NO-TILL SOYBEAN RESPONSES TO PHOSPHORUS AND POTASSIUM PLACEMENT AND ASSOCIATED CROP MANAGEMENT IN PRIOR CORN

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ABSTRACT

Conti, Ignacio Victor. M.S., Purdue University, August 2005, No-till Soybean Responses to Phosphorus and Potassium Placement and Associated Crop Management in Prior Corn. Major Professor: Dr. Tony J. Vyn

Conservation tillage adoption and new deep-banded placement alternatives for fertilizers in conjunction with strip tillage for corn have prompted concerns about P and K nutrient availability to no-till soybean in rotation. This research investigated the residual effects of prior P and K fertility placement and associated crop management in corn (76-cm row width) on subsequent nutrient uptake, yield and quality responses by soybean in no-till, narrow-row (38-cm) production systems. Two 3-year and one 2-year field experiments were established at two Indiana locations between 2001 and 2004. The experiment near Farmland involved prior tillage and K fertilizer rate factors; one 3-year experiment near West Lafayette involved soybean responses to five prior P plus K fertility placement treatments (with 2 corn hybrids and plant populations), and another 2-year experiment evaluated soybean response following five P and (or) K fertility placements (for two corn hybrids), plus an additional broadcast K split-split-plot application before soybean.

At Farmland, preceding tillage system (no-till, fall chisel and strip-till) had negligible effects on subsequent no-till soybean yield and quality responses. Although mean soybean yields were not increased by residual K fertilizer treatments, soybean seed

K concentrations were consistently higher after fall K, and fall plus starter-band K, treatments relative to zero K control. Spatial variability in soil-test K affected seed K concentrations even more than K treatments themselves. At West Lafayette, soybean yields, nutrient concentrations in leaves or seeds, and seed oil and protein were usually not negatively or positively affected by deep-banded (at either 15 or 30 cm) versus surface-broadcast application of P and K fertilizers even when vertical stratification of soil exchangeable K was pronounced. Direct broadcast application of K fertilizer before soybean planting had no effect on soybean parameters when both P and K fertilizers were deep-band or broadcast applied to prior corn. No-till soybean responses to P and (or) K treatments did not interact with either corn hybrid or plant population; these corn management factors had no impact on no-till soybean performance. Deep banding of P and K fertilizers for corn was, therefore, not detrimental to narrow-row, no-till soybean nutrient uptake or yield performance.

CHAPTER ONE
INTRODUCTION AND LITERATURE REVIEW

General Introduction and Objectives

No-till soybean production acreage has increased markedly since the late 1980s and early 1990s in many Midwestern states; this progression from just a small fraction of the acreage to a majority no-till acreage in several states has raised new concerns about K fertility management. No tillage causes major changes in nutrient availability with depth, soil temperature, water content, pest incidence, and root growth and distribution. Soybean K needs in no-till, relative to conventional systems, are more dependant on soil exchangeable K concentrations, root density and soil moisture and temperature in the surface layer than K uptake in conventional tillage systems. Therefore, traditional K management recommendations designed for soybean under conventional tillage may need to be revised to ensure that K nutrition, yield and quality of soybeans will not be restricted.

Concerns about K fertility management have increased as no-till soybean acreage has increased, as dry summer and compacted soil conditions have resulted in lower levels of K uptake, as information about the extent of K stratification in no-till soils have become better known, and as the deep banding of P and K fertilizers on 76-cm row centers have become a more popular alternative for strip-till corn farmers. Although the 20% no-till adoption rate for corn in Indiana suggests that there is much rotational tillage taking place from year to year within fields, the soil fertility evidence also indicates that soil K stratification can be almost as pronounced after conservation practices like fall chisel plowing or shallow, single-pass cultivation as they can be after a "pure" no-till system (Holanda et al., 1998).

One essential goal of K fertility management is to reduce incidences of seed yield loss and inferior seed quality resulting from areas of fields with below optimum soil-test K. Improved K fertilizer recommendations for no-till soybean may be essential in order to achieve more uniform crop yield and quality. In addition, recent quality research (Vyn et al., 2002) confirms that higher seed K in soybeans is positively associated with high concentration of isoflavones (a nutraceutical with purported human health benefits).

Most of the published research has been devoted to the effects of direct K applications to soybeans, but fewer reports are available concerning the residual effects of K fertilization, K placement, and tillage system for corn on subsequent no-till soybean in corn-soybean rotations.

Our objectives were (a) to evaluate the residual effects of P and K fertilizer in corn on soybean yield and K accumulation in narrow-row production systems, (b) to determine the benefit of broadcast K application before soybeans when K has been band applied to corn, (c) to evaluate the effects K fertilizer application on the spatial variability of soybean yields and seed quality in a no-till production system, and (d) to determine the relationships among soil-test K, trifoliolate leaf K concentration and seed K concentration.

Literature Review

Nutrient stratification

Conservation tillage practices in crop production usually lead to nutrient stratification in soils, especially those relative immobile nutrients such as Phosphorus (P) and Potassium (K). With these tillage systems, both P and K accumulate in the surface soil as a result of a minimal mixing of the soil following fertilizer applications and the recycling of nutrients from deeper soil layers by plants (Karathanasis and Wells, 1990; Karlen et al., 1991).

Tillage system and its associated fertilizer placement have a significant effect on the stratification of P and K. The no-tillage system has more of a stratification problem due to continual broadcast application of soil nutrients on the surface without subsequent incorporation (Vyn and Janovicek, 2001; Crozier et al., 1999). Without mechanical mixing of the fertilizer, these relatively immobile nutrients remain concentrated in approximately the upper 5 cm soil interval (Cruse et al., 1983; Ketcheson et al., 1980).

This stratification of nutrients is a concern because if the upper 5 cm of soil becomes dry, the surface-applied P and K will become less available to plants. Increases in soil moisture increase the P and K diffusion rate to the root surface (Mackay and Barber, 1985). The main reason is that the primary transportation mode of solution P and K to the root surface is diffusion. Diffusion is driven by a concentration gradient between the root surface and the adjacent soil (Barber, 1985), which is created when P and K uptake is greater than what is being supplied via mass flow. During water-deficient periods soil P and K are immobilized due to the tortuous pathway of diffusion and mass flow without the water carrier provided by the availability of moisture in the soil (Zeng and Brown, 2000). Furthermore, a deficiency in P and K availability affects root growth and its activity, decreasing the overall root area available for uptake (Seiffert et al., 1995). Stratification may never have an adverse effect on seed yield or quality reduction if adequate moisture is available throughout the growing season.

Nutrient placement

Fertilizer placement plays an important role in how rapidly nutrients will be available to plants. Selection of the appropriate application technique for a field depends in part on the previous soil fertility level, crop to be grown and the tillage system to be used.

Three types of fertilizer placement are common among corn/soybean growers. Broadcast fertilization is the spreading of nutrients on the soil surface. Row fertilizer or "starter" refers to the placement of nutrients 5 cm below and 5 cm to the side of seed. Finally, deep banding is the injection of nutrients 15-25 cm below the soil surface, usually below the intended crop row area.

Broadcast application of fertilizer is a low cost way to apply large amounts of nutrients; this method may be supplemented with smaller amounts placed close to seed during planting. However, broadcast application may lead to more accumulation of nutrients in the upper soil layer than banded applications. As previously stated, the stratification problems are more commonly observed in dryer seasons.

Deep banding in conservation tillage systems may have positive impacts on reducing surface accumulations of P and K fertilizers, consequently increasing the fertilizer efficiency.

Several reports showed erratic and small decreases in crop nutrient availability due to nutrient stratification in high rainfall areas of the Corn Belt (Singh et al., 1966; Belcher and Ragland, 1972; Moschler and Martens, 1975). Other work (Eckert and Johnson, 1985; Yibirin et al., 1993) showed, however, that shallow subsurface banding (5 cm beside and below the seeds) can significantly increase P and K fertilizer use efficiency compared with broadcast fertilizer application for no-till soybean and corn. This result agrees with long known effects of banding in minimizing retention of these nutrients by soil constituents and in increasing fertilizer use efficiency by crops.

Several studies (deMooy et al., 1973; Bharati et al., 1986; Rehm, 1995; Mallarino et al., 1991a and 1991b; Webb et al., 1992; Randall et al., 1997) showed that yield increases due to broadcast P or K fertilization of soybean in predominant Corn Belt soils are large and likely only in low-testing soils (less than approximately 90 to 130 mg K per kg by the ammonium acetate extractant applied to dry soil samples).

Published research comparing deep-banding with other placements for no-till soybean is limited and inconsistent. Hairston et al. (1990) showed that deep injection (15-cm depth) of P and K fertilizer gave yield responses superior to broadcast fertilizer applications on no-till soybean in some Mississippi soils testing low in P and K. Other research (Hudak et al., 1989) showed no K placement effect on yield of no-till soybean grown in a silt loam soil in Ohio. Research in Iowa (Borges and Mallarino, 2000) reported that both deep-banded and planter-banded K fertilizer in no-tillage systems produced slightly higher soybean yield than surface application on optimum to very high-testing soils, and that positive yield response to banding was not related to soil-test K levels or degree of soil K stratification. Furthermore, another investigation in Iowa (Buah et al., 2000) showed that no-till soybean responded to surface application at least as well as to planter-banded application, even though significant soil K stratification was evident when soil K levels were in the optimum, high, or very high ranges.

Residual effects

Biannual broadcast fertilizer application of P and K fertilizer prior to corn in a corn–soybean rotation has been common in conventional tillage systems in North America. However, because the area of no-till soybean in the Corn Belt has increased markedly since the late 1980s, new questions have been raised concerning the success of applying the nutrient management systems which were originally designed for conventional-till soybean to no-till soybean production.

Most of the published research has been devoted to the effects of direct P and K applications to soybeans, even though farmers typically apply P and K fertilizers before corn in rotation. There are fewer reports concerning the residual effects of P and K fertilization, placement, and tillage system for corn on subsequent no-till soybean in corn-soybean rotations.

