kg ha^{-1} of P as broadcast increased biomass as well. Across locations, the results of ANOVA for the mean early growth response indicated a curvilinear (quadratic plateau) trend (Figure 4.1a). The highest P rate applied (48.9 kg ha^{-1}) did not maximize early growth response. This result agree with those of Mallarino et al. (2009), who found a similar curvilinear early growth response to P fertilization; however they showed that 37 kg P ha^{-1} was sufficient to maximize early growth. Starter N and NP were not significantly different from the zero or 9.8 kg P ha^{-1} rate, respectively. The combination of starter and broadcast also did not increase early growth more than the 48.9 kg P ha^{-1} broadcast rate.

Broadcast treatments with a rate of 39.1 and 48.9 kg P ha^{-1} increased early P concentration over the control only at location 3 (Table 4.2). Starter N or NP had no effect on plant P concentration. At this location tissue P concentration was below the sufficiency level of 3.0 g kg^{-1} (Mills and Jones, 1996) and increased above this level with fertilization. None of the other locations showed P concentration that was significantly affected by fertilization. Across locations a poor relationship was found between early plant P concentration and broadcast P rates (data not shown). According to Terman et al. (1976) if the relative uptake rate of a nutrient is greater than the growth rate, concentrations will increase. However in the opposite situation, concentrations can decrease or have no change as a result of dilution effects. This can explain our results on the effect of P fertilization on plant P concentration. Hence early plant P uptake seems to show more frequent response than P concentration to fertilization (Table 4.2). Broadcast with 48.9 kg P ha^{-1} rate and the combination of starter NP and broadcast increased P uptake significantly over the control at locations 1 and 3. At location 3, 39.1 kg P ha^{-1} also increased P uptake and was not different than the highest rate. Across locations there was a positive linear relationship between P uptake and broadcast P rates (Figure 4.1b). Starter fertilizer N was not different than the zero P rate as starter NP was not different than the 9.8 kg P ha^{-1}. Starter after broadcast application and broadcast 50 kg P ha^{-1} affected early growth in the same magnitude.

Fertilization increased ear leaf P concentration only at location 3 where ear leaf P concentration at the control plots were slightly below the sufficiency level of 2.5 g kg^{-1} (Table 4.2) (Planck 1989). Broadcast treatments with a rate of 39.1 and 48.8 kg ha^{-1} of P and the combination of starter and broadcast increased ear leaf P concentration significantly over the control. At location 2 there was a slightly average increase in ear leaf P with starter NP and higher P fertilization rates. Across locations, there was a positive linear relationship between broadcast P rates and leaf P concentration (Figure 4.1c). Thus the highest P rate (48.9 kg P ha^{-1}) did not maximize ear leaf P concentration. Starter N was not different than the control whereas starter NP significantly increased ear leaf P concentration compare to the zero P rate and was not different than the 10 kg P ha^{-1} rate. Starter after broadcast did not increase ear leaf concentration more than broadcast P at the same rate (48.9 kg ha^{-1}).

Broadcast treatments did not affect corn yield compare to the control at any location or across locations (Table 4.2). Yield response was not observed at location 3 where soil STP was 15 ppm, which is below the critical value of 20 ppm (Leikam et al. 2003). According to Dodd and Mallarino (2005) corn yield may respond 50 to 70% of the time to annual P fertilization when soil test level is equal or less than 20 mg kg^{-1}, showing that there is a relatively high probability that yield response may not occur in soils below the critical level. This may explain the lack of yield response to P fertilization in this study. Starter N or NP also did not increase corn yield. This finding agrees with Rehm et al. (2010) study, where they found no corn yield response to any starter formulation.

Because location 1 did not yield enough to harvest and location 2 had very low yields due to the severe drought condition, more locations and continued study are needed to obtain a consistent result.

Soybean

Fertilization significantly affected trifoliate P concentration only at location 3, where all broadcast P rates treatments applied alone increased trifoliate P concentration, except for the 10 kg ha^{-1} rate of P (Table 4.3). The response at this location shows a linear relation with increase in P concentration with increases in P rate. Therefore, the highest two rates (39.1 and 48.9 kg P ha^{-1}) and the combination of starter and broadcast had the highest trifoliate P concentration. Starter NP did not increase P concentration compare to starter-N or the control. This result agrees with Buah et al. (2000) where they found that starter P did not affected P concentration in the soybean trifoliate at early bloom. Figure 4.2a illustrates the curvilinear (quadratic) response of leaf P concentration and broadcast P rates. Leaf P concentration nearly reached the maximum with the highest rate of 48.9 kg P ha^{-1}. Similarly Randall et al. (1997) showed that leaf P concentration did not increase further with P rates higher than 45 kg ha^{-1}. Mallarino et al. (2009) also found a positive response of leaf P concentration to P fertilization. However, his work shows a linear relationship instead of quadratic, and his highest rate of 50 kg P ha^{-1} was not enough for leaf P concentration to achieve its maximum, these results are similar to ours.

Soybean yield was significantly affected with fertilization at location 3 where soils test P was low (Table 4.3). Broadcast rates above 19.6 kg P ha^{-1} and the combination of starter and broadcast significantly increased yield whereas starter N or NP did not. This agrees with results from Rehm et al. (2010) where they found that starter NP did not increased soybean yield. Average across locations there was a significant treatment effect on soybean yield, with a curvilinear quadratic response of soybean yield to broadcast P rates (Figure 4.2b). The broadcast P rate that maximized soybeans grain yield was 15 kg ha^{-1} of P. Mallarino et al. (2009) indicates that a higher P rate (42 kg P ha^{-1}) was necessary to maximize yield. However this rate was average across responsive locations only, which may explain the higher P rate necessary to increase yield to maximum. Starter N-only was not different than the control showing no effect on yield. This agrees with Touchton and Rickerl (1986), where they found that starter N alone did not increase yield over the control, yet starter NP did. Similarly our study shows that starter NP increased soybean yield compare to the control and was not different than the 9.8 kg ha^{-1} rate. This suggests no advantage of starter over broadcast P with same P rate applied. Starter after broadcast application increased yield similar to the 48.9 kg P ha^{-1} rate. According to these results, any of the broadcast or starter treatment that contain P are effective to alleviate phosphorus deficiencies and increase soybean yield. This agrees with Bordoli and Mallarino (1998) where they found that in low testing soils placement did not affect yields.

Conclusion

Corn early growth indicated a curvilinear (quadratic plateau) and positive response to broadcast P and nearly achieved the maximum yield with 48.9 kg P ha^{-1} rate. Fertilization significantly increased corn early growth in two out of three locations. P uptake and ear leaf P concentration increased linearly with P broadcast application whereas early P concentration showed a very poor and non-significant relation to P application rate. Although early growth, P uptake and leaf P concentration were frequently increased by broadcast application, this increase did not reflect in higher corn grain yield. Starter N or NP also showed no yield increase.

A curvilinear (quadratic plateau) response of trifoliate P concentration to broadcast P rates was observed on soybean. The P rate that maximized the P concentration was the highest rate (48.9 kg P ha^{-1}). Starter NP also increased significantly trifoliate P concentration over the control, and as expected starter with N-only did not. Thus either broadcast or starter containing P was effective in increasing leaf P concentration. Significant treatment effects were observed on soybean yield. There was a quadratic- plateau response on soybean yield to broadcast P rates. The broadcast P rate that maximized soybean grain yield was 15 kg P ha^{-1}. Starter NP alone or in combination with broadcast also was effective in increasing yield whereas starter N-only did not. Hence, any of the placements evaluated that contain phosphorus are effective to alleviate phosphorus deficiencies and are recommended to increase soybean yield.

References

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn Growth and Development. PMR 1009. Iowa State Univ. Ext., Ames.

Bermudez, M., and A.P. Mallarino. 2002. Yield and early growth responses to starter fertilizer in no-till corn assessed with precision agriculture technologies. Agron J. 94:1024-1033.

Bordoli, J.M., and A.P. Mallarino. 1998. Deep and shallow banding of phosphorus and potassium as alternatives to broadcast fertilization for no-till corn. Agron. J. 90: 27-33.

Borges, R., and A.P. Mallarino. 2000. Grain yield, early growth, and nutrient uptake of no-till soybean as affected by phosphorus and potassium placement. Agron. J. 92: 380-388.

Bundy, L.G., and T.W. Andraski. 2001. Starter fertilizer response on high and very high testing soils. Better Crops with Plant Food. 85(2):3-5.

Ching, P.C., and S.A. Barber. 1979. Evaluation of temperature effects on K uptake by corn. Agron. J. 71:1040-1044.