Relevant research showed that no-till soybean yield response to residual starter K (102 kg ha^{-1}) was minor on high-testing soils with at least ten years of no-tillage management (Buah et al., 2000). However, on fields after six years in ridge-till with evident vertical soil K stratification, soybean response to residual deep-banded (10-cm depth) K was evident on a high-testing soil at a high rate (148 kg ha^{-1}) of fall K fertilizer (Rehm, 1995). Research in Ontario, Canada (Yin and Vyn, 2002a) concluded that subsequent no-till soybean responded more to residual K fertilizer rate than to application timing, tillage, and K fertilizer placement system in preceding corn. In another study in Ontario, Canada, Yin and Vyn (2002b) found that no-till soybean response to residual K fertilizer management for corn varied with the tillage systems utilized in corn. Incremental gains in soybean leaf K concentrations were consistent after K application for no-till corn, but less consistent after K application to zone-till and mulch-till corn. They also found that surface broadcasting of K fertilizer before corn was as effective for subsequent narrow-row soybean as deep banding of K before corn.

With regards to P fertilizer management residual effects, research in South Dakota (Bly et al., 1997) concluded that fertilizer P applied as a band to corn was identifiable two years later. The residual fertilizer in these bands increased soybean shoot dry matter weight, shoot P uptake, and seed yield compared to the control treatment of 0 kg ha^{-1} of P. However, the research found that the distance of the band from the row was more important that the band P concentration or previously applied P rate.

Other work in Ontario, Canada (Yin and Vyn, 2003b) showed the major influence of the previous corn row on the potassium nutrition and yield of subsequent no-till soybeans grown on low exchangeable K soils. They concluded that yield of no-till soybean in previous corn rows increased 10 to 44% compared to those between previous corn rows, and that previous corn row effect on soil K fertility, K nutrition, and yield of no-till soybeans occurred even when K fertilizer was not applied in the prior corn season.

They also concluded that corn row effects were rarely influenced by either tillage system or corn hybrid in the previous corn season.

Spatial variability

Although nutrient stratification is important, spatial variability in soil available P and exchangeable K may further restrict the achievement of satisfactory yields and consistent seed quality in no-till soybean production systems even when P or K fertilizers are routinely applied.

New farming technologies such as yield monitoring equipment and geographical position systems has allowed for the recording and documentation of the yield and seed quality variability. Consequently, additional soil and plant measures have been tested and used to achieve a better understanding of yield and quality variability. Better knowledge of spatial variability of soil patterns has caused additional interest in the achievement of more uniform and consistent crop yields.

Soils are not often homogeneous at any spatial scale. The parent material and the topography are some of the factors that result in spatial variations, but variation in soil properties is also a result of a number of long- and short-term soil management strategies. In agricultural field studies, better understanding of the intrinsic spatial variation is critical for appropriate interpretations of experiment outcomes.

Large within-field variation in yields has been attributed mostly to the interaction of within-season environmental conditions, field topography, and soil property variation. Batchelor and Paz (1997) concluded from their crop growth model that water availability could explain up to 69% of the soybean yield variation in Iowa on a variable soil type and topographical variation. Several researchers (Kravchenko et al., 2000; Cook and Bramley, 2000) have documented the effects of climatic conditions and drainage on corn and wheat response and how they have caused a reversal effect (highest yields in low areas in one year, and lowest yields in that same area in the following year) to occur in alternating years. Topographical positions were studied by Kravchenko et al. (2000), who found them to be one of the most important factors affecting yields, where the highest variability occurred on steep slopes, causing great variation in yield, and more consistent higher yields with less variability in low slope to lower sites. Edwards et al. (1988) also found that soil types were the major reason for grain yield differences within a field.

Within a field, differences in soil chemical properties and nutrient status may be induced by different soil types or by variations in profile development and soil depth. The coefficient of variation (C.V.) of concentration of nutrients such as P and K seems to be greater than for other soil chemical properties such as pH and organic matter (O.M.) within a field. Research in Spain by López-Granados et al. (2002) found that the C.V. for K concentration in the topsoil was 25% while the coefficients for pH, O.M. and P were 1, 6 and 28%, respectively. Other research in Belgium (Geypens et al., 1999) reported coefficient of variation of 4% for pH, 17% for P and 50% for K. Research in Iowa by Cambardella et al. (1999) found the C.V. for K in the topsoil to be 52% while the coefficients for pH, and P were 18.5% and 56%, respectively. In more recent research involving 23 farm fields in Ontario, Canada, Lauzon et al. (2005) reported a C.V. of 62% for P, 34% for K and 8% for pH. An inherently high C.V. for P or K in many agricultural fields may make it extremely difficult to obtain significant treatment differences for P or K fertilizer treatments. In addition, high spatial variability may also mean that soybean yield or seed quality responses may be more dependent on the precise exchangeable K concentrations at a particular sampling site than it is affected by same year or prior year fertility applications.

Placement of fertilizer and subsequent tillage may have a pronounced effect on the micro-spatial (i.e. associated with crop row position) variability patterns of residual soil K (Ebelhar and Varsa, 1999; Yin and Vyn, 2002a). Long term no-till management has resulted not only in vertical nutrient stratification but also in evident horizontal heterogeneity of soil available nutrients. Varsa et al. (2000) found that high concentrations of residual K were usually observed near crop rows with banded or dribbled K placement methods and that re-deposition of K from plant tissue may have contributed to elevated soil K near planted rows. Yin and Vyn (2003b) found that soil exchangeable K concentrations in preceding corn rows exceeded those between previous corn rows at depths up to 20 cm in spite of K application rate and K placement system for prior corn. When soybeans were planted close to former corn rows, soil K fertility, K nutrition and yield of subsequent no-till soybeans were increased.

Seed quality

In the past, plant breeders have traditionally emphasized breeding high yielding soybean rather than increasing the protein or oil content of soybean seed (Burton, 1985; Wilcox, 1985). This has changed considerably and a growing interest has been expressed by the food industry for obtaining soybean with superior seed qualities (Wilson, 1991). Higher protein content, higher oil content, higher contents of S-containing amino acids, such as methionine and cystein, and higher total isoflavones are some of the quality properties that have concentrated the efforts of breeders.

While genetic improvement is possible and desirable, it is also important to recognize that soybean seed quality is affected by environmental factors such as temperature, light, water availability, and soil physical and chemical properties (Gibson and Mullen, 1996; Raper and Kramer, 1987; Spilker et al., 1981) and also by nutrient management (Vyn et al., 2002; Jones et al., 1971; Sale et al., 1986).

Previous research in soil fertility and nutrient management has focused mostly on the optimum levels of nutrients for high or economically optimum soybean yield. The impacts of soil fertility levels and management practices on seed quality frequently are not evaluated.

Jones and Lutz (1971) found that the average oil content of soybeans decreased rapidly with increased rates of P without K application but was not significantly affected when two rates of P were applied with two rates of K. They also found that without added K the protein content increased sharply with increased rates of P. In another study, Gaydou and Arrivets (1983) reported that the addition of phosphorus resulted in a significant oil and protein content increases. On the other hand, the addition of potassium resulted in a significant oil content increase but resulted in a highly significant decrease in protein concentration. In another experiment in Australia (Sale et al., 1986), seed produced by K deficient plants contained low oil and high crude protein concentrations compared with seed from plants supplied with adequate K. In recent research Mallarino et al. (2005) reported that the application of fertilizer P and K seldom affected soybean seed oil and protein concentrations either applied directly to the soil before planting or by foliar application at the V5 to V7 growth stages. Even when there was a fertilization effect on seed oil and protein concentration, the responses were small and unrelated to positive seed yield responses.

With regards to seed nutrient concentration, Cartter et al. (1942) showed that nutrient content can be affected by several factors and that cultivars differ in seed nutrient content. Nelson et al. (1945) reported that increasing levels of fertilizer K applied as side-dressing increased the seed K concentration on a particular soybean variety from 1.58% to 1.92%. In other studies, Coale and Grove (1991) and Terman (1977) showed seed K concentrations to be increased by direct application of fertilizer K on soybean. However, Yin and Vyn (2002a) may have been the first to report soybean K concentrations increases due to the residual effect of K fertilizer applied to the previous corn crop. The same authors also reported that previous tillage systems for corn had no significant effect on seed K concentration of subsequent no-till soybeans. Yin and Vyn (2003a) showed evidence that not only would direct application of fertilizer K increase seed K concentrations, but also that banded fertilizer K raised seed K concentrations more than broadcast application.

In recent research Vyn et al. (2002) reported significant increases in daidzein, genistein, and total isoflavones with direct banded application of fertilizer K or residual broadcast application of K on low-K soils. Isoflavones are a group of phytochemicals that are thought to contribute to the healthful effects of soybean in human diets. In this report the authors suggested that K concentrations in soybean leaves and soybean seeds may play an important role in controlling seed isoflavone concentration of soybean on soils with low concentrations of K. Yin and Vyn (2005) also reported a positive relation between seed yield and the concentrations and yields of individual and total isoflavones. They suggested that, because of this positive relationship, high isoflavones concentrations can be achieved with high soybean yields even when soybean variety was not selected based on its high content of isoflavones.

No-till soybean research opportunities

Conservation tillage causes major changes in nutrient availability with depth, soil temperature, water content and root growth and distribution. For that reason, traditional fertilizer management systems originally designed for soybean under conventional tillage may need to be revised to ensure that nutrition, yield and quality of soybeans will not be restricted.

The no-tillage system has more of a nutrient stratification problem, especially those of relatively immobile nutrients such us P and K, due to their continual broadcast application on the surface without subsequent incorporation (Vyn and Janovicek, 2001; Crozier et al., 1999). The availability of these nutrients may be restricted when drier years occur. Deep banding in conservational tillage systems may have positive impacts on reducing surface accumulations of P and K fertilizers, consequently increasing the fertilizer efficiency. However, published research comparing deep-banding with other placements for no-till soybean is limited and inconsistent. Nutrient placement may also play an important role not only when vertical stratification is a concern, but also when horizontal nutrient availability could be the reason of inconsistent and nom-uniform yield and quality results.