Hach Co. 1991. Intructional manual. Digesdahl digestion apparatus model 23130-20. Boulder, Co.

Combs, S.M. and M.V. Nathan.1998. Soil organic matter. p.53-57. In J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.

Dodd, J.R. and A.P. Mallarino. 2005. Soil test phosphorus and crop grain yield responses to long-term phosphorus fertilization for corn-soybean rotations. Soil Sci. Soc. Am. J. 69:1118-1128.

Eckert, D.J., and J.W. Johnson. 1985. Phosphorus fertilization in no-tillage corn production. Agron. J. 77:789-792.

Fixen, P.E., T.W. Bruulsema, T.L. Jensen, R.M. Mikkelsen, S.T. Murrel, and S.B. Phillips et al. 2010. The fertility of North American soils. Better Crop With Plant Food. 94(4): 6-8.

Fortin, M.C. 1993. Soil temperature, soil-water, and no-till corn development in-row residue removal. Agron. J. 85:571-576.

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. p.21-30. In J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.), Missouri Agric. Exp. Stn., Columbia.

Ham, G.E., W.W. Nelson, S.D. Evans, and R.D. Frazier. 1973. Influence of fertilizer placement on yield response of soybean. Agron J. 65:81-84.

Havlin, J.L., S.L. Tisdale, J.D., Beaton, and W.L. Nelson. 2005. Soil Fertility and Fertilizers. 7th ed. Pearson Education.

Howard, D.D., M.E. Essington, and J. Logan. 2002. Long-term broadcast and banded phosphorus fertilization of corn produced using two tillage systems. Agron. J.94:51-56.

Howard, D.D., and D.D. Tyler. 1987. Comparison of surface applied phosphorus and potassium rates and in-furrow fertilizer combinations for no-till corn. J. Fert. Issues 4: 48-52.

Kaiser, D.E., A.P. Mallarino, and M. Bermudez. 2005. Corn grain yield, early growth, and early nutrient uptake as affected by broadcast and in-furrow starter fertilization. Agron. J. 97:620-626.

Leikam, D.F., R.E Lamond, and D.B. Mengel. 2003. Soil test interpretation and fertilizer recommendation. MF-2586. Kansas State Univ. Ext., Manhattan.

Mackay, A.D., and S.A. Barber. 1985. Soil moisture effects on root growth and phosphorus uptake by corn. Agron. J. 77:519-523.

Mallarino, A.P. 2009. Phosphorus and potassium placement methods for corn and soybean: an Iowa perspective. p. 109-115. In Proc. Conf. Crop Management, 48th, Madison, WI. 13-25 Jan. 2009. University of Wisconsin, Madison, WI.

Mallarino, A.P., S.R. Barcos, J.R. Prater, and D.J. Wittry. 2009. Timing of Broadcast phosphorus fertilization for no-till corn and soybean. Soil Sci. Soc. Am. J. 73:2143-2150.

Mallarino, A.P., D.W. Barker, R. Borges, and J.C. North. 1998. Tillage and fertilizer placement for the corn-soybean rotation. p.231-237. In Proc. Conf., Integrated Crop Management, Ames, IA. 17-18 Nov. Iowa State Univ. Ext., Ames, IA.

Mallarino, A.P., N. Bergmann, and D.E. Kaiser. 2011. Corn responses to in-furrow phosphorus and potassium starter fertilizer applications. Agron. J. 103:685-694.

McCallister, D. L., C.A Shapiro, W.R. Raun, F.N. Anderson, G.W. Rehm, O.P. Engelstad et al. (1987). Rate of phosphorus and potassium buildup/decline with fertilization for corn and wheat on Nebraska Mollisols. Soil Sci. Soc. Am. J. 51:1646-1652.

Mills, H.A., and J.B. Jones. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Micro-Macro, Athens, GA.

Murphy, J., and J.P. Riley. 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta. 26:31-36.

Osborne, S.L., and W.E. Riedell. 2006. Starter nitrogen fertilizer impact on soybeans yield and quality in the northern Great Plains. Agron. J. 98:1569-1574.

Pederson, P. 2009. Soybean Growth and Development. PM 1945. Iowa State Univ. Ext., Ames.

Randall, G.W., and R.G. Hoeft. 1988. Placement methods for improved efficiency of P and K fertilizers: a review. J. Prod. Agr. 1:70-79.