Most prior soybean research on responses to P and K fertility has been in either 19-cm or 76-cm row widths. There is a real need to investigate the responses of 38-cm row width soybean to P and K placement especially following deep banding. The 38 cm row width situation may be especially unique for residual fertilizer investigations since these rows are almost always going to be positioned 14 to 24 cm from a corn row in 76 cm corn fields. Access to the residual fertilizer in the deep band below the corn row may be better in such system than for a soybean row positioned midway (38 cm) between corn rows, yet inferior to that of soybean rows positioned on top of former corn row.

With regards to quality issues, previous research in soil fertility and nutrient management has focused mostly on the optimum levels of nutrients for high or economically optimum soybean yield. However, the impacts of soil fertility levels and management practices on seed quality are seldom evaluated.

Although effects of tillage system and direct K fertilization on soybean yield and quality have been investigated in the past, fewer reports are available concerning the residual effects of previous tillage system and its related P and K fertilizer placement for corn on subsequent no-till soybean in corn-soybean rotations.

CHAPTER TWO
NO-TILL SOYBEAN RESPONSES TO PRIOR TILLAGE, RESIDUAL FERTILIZER K AND SITE-SPECIFIC EXCHANGEABLE K ON VARIABLE SOILS

Abstract

Traditional K management recommendations designed for soybean under conventional tillage may need to be revised for conservation systems to ensure that K nutrition, yield and quality of soybeans will not be restricted. Few reports are available concerning the residual effects of K fertilization and tillage system for corn on subsequent no-till soybean in corn-soybean rotations.

In the spring of 2001, a field experiment was established near Farmland in East-central Indiana in order to evaluate the response of no-till soybeans to prior conservation tillage systems and alternate K fertilizer rates and system-dependent placements. Tillage treatments included No-till, Fall chisel and Strip-till while K fertility treatments included a control, a Fall application alone and a Fall plus a Spring application of fertilizer K.

Analysis of Covariance was used to analyze soil and plant data for a split-plot experimental design with the covariate (initial soil K content at the 5 to 15 cm depth) measured for each of the sampling positions. Significance of fixed effects of prior tillage and K fertility treatments were evaluated at three different levels of the covariate: Low (<90 mg kg^{-1} of initial soil K content), Medium (90-120 mg kg^{-1} of initial soil K content)

and High (>120 mg kg^{-1} of initial soil K content). A regression model was also adjusted between seed K concentrations and initial soil K content.

The results of this 3-year study show that leaf K concentrations were increased by the residual effects of K fertilizer applications in 2 out of 3 years. Mean soybean yields were not significantly increased in response to the residual K fertilizer treatments except for 1 year, and then only at low levels of initial soil K. Soybean seed K concentrations were consistently higher (in absolute terms, from 0.10 to 0.28% higher at low and medium levels of initial soil-test K, respectively) after the fall K alone, and fall plus spring K fertility treatments relative to the control in 2001 and 2002. In 2003, a much smaller, but significant, increase in seed K was observed only at medium levels of initial soil K. Soybean yields were observed to be the highest in the year when seed K concentration levels were above 17 g kg^{-1}. Neither soybean yields nor seed K concentrations were ever increased by K fertilizer applications to prior corn when soybean response means were adjusted to initial soil K above 120 mg kg^{-1} at the 5 to 15 cm depth. Seed protein and oil were affected by previous K fertility treatments but not by the previous tillage system itself. In general, K applications were correlated with small increases in seed oil and decreases in protein content. However, initial soil exchangeable K played a more important role than the K fertility treatments themselves in affecting soybean response.

Introduction

Conservation tillage causes major changes in nutrient availability with depth, soil temperature, water content, pest incidence, and root growth and distribution. Soybean K needs in conservation tillage systems, relative to conventional systems, are more dependant on soil exchangeable K concentrations, root density and soil moisture and temperature in the surface layer. Therefore, traditional K management recommendations designed for soybean under conventional tillage may need to be revised to ensure that K nutrition, yield and quality of soybeans will not be restricted.

Concerns about K fertility management have increased not only because the increase in no-till soybean acreage but also because drier summers and compacted soil conditions have resulted in lower levels of K uptake, information about the extent of K stratification in no-till soils have become better known, and the deep banding of P and K fertilizers on 76.2 cm row centers have become a more popular alternative for strip-till corn farmers. The 20% no-till adoption rate for corn in Indiana (Evans et al., 2000) versus the 60% adoption rate for soybeans suggests that there is much rotational tillage taking place from year to year within fields. However, the soil fertility evidence also indicates that soil K stratification can be almost as pronounced after conservation practices like fall chisel plowing or shallow, single-pass cultivation as they can be after a "pure" no-till system (Holanda et al., 1998).

Tillage system and its related fertilizer placement have a significant effect on the stratification of P and K. The no-tillage system has more vertical stratification due to continual broadcast application of soil nutrients on the surface without subsequent incorporation (Vyn and Janovicek, 2001; Crozier et al., 1999). Without mechanical incorporation of the fertilizer, these relatively immobile nutrients remain concentrated in about the upper 5 cm of soil (Cruse et al., 1983; Ketcheson et al., 1980). This stratification of nutrients is a concern because if the upper 5 cm of soil becomes dry, the surface-applied P and K will become less available to plants.

One essential goal of K fertility management is to reduce the incidences of seed yield loss and inferior seed quality resulting from areas of fields with below optimum soil-test K. Placement of fertilizer and subsequent tillage may have a pronounced effect on the spatial variability patterns of residual soil K (Ebelhar and Varsa, 1999; Yin and Vyn, 2002). Long term no-till management has resulted not only in vertical nutrient stratification but also in pronounced horizontal heterogeneity of soil available nutrients. Improved K fertilizer recommendations for no-till soybean may be essential in order to achieve more uniform crop yield and quality.

Soils are not often homogeneous at any spatial scale. In agricultural field studies, better understanding of the intrinsic spatial variation is critical for appropriate interpretations of experiment outcomes.

Within a field, differences in soil chemical properties and nutrient status may be induced by different soil types or by variations in profile development and soil depth. The coefficient of variation (C.V.) of concentration of nutrients such as P and K seems to be greater than for other soil chemical properties such as pH and organic matter (O.M.) within a field. Research in Spain by López-Granados et al. (2002) found that the C.V. for K concentration in the topsoil was 25% while the coefficients for pH, O.M. and P were 1, 6 and 28%, respectively. Other research in Belgium (Geypens et al., 1999) reported coefficient of variation of 4% for pH, 17% for P and 50% for K. Research in Iowa by Cambardella et al. (1999) found the C.V. for K in the topsoil to be 52% while the coefficients for pH, and P were 18.5% and 56%, respectively. In more recent research involving 23 farm fields in Ontario, Canada Lauzon et al. (2005) reported a C.V. of 62% for P, 34% for K and 8% for pH. An inherently high C.V. for K in many agricultural fields may make it extremely difficult to obtain significant treatment differences for K fertilizer treatments. In addition, high spatial variability may also mean that soybean yield or seed quality responses may be more dependent on the precise exchangeable K concentrations at a particular sampling site than it is affected by same year or prior year fertility applications.

Most of the published research has been devoted to the effects of direct tillage system and K applications to soybeans, but fewer reports are available concerning the residual effects of K fertilization, K placement, and tillage system for corn on subsequent no-till soybean in corn-soybean rotations. Relevant research showed that no-till soybean yield response to residual starter K (102 kg ha^{-1}) was negligible on high-testing soils with at least ten years of no-tillage management (Buah et al., 2000). However, on fields after six years in ridge-till with evident vertical soil K stratification, soybean response to residual deep-banded (10-cm depth) K was evident on a high-testing soil at a high rate (148 kg ha^{-1}) of fall K fertilizer (Rehm, 1995). Research in Ontario, Canada (Yin and Vyn, 2002) concluded that subsequent no-till soybean responded more to residual K fertilizer rate than to application timing, tillage, and K fertilizer placement method in preceding corn. In another study involving low-testing K soils in Ontario, Canada, the same authors (Yin and Vyn, 2003) also found that no-till soybean response to residual K fertilizer management for corn varied with the tillage systems utilized in corn.

The primary objectives of this study were (a) to evaluate the residual effects of prior tillage system and K fertilizer application on soybean yields and seed quality in a no-till production system, and (b) how spatial variability in soil-test K status affects those soybean responses.

Materials and Methods

Site description

In the spring of 2001, a field experiment was established near Farmland in East-central Indiana at the Davis Purdue Agricultural Center (DPAC) in order to evaluate the response of no-till soybeans to prior conservation tillage systems and alternate K fertilizer rates and system-dependent placements. Geographical coordinates for the field site are 40º 27' North Latitude, 85º 15' West Longitude. Research plots each year were adjacent sites in the same field and it always involved first-year soybean crop after corn.

The research was conducted across four major soil series, all derived from dense glacial till materials with native vegetation of deciduous trees. Blount silt loam (fine, illitic, mesic Aeric Ochraqualfs) was predominately found on the crests of the existing drainage ways and is classified as being nearly level with somewhat poor drainage. Condit silt loam (Typic Epiaqualfs) was predominately found on the slopes of the drainage ways, varied between 0-1 percent slope and is somewhat poorly drained. Glynwood silt loam (fine, illitic, mesic Aquic Hapludalfs) is found on the slopes of the till drainage ways and has been classified as a moderately well drained soil, normally with a 1-4 percent slope. Pewamo silty clay loam (fine, mixed, mesic Typic Aargiaquolls) was found in natural drainage ways and is classified as having poor drainage.

Cultural practices

Golden Harvest H3 520 RR soybean variety was no-till planted during May in 2001, 2002 and in 2003 at populations of 457,000 seeds ha^{-1} using a John Deere 750 planter in 38.1 cm row widths.

A split-plot experimental design was used with six replications, complete randomization of tillage blocks and additional randomization of the sub-block K fertility treatments. Plot dimensions were 4.6 meters wide by 152.5 meters long in which 12 soybean rows spaced at 38.1 cm were planted. Within each plot four sampling positions were established (spaced at 30 meters intervals in the center of each plot) and geo-referenced for future soil and plant sampling.