Reeves, D.W., J.T. Touchton, and C.H. Burmester. 1986. Starter fertilizer combinations and placement for conventional and no-tillage corn. J. Fert. Issues. 3:80-85.

Rehm, G.W. 1986. Response of irrigated soybeans to rate and placement of fertilizer phosphorus. Soil Sci. Soc. Am. J. 50:1227-1230.

Rehm, G.W., and J.A. Lamb. 2009. Corn response to fluid fertilizers placed near the seed at planting. Soil Sci. Soc. Am. J. 73:1427-1434.

Rehm, G.W., and J. A. Lamb. 2010. Soybean response to fluid fertilizers placed near the seed at planting. Soil Sci. Soc.Am. J. 74:2223-2229.

Rehm, G.W., S.D. Evans, W.W. Nelson, and G.W. Randall. 1988. Influence of placement of phosphorus and potassium on yield of corn and soybean. J. Fert. Issues. 5:6-13.

SAS Institute. 2006. The SAS system for Windows. Version 9.1. SAS Inst., Cary, CN.

Scharf, P.C. 1999. On-farm starter fertilizer response in no-till Corn. J. Prod. Agr. 12:692-695.

Sij, J.W., F.T. Turner, and J.P. Craigmiles. 1979. “Starter nitrogen” fertilization in soybean culture. Commun. Soil. Sci. Plant Anal. 10:1451-1457.

Starling, M.E., C.W. Wood, and D.B. Weaver. 2000. Late-planted soybeans respond to nitrogen starter. Fluid J. 28:26-30.

Terman, G.L., F.E. Khasawneh, S.E. Allen, and O.P. Engelstad. 1976. Yield-nutrient nutrient-absorption relationships as affected by environmental growth factors. Agron. J.68:107-111.

Touchton, J.T., and D.H. Rickerl. 1986. Soybean growth and yield responses to starter fertilizers. Soil Sci. Soc. Am. J. 50:234-237.

Touchton, J.T. 1988. Starter fertilizer combinations for corn grown on soils high in residual-P. J. Fert. Issues 5:126-130.

USDA-National Agricultural Statistic Service. 2000. Fertilizer totals, incl. lime and soil conditioners – Index for price paid. Available at http://quickstats.nass.usda.gov/results/26CFDD8E-D79A-3EC9-87F4-F6528737C183?pivot=short_desc (verified 30 nov. 2012).

Vetsch, J.A., and G.W. Randall. 2000. Enhancing no-tillage systems for corn with starter fertilizers, row cleaners, and nitrogen placement methods. Agron. J. 92: 309-315.

Warncke, D., and J.R. Brown 1998. Potassium and other basic cations. p.31-34. In J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.

Watson, M.E., and J.R. Brown 1998. pH and lime requirement. p.13-16. In J. R. Brown (Ed.) Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn, Columbia.

Webb, J.R., A.P. Mallarino, and A.M. Blackmer. 1992. Effects of residual and annualy applied phosphorus on soil test values and yields of corn and soybean. J. Prod. Agri. 5:148-152.

Figures and Tables

Table 4.1. Location description, soil classification, preliminary soil analysis, hybrids, varieties, tillage, and planting date.

			Soil classification		Soil test						
Year	Location	County	Series†	Subgroup‡	STP	STK	pH	OM	Variety§/ Hybrid¶	Tillage system#	Planting date
					- - mg kg^{-1} - -			g kg^{-1}			
					Corn						
2012	1	Franklin	Woodson SL	A. Argiaquolls	23	142	5.9	26	Midland 417	NT	11 Apr. 2012
2012	2	Osage	Kenoma SL	V. Argiudolls	25	204	6.3	29	P35F37	NT	18 Apr. 2012
2012	3	Republic	Crete SL	P. Argiustolls	15	626	6.3	29	P33D39	RT	27 Apr. 2012
					Soybean						
2012	1	Franklin	Woodson SL	A. Argiaquolls	21	113	6.0	25	P94Y70	NT	17 May 2012
2012	2	Osage	Kenoma SL	V. Argiudolls	20	215	6.2	30	AG4606	NT	04 June 2012
2012	3	Republic	Crete SL	P. Argiustolls	6	595	6.3	34	DK S39-U2	RT	23 May 2012

† SL, Silt Loam;
‡ A, Abruptic; V, Vertic; P, Pachic;
§ P, Pioneer; AG, AsGrow;
¶ Corn Hybrid: DK, DeKalb.
# NT, No-till; RT, Ridge-till.

Table 4.2. Phosphorus fertilization and placement effects on corn early growth, early P concentration and uptake in corn at the V6 -V7 growth stage, P concentration in the ear leaf at the R2 growth stage and grain yield.

	Treatment									
					Broadcast P rates (kg ha^{-1})					Significance
Location†	Control	Starter-N‡	Starter N-P§	Starter N-P + Broad. ¶	10	20	30	40	50	P<F
	- - - - - - - - - - - - biomass, g plant^{-1} - - - - - - - - - - - -									Biomass
1	6.6cd#	6.4d	6.7cd	8.1a	6.5d	7.3bc	6.7cd	7.1bcd	7.7ab	0.011
2	8.7	9.8	9.9	9.5	8.3	9.9	9.7	9.7	9.3	0.885
3	8.9cde	8.1e	8.8de	10.8a	10.2ab	9.5bcd	9.8abcd	10.0abc	10.5ab	0.014
	- - - - - - - - - - - - plant P concentration, g kg^{-1} - - - - - - - - - - - -									Plant P conc.
1	3.5	3.6	3.4	3.3	3.6	3.5	3.3	3.3	3.5	0.277
2	3.7	3.7	3.9	4.0	3.9	3.7	3.6	3.9	3.9	0.519
3	2.8bc	2.7bc	2.6c	2.9ab	2.8bc	2.8bc	2.9ab	3.2a	3.1a	0.024
	- - - - - - - - - - - - plant P uptake, mg plant^{-1} - - - - - - - - - - - -									Plant P uptake
1	23.0bc	23.1bc	22.8bc	26.8a	23.2bc	25.5ab	23.8bc	22.5c	27.0a	0.054
2	32.0	36.2	39.0	38.0	32.8	36.2	34.3	37	36.7	0.859
3	25.3cd	22.3d	22.0d	31.8a	28.8abc	26.5bcd	28.8abc	31.3ab	21.8a	0.004
	- - - - - - - - - - - - ear leaf P concentration, g kg^{-1} - - - - - - - - - - - -									Ear leaf P conc.
2	2.5	2.3	2.7	2.8	2.6	2.4	2.7	2.7	2.6	0.692
3	2.4c	2.4c	2.4c	2.8ab	2.5c	2.6bc	2.6bc	2.8ab	2.8a	0.008
	- - - - - - - - - - - - yield, Mg ha^{-1} - - - - - - - - - - - -									Yield
2	2.25	2.47	2.20	2.48	20.20	1.53	1.80	2.05	2.02	0.894
3	15.35	14.84	15.25	15.19	15.05	15.20	15.18	15.70	15.36	0.620

† At location 1 there is no data available for ear leaf P concentration and yield due to severe drought conditions.
‡ 20 kg ha^{-1} of N ;
§ 20 kg ha^{-1} of N and 10 kg P ha^{-1};
¶ Broadcast 40 kg P ha^{-1};
# Means followed by the same letter between columns are not significantly different at $P \leq 0.10$.

Table 4.3. Phosphorus fertilization and placement effects on soybean leaf (trifoliate) P concentration at the R1 growth stage and on soybean yield.

Location	Treatment									Significance
					Broadcast P rates (kg ha^{-1})					
	Control	Starter-N†	Starter N-P‡	Starter N-P + Broad. §	10	20	30	40	50	P<F
	leaf P concentration, g kg^{-1}									Leaf P conc.
1	3.1	3.3	3.2	3.3	3.3	3.3	3.3	3.3	3.3	0.721
2	3.3	3.3	3.4	3.4	3.5	3.3	3.5	3.3	3.4	0.850
3	3.6d¶	3.5d	3.9cd	4.6a	3.8cd	3.9c	4.1bc	4.4ab	4.5a	<0.001
	yield, kg ha^{-1}									Yield
1	1360	1320	1360	1310	1480	1390	1480	1450	1300	0.782
2	1580	1680	1810	1740	1720	1720	1790	1810	1730	0.965
3	4470d	4280d	4530cd	4720bc	4720bc	4760abc	5090a	4760abc	5030ab	0.002

† 20 kg ha^{-1} of N ;
‡ § 20 kg ha^{-1} of N and 10 kg P ha^{-1};
§ Broadcast 40 kg P ha^{-1};
¶ Means followed by the same letter between columns are not significantly different at P≤ 0.10.