The prior main tillage effects among fall chisel with spring field cultivation (conventional practice in Indiana), strip tillage to a depth of 20 cm, and no-till were compared. The influence of prior K placement and rate interactions with tillage effects was also compared. A detailed treatment description is given below.

Main Plot (tillage):

1. No-till (NT).
2. Fall chisel, with spring cultivation (FC). A Brillion chisel plow at a depth of 15 cm, followed in the spring by a single pass of a Glencoe field cultivator.
3. Fall Strip tillage (ST). A DMI 2500 tool bar with a mole knife attachment to a depth of 20 cm and no additional tillage in the spring.

Sub Plots (K rate and placement):

1. No K (No K). No K was applied to the plot.

2. Fall K (Fall K). Broadcast application of 100 kg ha^{-1} of K_20 as 0-0-60 in NT and FC main treatments. In the strip-till treatment, 100 kg ha^{-1} K_2O was placed in the intended row areas at a depth of 15-18 cm with a DMI toolbar.
3. Fall K plus Spring starter (F&S K). Fall K application (as stated in #2 above) followed by additional 56 kg ha^{-1} of K_20 in a 5 cm x 5 cm liquid starter band placed at planting.

Weed control was achieved by application of glyphosate (Round up). In 2001, Round-up (glyphosate) was applied at 2.3 liters ha^{-1}. In 2002 and 2003 Round-up (glyphosate) was again applied at 2.3 liters ha^{-1}.

Soil measurements

Soil samples were taken to determine both the soil exchangeable K status and the extent of stratification that was present in the soil. These measurements were essential in understanding the variability in response (or lack of response) to both tillage operations and alternate K rates.

Soil fertility samples were taken at each of the four sampling positions within each plot in mid-June. Each sample was a composite of 10-12 cores that were sampled within 3 meters of the sample points. Sample depths were 0 to 5 cm, 5 to 15 cm and 15 to 25 cm.

After collection, the soil samples were dried with forced air at room temperature. Once dry, the samples were ground using a flail grinder (Dyna crush soil crusher flail grinder, Model DC-2 Custom Laboratory Equipment Inc., Orange City, Florida), and passed through a 2 mm sieve. The ground soil samples were placed in bags for storage and sent to an independent laboratory and analyzed for pH, organic matter, P content using Mehlich 3, K content, Mg and Ca content and Cation Exchange Capacity. Table 2-1 shows a summary of the site's chemical properties each year.

Table 2-1. Summary of soil chemical properties in 2001, 2002 and 2003.

Depth	OM (%)	pH	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})
			2001			
0-5 cm	4.1	5.8	54	166	457	2045
5-15 cm	3.1	6.2	24	114	503	2286
15-25 cm	--	--	14	115	619	2653
			2002			
0-5 cm	3.7	6.5	54	189	624	2273
5-15 cm	3.1	6.1	23	128	541	2243
15-25 cm	--	--	13	134	683	2817
			2003			
0-5 cm	3.9	6.7	50	215	593	2053
5-15 cm	3.2	6.1	22	124	512	2038
15-25 cm	--	--	14	111	582	2338

Organic matter and pH values were obtained only for the first two depth intervals.

Soybean measurements

Several plant measurements were taken throughout the growing season. These measures include leaf K concentrations at the R1 growth stage, seed yield, seed moisture, oil content, protein content, and seed K levels.

Leaf K was sampled when 50% of the plants were at the first reproductive stage (R1). Twenty trifoliolate leaves were taken to make a composite sample in each sampling area. These composite samples were then dried in a 60ºC oven and subsequently ground through a 1 mm sieve by a rotary blade grinder (Thomas Wiley Mill Model ED-5, Arthur H. Thomas Co. Phila, PA. USA). The ground samples were then sent to an independent laboratory and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, manganese, copper and zinc.

Seed yield was obtained from the combine's Ag Leader PF3000 yield monitor in 2001, 2002 and 2003 (monitor measures yield via pressure across a flow plate). The flow data (recorded as lb sec^{-1}) was exported into Microsoft Excel and converted to 130 g kg^{-1} moisture and then to Mg ha^{-1} sec^{-1}. Five adjacent flow points were averaged together to give a smoothed yield estimate. Then the closest average yield point to the sampling point was assigned the yield for that area (a distance of approximately 7.62 m). This assignment was done in the ArcView software package (ESRI, ArcView 3.2, 2000; Environ Systems Research Institute, Inc., Redlands, CA, USA.) through the geo-processing "join" function. These averaged yield values for each sample area were the values used in the statistical analysis in the three years.

Seed moisture was measured by collecting a grab sample from the seed flow as it entered the combine's holding bin. This was accomplished by waiting 12 seconds after the sample area was cut before bagging the sample, in order for the seed from each sample area to be processed through the combine. This sample was subsequently run through a Dickey John GAC II moisture meter (Dickey-John Corporation, Auburn, IL, U.S.A.) to obtain moisture values used in subsequent statistical analysis.

Seed quality (oil and protein content) was also run on the soybean grab samples pulled from each harvest area. Seed concentrations were obtained through near infrared analysis via an InfratecR 1229 Whole Grain Analyzer. This near infrared (NIR) analysis is widely used for routine compositional testing of seed. The standard analyses given by the InfratecR analysis are moisture, oil, fiber, and protein content. These values were then adjusted to the standard moisture content of 130 g kg^{-1} by using the formula CDB = 100*(CM/100-M) or CM = (CDB (100-M))/100, where CM=current moisture, M=percent moisture desired and, CDB=percent component (oil or protein) (Maier and Briggs, 1997).

Seed K levels were derived for each of the sampling areas. A portion of around 50 grams was taken from each seed quality sample and dried in an oven at 60ºC. The sample was then ground using a rotary blade grinder (Thomas Wiley Mill Model ED-5, Arthur H. Thomas Co. Phila, PA. USA) and forced through a 2 mm sieve. The ground samples were then sent to an independent laboratory and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, manganese, copper and zinc.

Statistical analysis

All statistical analysis used to determine treatment effects were done using Statistical Analysis System, SAS (version 9.1, SAS Institute, Cary, NC). Analysis of Covariance was used to analyze the data for a split-plot experimental design with the covariate (initial soil K content at the 5 to 15 cm depth) measured for each of the sampling positions. Since four sampling position were established and geo-referenced in each plot, a total of 216 data points were available for each parameter each year. Significance of fixed effects of prior tillage and K fertility treatments were evaluated at three different levels of the covariate: Low (<90 mg kg^{-1} of initial soil K content), Medium (90-120 mg kg^{-1} of initial soil K content) and High (>120 mg kg^{-1} of initial soil K content). Means comparison tests were performed according to Tukey (α=0.05).

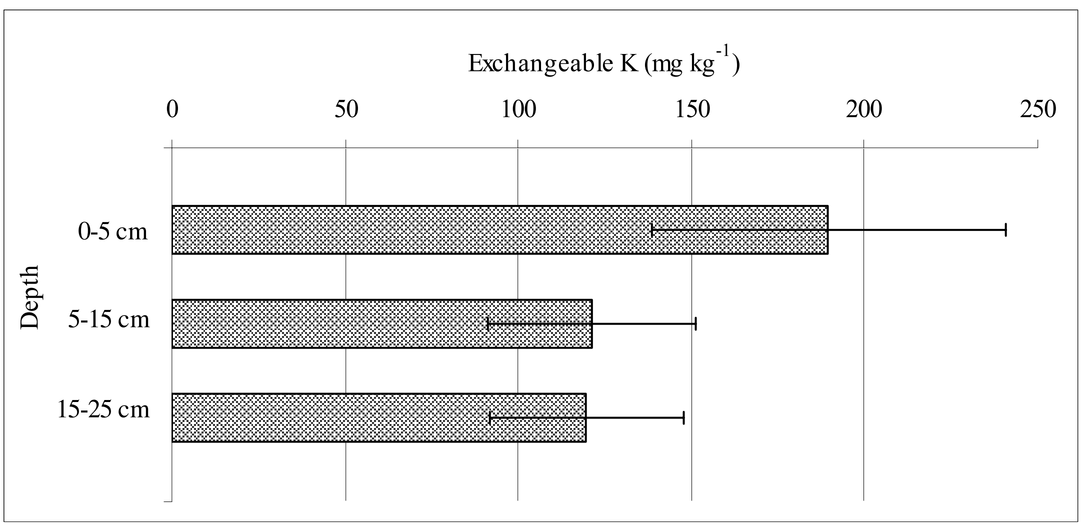
A linear regression model was also adjusted using Statistical Analysis System, SAS (version 9.1, SAS Institute, Cary, NC) between soybean seed K concentrations and initial soil K concentration (measured at the 5 to 15 cm depth interval) on a sub-sample basis. A total of 216 sub-samples were used in the regression analysis each year. Levels of significance less than P=0.05 were declared significant.

Results and Discussion

Soil K concentrations

Significant levels of soil K stratification were observed in the experiment area across all tillage and K treatments. Figure 2-1 shows the mean soil K concentrations for the combined year data. In 2001 the concentrations at the 0 to 5 cm depth averaged 166 mg kg^{-1}, in 2002 they averaged 188 mg kg^{-1}, and in 2003 they averaged 215 mg kg^{-1}. Soil concentrations averaged 115 mg kg^{-1}, 133 mg kg^{-1} and 111 mg kg^{-1} at the 15 to 25 cm depth for the 2001, 2002 and 2003, respectively. Potassium stratification, therefore, was somewhat more pronounced in 2003 than in 2001 and 2002. The ratio between the soil exchangeable K between the 0 to 5 depth and the 15 to 25 depth was 1.45, 1.41 and 1.93 for 2001, 2002 and 2003, respectively.

Figure 2-1. Combined year soil exchangeable K concentration from different depth intervals.



Error bars are standard deviations.

Soil exchangeable K at the three different depths was analyzed as a response variable across tillage systems and K fertility treatments. Tillage did not affect the mean exchangeable K concentrations at any of the three soil depths. As expected, the soil exchangeable K was significantly affected by the previous K fertility treatment at the 0 to 5 cm depth. The No K treatment always had the lowest soil exchangeable K. For all years except 2002, the Fall plus Spring application resulted in a significant higher value compared to the No K treatment. In 2002 and 2003 the Fall application was also significantly different from the No K treatment. Only in 2003 was there a significant K fertility effect on the soil exchangeable K at the 5 to 15 cm depth. There, both Fall application and Fall plus Spring application were higher than the control but not different from each other. This might have been a result of 2 consecutive years of K application since the experiment in 2003 was placed in the same experimental area as in 2001. Soil exchangeable K at the 15 to 25 cm depth was never affected by the previous K fertility treatment. Table 2-2 illustrates the K fertility effects on soil exchangeable K concentrations at the three depths for 2001, 2002 and 2003.

Table 2-2. Soil exchangeable K concentration at different depth intervals as affected by previous K fertility treatments in 2001, 2002 and 2003.

		Depth		
Year	Fertility treatment	0-5 cm	5-15 cm	15-25 cm
		---------Soil K concentration (mg kg^{-1})---------		
	No K	160 b	113	115
2001	Fall K	167 ab	114	115
	F&S K	170 a	115	115
mean		166	114	115
	No K	176 b	126	132
2002	Fall K	198 a	131	134
	F&S K	192 ab	124	131
mean		188	127	132
	No K	178 c	113 b	105
2003	Fall K	216 b	126 a	113
	F&S K	245 a	129 a	113
mean		213	123	110

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05). No K= Control, Fall K= Fall application of fertilizer K and F&S K= Fall plus Spring application of fertilizer K.

R1 nutrient analysis

Leaf K content at the R1 growth stage of development indicates the levels of soybean K nutrition at early growth stages. As previously stated, analysis of covariance was used to analyze the data for a split-plot experimental design with the covariate (initial soil K content at the 5 to 15 cm depth) measured for each of the sampling positions. Significance of fixed effects of prior tillage and K fertility treatments were evaluated at three different levels of the covariate: Low (<90 mg kg^{-1} of initial soil K content), Medium (90-120 mg kg^{-1} of initial soil K content) and High (>120 mg kg^{-1} of initial soil K content).

Table 2-3 shows the tillage treatment and K fertility treatment effects on leaf K concentration at the R1 growth stage at different levels of initial soil K content. At the low level of the covariate, either tillage effects or K fertility effects were found to be significant just once in three years. In year 2002, there was a significant tillage effect on the K leaf content at the R1 growth stage. For that year, No-till resulted in the highest leaf K content, significantly different from the Strip tillage system but not from the Fall Chisel. However, there was no significant difference between Strip tillage and Fall Chisel. In year 2003, only a K fertility effect was found to be significant. For that year, both Fall application and Fall plus Spring application resulted in higher leaf K content than the No K treatment. However, both applications were not found to be different from each other. At the medium level of the covariate, the tillage by fertility interaction was significant in 2002, and fertility effects were significant in 2003. For 2002 the Fall plus Spring application resulted in higher leaf K content compared to the No K treatment and to the Fall application, but only in No-till. In 2003, both Fall application and the Fall plus

Spring application resulted in higher leaf K concentration compared to the No K treatment across all tillage systems. At the high level of the covariate a K fertility effect was significant in year 2003, just as it was observed for the other two levels of the covariate. The Fall application and the Fall plus Spring application resulted in higher leaf K concentration compared to the No K treatment.

Table 2-3. Leaf K concentration (R1 growth stage) as affected by previous tillage systems and K fertility treatments presented as adjusted means for different levels of initial soil K concentration in 2001, 2002 and 2003.

Initial soil K	Low (<90 mg kg^{-1})				Medium (90-120 mg kg^{-1})				High (>120 mg kg^{-1})			
K treatment	No K	Fall K	F&S K	Mean	No K	Fall K	F&S K	Mean	No K	Fall K	F&S K	Mean
Tillage	---Leaf K concentration (g kg^{-1})---											
							2001					
NT	20.1	20.3	20.2	20.2	20.5	20.4	20.3	20.4	20.8	20.4	20.6	20.6
FC	20.0	20.3	19.8	20.0	20.5	20.6	20.1	20.4	21.0	20.9	20.5	20.8
ST	19.6	20.0	20.0	19.9	19.8	20.3	20.4	20.2	20.1	20.7	20.9	20.6
Mean	19.9	20.2	20.0		20.3	20.4	20.3		20.6	20.7	20.6	
							2002					
NT	18.9	19.6	19.3	19.3 a	18.5B	18.8B	19.4A	18.9	18.1	18.0	19.4	18.5
FC	18.4	18.7	18.5	18.5 ab	18.1	18.3	18.3	18.2	17.8	17.9	18.1	17.9
ST	17.9	18.1	18.0	18.0 b	17.8	17.8	17.6	17.8	17.7	17.5	17.1	17.5
Mean	18.4	18.8	18.6		18.1	18.3	18.4		17.9	17.8	18.2	
							2003					
NT	19.8	22.4	23.1	21.8	22.0	23.1	24.0	23.0	24.5	23.8	25.1	24.5
FC	18.5	21.8	21.4	20.6	20.4	23.0	23.1	22.2	22.5	24.4	25.0	24.0
ST	19.0	22.9	21.9	21.3	21.1	24.1	23.0	22.7	23.5	25.4	24.3	24.4
Mean	19.1B	22.4A	22.1A		21.2B	23.4B	23.4A		23.5B	24.6A	24.8A	

Means followed by the same letter, or no letter, within a columns or means followed by the same capital letter, or no letter, within a row are not significantly different according to Tukey (α=0.05). NT= No-till, FC= Fall chisel, ST= Strip till, No K= Control, Fall K= Fall application of fertilizer K and F&S K= Fall plus Spring application of fertilizer K.

In general, these results are in agreement with those of Yin et al. (2002) who reported that soybean leaf K concentrations were frequently increased by K fertilization at high rates (84 kg ha^{-1} of K) for the previous corn and that previous tillage system for corn had no significant effect on soybean leaf K concentration at the R1 growth stage. A previous report by Hudak et al. (1989) also showed increased leaf K concentration in soybean at the R1 growth stage with deep-banded or broadcast K in various tillage systems.

Soybean yield

Table 2-4 shows the K fertility treatment effects on seed yield at different levels of initial soil K content. Seed yield was never affected by the previous tillage system. Only the previous K fertility treatment was found to have a significant effect on the seed yield and then only in the last year of the study. The effect of this factor was significant only at the low level of the covariate but not at the medium or high levels. The Fall application and the Fall plus Spring application resulted in higher seed yields compared to the No K treatment. However, the treatments with K application were not different from each other. The Fall application and the Fall plus Spring application resulted in approximately a 5% increase in seed yield compared to the No K treatment.

In previous research, Yin et al. (2002) reported similar results. In that study the authors concluded that residual effects of tillage systems on soybean yield were not significant in any of the five years of the experiment. They also found that yield responses to the residual K were relatively small and they found those responses only with medium-K soils. In another study, Buah et al. (2000) reported that soybean yield responses to residual K fertilizer were insignificant on high-K soils.

Table 2-4. Soybean seed yield as affected by previous K fertility treatments presented as adjusted means for different levels of initial soil K concentration in 2001, 2002 and 2003.

	2001			2002			2003		
K treatment	No K	Fall K	F&S K	No K	Fall K	F&S K	No K	Fall K	F&S K
Initial soil K	------Seed yield (Mg ha^{-1})------								
Low (<90 mg kg^{-1})	3.81	3.70	3.79	2.09	2.18	2.30	2.48 B	2.63 A	2.59 A
Medium (90-120 mg kg^{-1})	3.79	3.68	3.76	2.52	2.56	2.60	2.55	2.63	2.63
High (>120 mg kg^{-1})	3.77	3.66	3.72	3.00	2.98	2.94	2.62	2.63	2.67

Means followed by the same capital letter, or no letter, within a row are not significantly different according to Tukey (α=0.05). No K= Control, Fall K= Fall application of fertilizer K and F&S K= Fall plus Spring application of fertilizer K.

Seed nutrient and composition analysis

Measures of soybean seed included nutrient concentration and quality. Seed oil and protein content as percentage of seed dry weight were measured as quality parameters. Table 2-5 shows the K fertility treatment effects on seed K concentration at different levels of initial soil K content. Seed K concentration was never affected by the previous tillage system at any of the three levels of the covariate. Previous K fertility treatments were significant for all the three years of the study. Results for the first two years were very similar. Effects of previous K fertility treatment were only significant when treatments were compared at the low and medium level of the covariate. For both levels, and for both 2001 and 2002, the Fall application and the Fall plus Spring application resulted in higher seed K levels compared to the No K treatment but were not different from each other. In 2003, differences were only observed at the medium level of the covariate. There, the Fall application and the Fall plus Spring application resulted in higher seed K levels compared to the No K treatment but they were again not different from each other.

In general these results are in agreement with those reported by Yin et al. (2002) who showed that there was no significant effect of previous tillage system for corn on the soybean seed K concentration in any of the years of the experiment, but that there was a frequent increase on seed K concentrations due to residual effects of K fertilizer applied to the previous corn.

Table 2-5. Seed K concentration as affected by previous K fertility treatments presented as adjusted means for different levels of initial soil K concentration in 2001, 2002 and 2003.

	2001			2002			2003		
K treatment	No K	Fall K	F&S K	No K	Fall K	F&S K	No K	Fall K	F&S K
Initial soil K	----------------------------Seed K concentration (g kg^{-1})--------------------------								
Low (<90 mg kg^{-1})	14.4 B	17.1 A	17.2 A	10.7 B	12.1 A	13.0 A	15.2	15.4	15.4
Medium (90-120 mg kg^{-1})	18.3 B	19.9 A	20.3 A	12.7 B	13.7 A	14.2 A	15.1 B	15.3 A	15.3 A
High (>120 mg kg^{-1})	22.6	23.1	23.7	14.9	15.4	15.5	15.0	15.2	15.2

Means followed by the capital same letter, or no letter, within a row are not significantly different according to Tukey (α=0.05). No K= Control, Fall K= Fall application of fertilizer K and F&S K= Fall plus Spring application of fertilizer K.