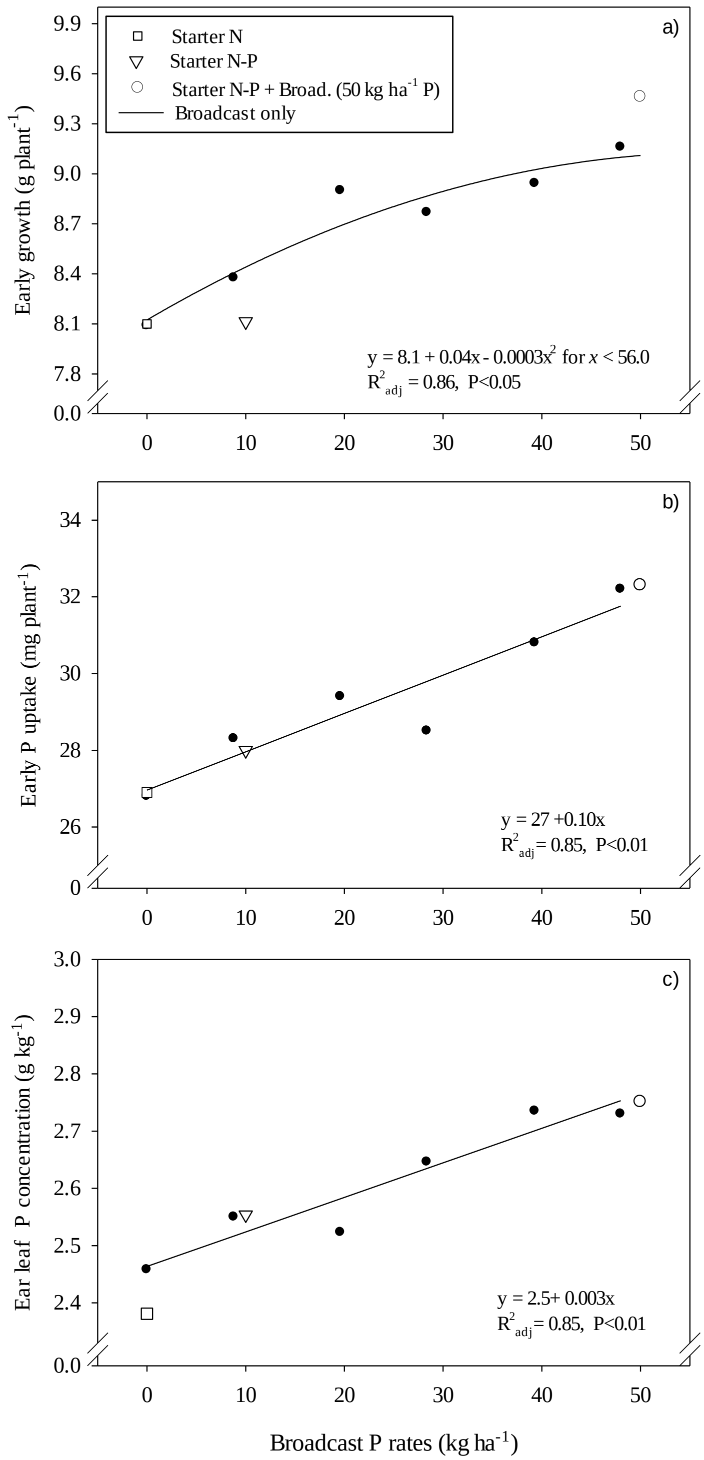

Figure 4.1. Mean corn early growth (a) and uptake (b) at V6 growth stage, and ear leaf P concentration (c), response to P fertilization across locations. Models were fit across the broadcast P rates only.