Table 2-6 shows the K fertility treatment effects on seed protein concentration at different levels of initial soil K content. Seed protein concentration was never affected by the previous tillage system at any of the three levels of the covariate. Previous K fertility treatment effects were found to be significant in two of the three years. In 2001, that effect was found to be significant at the low and medium level of the covariate, while in year 2003 it was observed for all levels of the covariate. Results from year 2001 were somewhat confusing since the Fall plus Spring application resulted in lower levels of protein content compared to the Fall application at the low and medium level of the covariate. However, neither the Fall application nor the Fall plus Spring application were significantly different from the No K treatment. In year 2003, at the low, medium and high levels of the covariate, the Fall application and the Fall plus spring application resulted in lower levels of seed protein concentration compared to the No K treatment.

Table 2-6. Seed protein concentration as affected by previous K fertility treatments presented as adjusted means for different levels of initial soil K concentration in 2001, 2002 and 2003.

	2001			2002			2003		
K treatment	No K	Fall K	F & S K	No K	Fall K	F & S K	No K	Fall K	F & S K
Initial soil K	------------------------Seed protein concentration (g kg^{-1})------------------------								
Low (<90 mg kg^{-1})	367 AB	365 B	370 A	370	368	368	365 A	360 B	360 B
Medium (90-120 mg kg^{-1})	364 AB	362 B	365 A	370	369	368	365 A	361 B	361 B
High (>120 mg kg^{-1})	360	359	361	370	370	367	365 A	361 B	360 B

Means followed by the same capital letter, or no letter, within a row are not significantly different according to Tukey (α=0.05). No K= Control, Fall K= Fall application of fertilizer K and F&S K= Fall plus Spring application of fertilizer K.

Table 2-7 shows the tillage treatment and K fertility treatment effects on seed oil concentration at different levels of initial soil K content. In year 2001 neither tillage systems nor K fertility treatment affected the seed oil concentration. An interaction effect of prior tillage system and previous K fertility treatment was found to be significant in 2002, while in 2003 only a K fertility effect was observed. In 2002, at low and medium levels of the covariate, a K fertility treatment effect was significant but only within the Fall Chisel system. The Fall plus Spring application resulted in higher seed oil concentration compared to the No K treatment and to the Fall application. For that year, and at the high level of the covariate, the same results were found but then only across all tillage systems. In 2003, the same trend was observed at the low, medium and high levels of the covariate. For the three covariate levels, only a K fertility effect was significant. In all cases, the Fall application and the Fall plus Spring application resulted in higher levels of seed oil concentration compared to the No K treatment. However, those two treatments were not significantly different from each other.

Table 2-7. Seed oil concentration as affected by previous tillage systems and K fertility treatments presented as adjusted means for different levels of initial soil K concentration in 2001, 2002 and 2003.

Initial soil K	Low (<90 mg kg^{-1})			Medium (90-120 mg kg^{-1})			High (>120 mg kg^{-1})		
K treatment	No K	Fall K	F&S K	No K	Fall K	F&S K	No K	Fall K	F&S K
Tillage	---Seed oil concentration. (g kg^{-1})---								
	2001								
NT	177	178	176	178	179	177	179	180	178
FC	174	175	175	176	177	176	178	178	178
ST	176	177	175	177	177	177	178	178	179
Mean	176	177	175	177	178	177	178	179	178
	2002								
NT	172	174	173	171	173	173	171	172	172
FC	171 B	171 B	175 A	172 B	171 B	175 A	173	171	175
ST	173	174	172	172	173	173	171	173	175
Mean	172	173	173	172	172	174	171 B	172 B	174 A
	2003								
NT	176	177	178	176	177	178	175	177	177
FC	175	178	179	175	178	179	175	178	178
ST	175	177	177	175	177	177	175	177	177
Mean	175 B	178 A	178 A	175 B	177 A	178 A	175 B	177 A	177 A

Means followed by the same capital letter, or no letter, within a row are not significantly different according to Tukey (α=0.05). NT= No-till, FC= Fall chisel, ST= Strip till, No K= Control, Fall K= Fall application of fertilizer K and F&S K= Fall plus Spring application of fertilizer K.

These results are in general, but in a smaller proportion, in agreement with those reported by Gaydou and Arrivets (1983) that showed that the addition of potassium resulted in a significant oil content increase but also resulted in a highly significant protein decrease. In another experiment in Australia (Sale et al., 1986), seed produced by K deficient plants contained low oil and high crude protein concentrations compared with seed from plants supplied with adequate K.

The results obtained in this study are in agreement with more recent research by Mallarino et al. (2005) that reported that the application of fertilizer P and K seldom affected soybean seed oil and protein concentrations. Even when there was a fertilization effect on seed oil and protein concentration, the responses were small.

Regression analysis

As previously stated, a linear regression model was developed between soybean seed K concentrations and initial soil K concentration (measured at the 0 to 5, 5 to 15 and 15 to 25 cm depth interval) on sub-sample basis.

Figures 2-2, 2-3 and 2-4 show the results of the regression analysis of seed K concentration and initial soil K concentration measured at the 0 to 5 cm depth interval in 2001, 2002 and 2003, respectively. In 2 out of 3 years the regression model was significant, and seed K concentrations were positively related to initial soil K concentrations with meaningful R^2 values. In 2001, the model explained the 57% of the variation in seed K concentrations while in 2002 initial soil K status explained 43% of the variation.

Figure 2-2. Regression of seed K concentration with initial soil K concentration at 0 to 5 cm depth in year 2001.

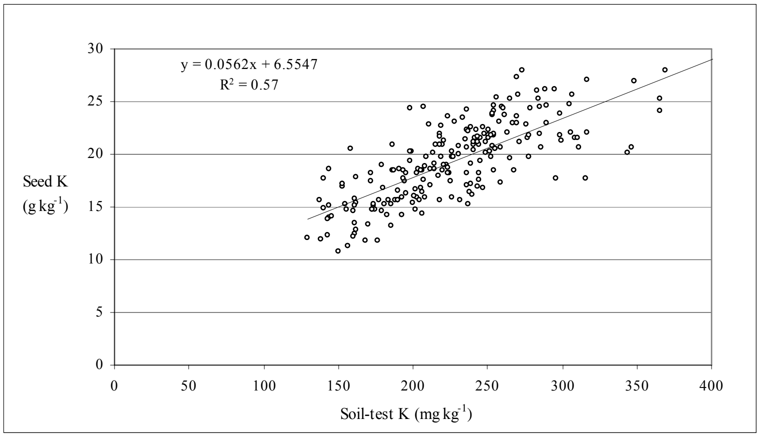


Figure 2-3. Regression of seed K concentration with initial soil K concentration at 0 to 5 cm depth in year 2002.

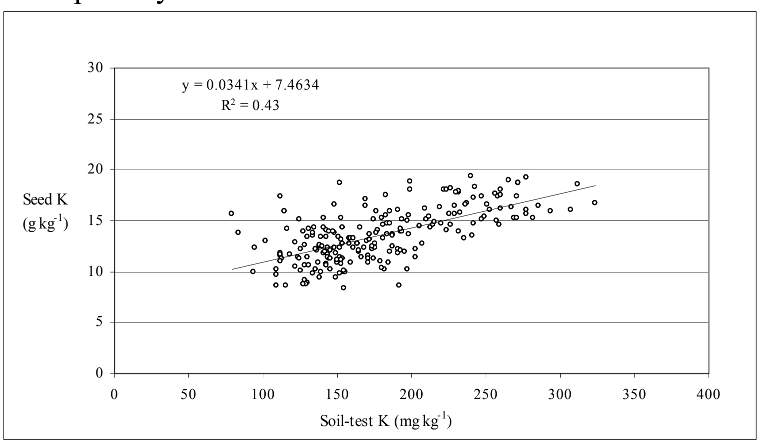
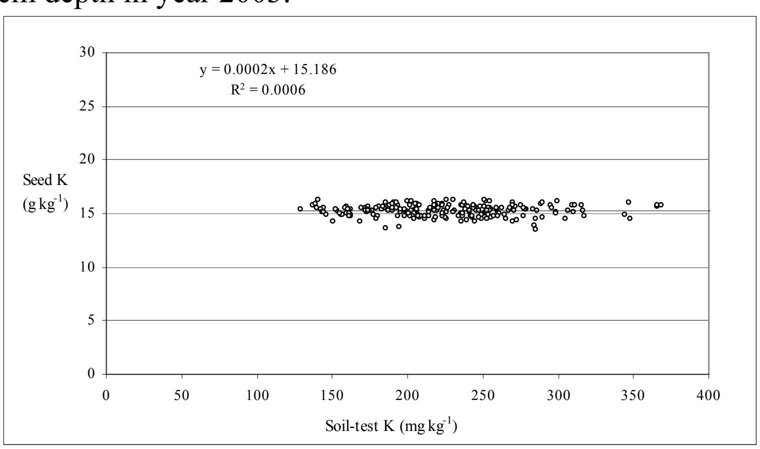


Figure 2-4. Regression of seed K concentration with initial soil K concentration at 0 to 5 cm depth in year 2003.



Figures 2-5, 2-6 and 2-7 show the results of the regression analysis of seed K concentration and initial soil K concentration measured at the 5 to 15 cm depth interval in 2001, 2002 and 2003, respectively. Results were very similar to those for the 0 to 5 cm depth interval. In 2 out of 3 years the regression model was significant, and seed K concentrations were positively related to initial soil K concentrations with meaningful R^2 values. In 2001, the model explained the 56% of the variation in seed K concentrations while in 2002 initial soil K status explained 40% of the variation.

Figure 2-5. Regression of seed K concentration with initial soil K concentration at 5 to 15 cm depth in year 2001.

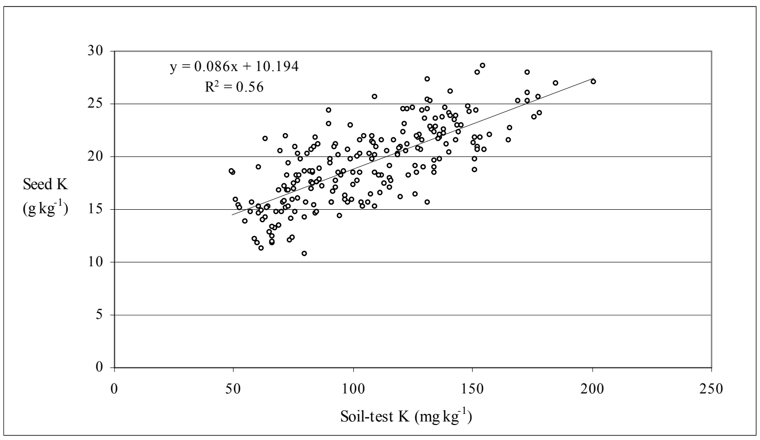


Figure 2-6. Regression of seed K concentration with initial soil K concentration at 5 to 15 cm depth in year 2002.

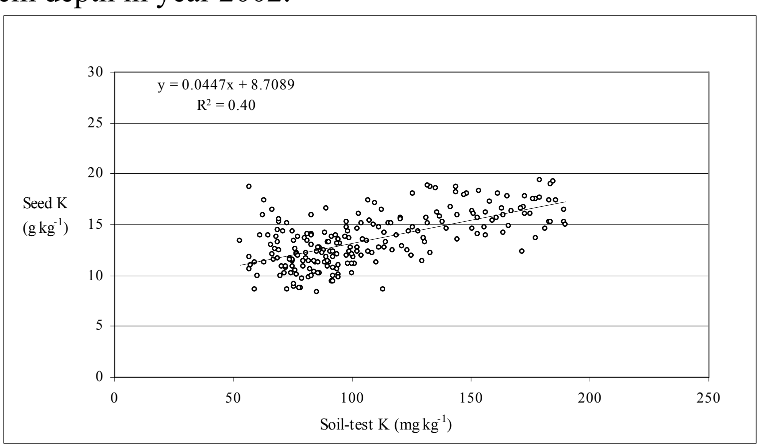
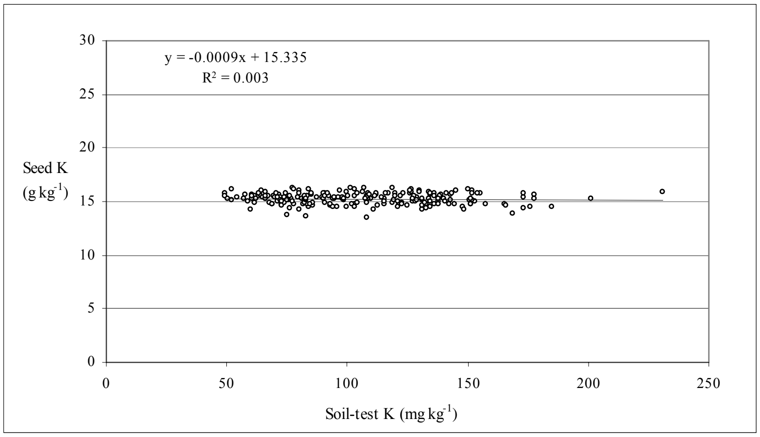


Figure 2-7. Regression of seed K concentration with initial soil K concentration at 5 to 15 cm depth in year 2003.



Finally, Figures 2-8, 2-9 and 2-10 show the results of the regression analysis of seed K concentration and initial soil K concentration measured at the 15 to 25 cm depth interval in 2001, 2002 and 2003, respectively. Results were similar compared to the first two depth intervals but the R^2 were lower. In 2 out of 3 years the regression model was significant, and seed K concentrations were positively related to initial soil K concentrations with meaningful R^2 values. In 2001, the model explained the 43% of the variation in seed K concentrations while in 2002 initial soil K status explained 35% of the variation.

Figure 2-8. Regression of seed K concentration with initial soil K concentration at 15 to 25 cm depth in year 2001.

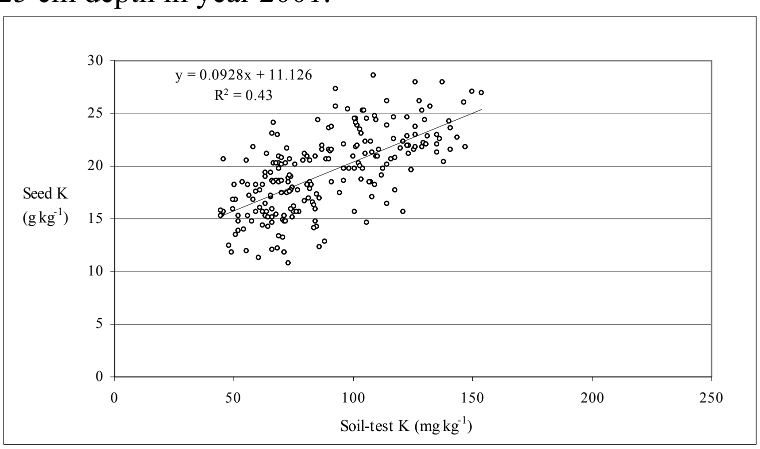


Figure 2-9. Regression of seed K concentration with initial soil K concentration at 15 to 25 cm depth in year 2002.

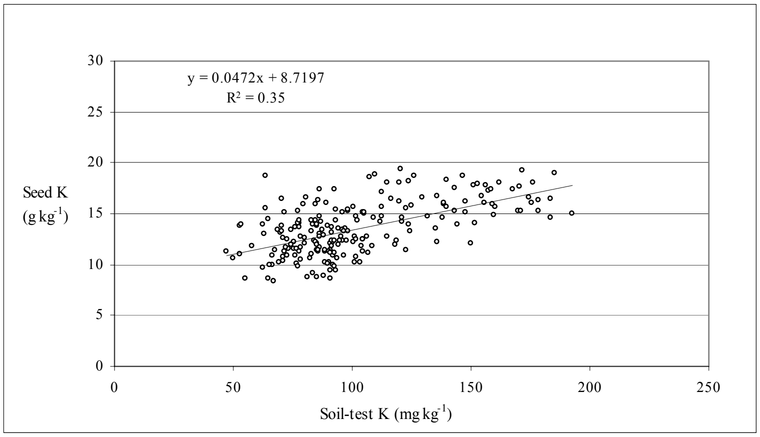
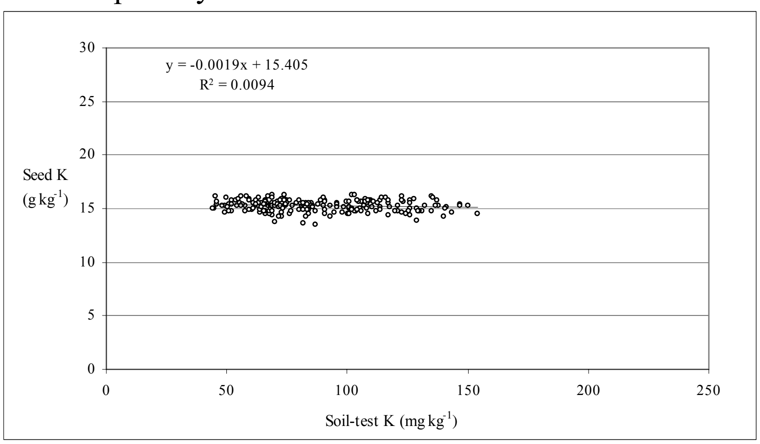


Figure 2-10. Regression of seed K concentration with initial soil K concentration at 15 to 25 cm depth in year 2003.



There was very little variation in seed K concentration in 2003 (13.5 to16.5 g kg^{-1}) and this might explain the almost total absence of a relationship with initial soil K status at any of the three depth intervals that year. Mean seed K concentrations (Table 2-5) were also least affected by residual K fertility treatments in 2003, relative to 2001 or 2002. It would be interesting to understand better the environmental factors which lead to strong relationship between soil K concentration and seed K in one year, but very poor relationship in another year even when the same cultivar is used and the site is exactly the same as it was in 2001.

Conclusions

The results of this 3-year study show that tillage systems in the prior corn year had almost no influence on no-till soybean response parameters. Residual effects of K fertilizer treatments were apparent for one or more soybean parameters in all 3 years. Leaf K concentrations were higher following applied K treatments in 2002 and 2003, but not in 2001. Mean soybean yields were not significantly increased in response to the residual K fertilizer treatments except in 2003, and then only at low levels of initial soil K. Soybean seed K concentrations were consistently higher (in absolute terms, from 0.10 to 0.28% higher at low and medium levels of initial soil-test K, respectively) after the fall K and fall plus spring K fertility treatments relative to the control in 2001 and 2002. In 2003, a much smaller, but significant, increase in seed K was observed only at medium levels of initial soil K.

The absolute seed K percentages ranged widely from year to year even though the same variety was used each year. Initial soil K status seems to play a more important role than previous tillage or K fertilization in controlling soybean seed K concentrations. In 2 out of 3 years, regression models suggested that between 40 to 57% of the variability in seed K concentration could be explained by soil K concentrations in the 0 to 5 or 5 to 15 cm depth.

Soybean yields were observed to be the highest in the year when seed K concentration was above 17 g kg^{-1}. Neither soybean yields nor seed K concentrations were ever increased by K fertilizer applications to prior corn when soybean response means were adjusted to initial soil K above 120 mg kg^{-1} at the 5 to 15 cm depth.

With regard to seed quality, both protein and oil concentrations were significantly affected by the previous K fertility treatment in 2002 and 2003 but only to a very small degree that may have little commercial relevance. In general, treatments that involved one or two applications of K fertilizer were associated with a small decrease in seed protein concentration and an increase in oil concentration.

Because soybean yield and quality responses to previous tillage systems for corn including No-till, Fall Chisel and Strip-till were negligible, growers should not be concerned about the effects of the preceding corn tillage system on subsequent no-till soybeans. Furthermore, residual effects of K fertilization on soybean yield and quality were frequently found only at low to medium-K soils, and even then the effects were minor. Overall initial soil K status was a much more important factor affecting soybean yield and quality responses than the residual effects of the previous tillage system or K fertilization.