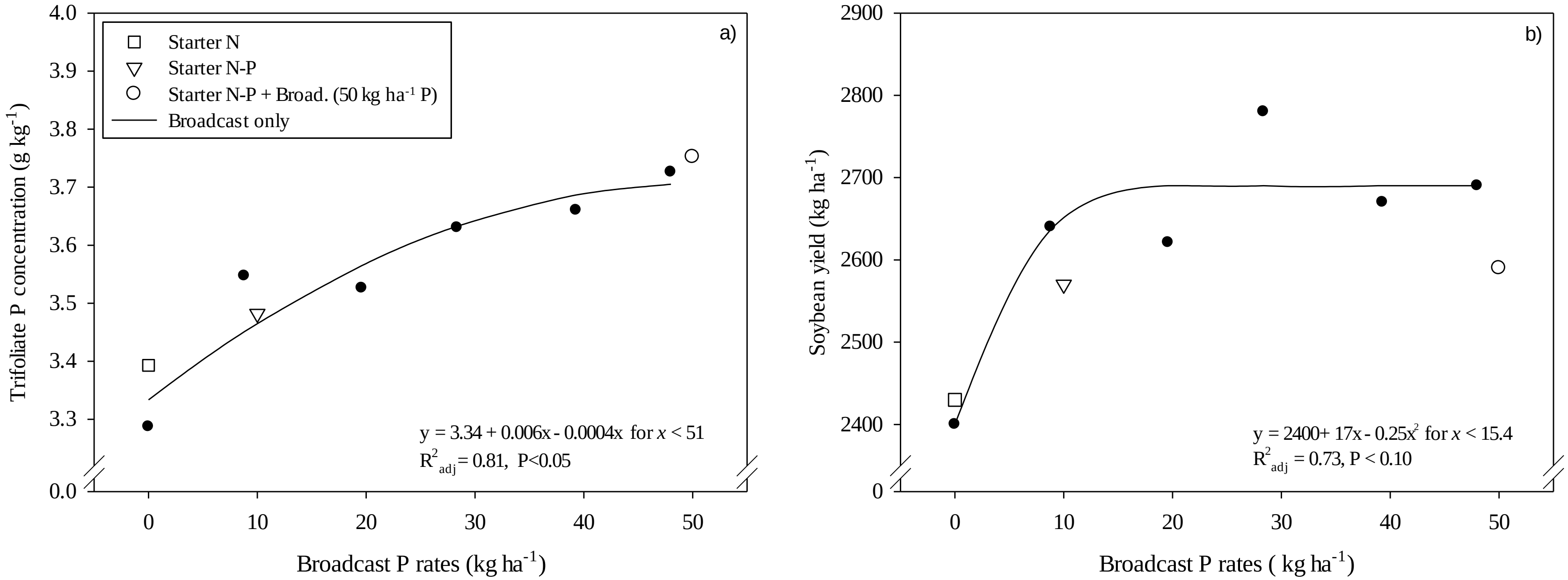

Figure 4.2. Mean soybean trifoliate P concentration (a) and grain yield (b) response to P fertilization across locations. Models were fit across the broadcast P rates only.

Chapter 5 - General Conclusions

The use of starter fertilizer under dryland and no tillage conditions often increase yields, especially when nitrogen application is applied as sidedress after planting. Although early growth is normally increased by starter application, corn yield response seldom occurs under conventional tillage, pre-plant N application and soils with high soil test P and K. Broadcast P frequently increases early growth, P uptake and leaf P concentration, however this increase does not always result in higher corn grain yield in soils with high STP.

Soybean yield was generally not affected by starter or broadcast application with STP higher than 20 mg kg^{-1}. However in the second study, soybean yield was increased with broadcast maintenance rates for P and K under soils with STP and STK above the critical level of 20 and 130 mg kg^{-1}, respectively. Therefore maintenance rates may be effective not only to sustain STP and STK levels but also to improve soybean yield with applications before soybean. When soils are low in P, both broadcast and starter NP are effective in increasing soybean yield. Starter N-only had no effect on soybean yield in our study.

Most producers in Kansas do not apply fertilizer P or K before soybean; instead they generally rely on residual effects from corn fertilization the previous year. We found however that residual fertilization was less effective in increasing soybean yields and that direct fertilization with smaller annual P and K applications may be more effective than larger semiannual application for increasing soybean yields.

Application of P and K fertilizer generated significant increases in soil test levels for these nutrients one year after application. The rate of P and K fertilizer required to increase 1 mg kg^{-1} yr^{-1} of the respective nutrients was between 2.8 - 5.1 kg ha^{-1} for P and between 1.0 - 2.5 kg ha^{-1} for K, respectively. These values are lower than current guidelines, suggesting that producers with similar soils may be over appling P and K fertilizer. More research is needed involving several locations and soils types across Kansas to obtain more accurate results on soil test level response to fertilization in Kansas.