CHAPTER THREE
NO-TILL SOYBEAN RESPONSES TO ALTERNATE BANDING DEPTHS OF COMBINED P AND K FERTILIZERS IN PRIOR CORN

Abstract

Application of P and K fertilizers to corn in a 2-year cropping sequence (corn–soybean rotation) has been common in conventional tillage systems in the Corn Belt states. Traditional P and K application and placement recommendations designed for soybean under conventional tillage may need to be revised to ensure that P and K nutrition, yield and quality of soybeans will not be restricted under conservation tillage systems.

In 2002 a field study was initiated to determine no-till soybean responses to broadcast and alternate banding depths of combined P and K fertilizers in prior corn. The experiment was repeated in 2003 and 2004 at the same Agronomy Research Farm near West Lafayette, IN. Treatments included two previous corn hybrids, two prior corn populations and five previous fertility treatments including a control (no added P or K other than starter), Broadcast P and K (applied on the surface), Shallow band P and K (applied at a 15 cm depth), Deep band P and K (applied at a 30 cm depth) and Shallow plus Deep P and K (rate was split between the two depths).

The results of this 3-year study show that that previous corn hybrid, previous corn population and previous P and K fertility treatments had no to little influence on no-till soybean yield and quality parameters. At least one of the band applications of P and K

fertilizers (i.e. shallow band, deep band or the combination of both) was not significantly different from the broadcast application in any of the soybean parameters measured. Ultra-deep placement (30cm) was neither worse nor better than broadcast or shallow band placement for soybean response parameters. Band placement of P and K at either 15-cm or 30-cm depth was never inferior to broadcast P and K placement with regards to seed yield or seed quality (i.e. oil and protein content). However, it is equally true that P and K banding at either depth was not beneficial to soybean production even when vertical K stratification was evident and pronounced (i.e. stratification ratios above 1.7).

With regard to seed quality, both protein and oil concentrations were significantly affected by the previous fertility treatments at least in one year of the study but only to a very small degree that may have little commercial relevance.

Soil exchangeable K concentrations at the 0 to 20 cm depth were greater in the previous corn rows than those between previous corn rows, regardless of previous fertility treatment (even when no fertilizer was previously applied), but this doesn't seem to be an availability issue when soybean are planted in 38 cm row widths.

The similar responses of band nutrient placement compared to broadcast placement suggest that no-till soybean growers should not be concerned about which placement method (i.e. broadcast, 15-cm band or 30-cm band) they select for the preceding corn in corn-soybean rotations in soils similar to those of this study. Furthermore, attempts to overcome soil K vertical stratification with deep banding was never beneficial to soybean responses in this study on soils with high organic matter levels and high water holding capacity.

Introduction

Biannual broadcast fertilizer application of P and K fertilizer prior to corn in a corn–soybean rotation has been a common practice in conventional tillage systems in North America. However, because the area of no-till soybean in the Corn Belt has increased markedly since the late 1980s, new questions have been raised concerning the success of applying the nutrient management systems which were originally designed for conventional-till soybean to no-till soybean production. These nutrient management systems may no longer be suitable for narrow-row no-till soybean production.

Relatively immobile nutrients such as P and K remain concentrated in about the upper 5 cm of soil when there is no subsequent mechanical incorporation of the fertilizer, (Cruse et al., 1983; Ketcheson et al., 1980). This stratification of nutrients is a concern because if the upper 5 or 10 cm of soil becomes dry, the surface-applied P and K will become less available to plants.

Published research comparing deep-banding with other placements for no-till soybean is somewhat limited and inconsistent. Research by Eckert and Johnson (1985) and by Yibirin et al. (1993) showed that shallow subsurface banding (5 cm beside and below the seeds) can significantly increase P and K fertilizer use efficiency compared with broadcast fertilizer application for no-till soybean. This result agrees with long known effects of banding in minimizing retention of these nutrients by soil constituents and in increasing fertilizer use efficiency by crops.

Other research (Hairston et al., 1990) showed that deep injection (15-cm depth) of P and K fertilizer gave yield responses superior to broadcast fertilizer applications on no-till soybean in some Mississippi soils testing low in P and K. Research reported by Hudak et al. (1989) showed no K placement effect on yield of no-till soybean grown in a silt loam soil in Ohio. Another study in Iowa by Borges and Mallarino (2000) reported that both deep-banded and planter-banded K fertilizer in no-tillage systems produced slightly higher soybean yield than surface application on optimum to very high-testing soils although the positive response was only significant at 2 locations out of 20. These authors also reported that the positive yield response to banding was not related to soil K levels or degree of soil K stratification. Recent research in Iowa by Buah et al. (2000) showed that no-till soybean responded to surface application at least as well as to planter-banded application, even though significant soil K stratification was evident when soil K levels were in the optimum, high, or very high ranges. More recent research in Ontario, Canada (Yin and Vyn, 2002a) showed that direct subsurface banding of K fertilizer in soybeans often resulted in similar leaf K and seed yield as that after surface broadcast application across all tillage systems used in that study (zone-till, fall disk and no-till).

Most of the published research has been devoted to the effects of direct P and K fertilizer application and placement to soybeans, but fewer reports are available concerning the residual effects of those nutrients on subsequent no-till soybean in corn-soybean rotations. Relevant research showed that no-till soybean yield response to residual fertilizer K (102 kg ha^{-1}) was negligible on high-testing soils with at least ten years of no-tillage management (Buah et al., 2000). However, on fields after six years in ridge till with evident vertical soil K stratification, soybean response to residual deep-banded (10-cm depth) K was evident on a high-testing soil at a high rate (148 kg ha^{-1}) of fall K fertilizer (Rehm, 1995). Research in Ontario, Canada by Yin and Vyn (2002b) concluded that subsequent no-till soybean responded more to residual K fertilizer rate than to application timing, tillage, and K fertilizer placement method in preceding corn.

Research in South Dakota by Bly et al. (1997) regarding P fertilizer management residual effects, concluded that fertilizer P applied as a band to corn was identifiable two years later. The residual fertilizer in these bands increased soybean shoot dry matter weight, shoot P uptake, and seed yield compared to the control treatment (0 kg ha^{-1} of P). However, the authors found that the distance of the band from the soybean row was a more important factor affecting soybean responses than the band P concentration or previously applied P rate. Shoot P uptake and seed yield were significantly increased over the control treatment when the band distance was less than 9 cm from the planted row.

Yin and Vyn (2003b) in more recent research in Ontario, Canada, reported that the extent of soybean responses to direct or residual K application in a corn-soybean rotation may depend on the relative proximity of soybean rows to previous corn rows. They concluded that soybean responses to residual K fertilizer may be greater in those soybean rows that were planted close to where K fertilizer was banded for the prior corn.

None of the reports on soybean response to residual P or K have investigated the effects of different banding depths of these nutrients or the effects of previous corn plant population on the availability of P and K for the subsequent no-till soybean crop.

The primary objective of this study was to determine no-till soybean yield and quality responses to broadcast and alternate banding depths of combined P and K fertilizers in prior corn managed with varying hybrid and population treatments.

Materials and Methods

Site description

In the spring of 2002 a study was initiated at the Purdue Animal Sciences Research and Education Center (ASREC) located near West Lafayette, Indiana (40° 28' N Lat., 86° 59' W Lon.). The research was conducted across a mix of Toronto-Millbrook complex (fine, silty, mesic Udollic Ochraqualf) and Drummer soils (fine, silty, mesic Typic Haploquoll). The Toronto-Millbrook complex is classified as being a somewhat poorly drained, deep soil with 0 to 2 percent slopes and a silt loam texture. The Drummer soil is classified as being a very deep, nearly level, poorly drained soil with a silty clay loam texture.

Cultural practices

The site was in a corn-soybean rotation. In 2002, soybeans were no-till planted on one half of the site and corn on the other. In 2003, these were switched and in 2004 the set up was as in 2002.

Soybeans were no-till planted in 38.1 cm rows using a John Deere 1780 row-crop planter at a seeding rate of 432,000 plants ha^{-1}. The Pioneer variety 93B67 was planted in 2002 and 2003. In 2004 one half of each plot was planted with the previous soybean variety and the other half with Pioneer 96M80 (though only the 93B67 results are discussed here).

During the growing season, weed and insect control products were applied as necessary. Weed control was achieved by one or more post-emergent applications of glyphosate (Round up). For each application, the glyphosate was applied at 2.3 liters ha^{-1}. In August of 2003, λ-cyhalothrin (Warrior) was aerially applied at 270 g ha^{-1}.

The experiment was arranged as a split-split-plot design, as a randomized complete block. There were four replications in 2002, five replications in 2003 and again four replications in 2004. Plot areas were 19.8 x 9.1 m. Two hybrids were randomly assigned to the whole plots, with the two populations being the split plot. Within these, five fertility treatments were randomly assigned. The plot design and treatments are described in more detail below.

Main Plots (2 Prior Hybrids):

1. Pioneer 34B24: 110 CRM, Bt
2. Pioneer 34M95: 110 CRM, Bt

Sub-Plots (2 Prior populations)

1. 79,000 plants ha^{-1}
2. 104,000 plants ha^{-1}

Sub-Sub-Plots (5 Prior Fertility Treatments):

1. Control: no added P or K other than starter
2. Broadcast P and K: applied on the surface and lightly incorporated
3. 15 cm Band P and K
4. 30 cm Band P and K
5. 15 + 30 cm Band P and K: rate was split between the two depths

The rates of P and K for all treatments, excluding the control, were 99 kg ha^{-1} P_2O_5 and 129 kg ha^{-1} K_2O. Phosphorous fertilizer was applied as 0-46-0 and K was applied as muriate of potash (0-0-60) before planting. All banded treatments were applied at the appropriate depth(s) with a Gandy distribution system attached to a strip tillage implement (DMI Nutriplacr 2500); either fall or spring strip tillage was applied to all fertility treatments even if fertilizer was not banded.

Soil measurements

Soil samples were taken in mid-June of each year. Sampling was done in two different positions within each plot. Those positions were in the previous corn rows and between the previous corn rows. All plots were sampled by bulking 10-12 soil cores per plot per position. These were sub-divided into three depth-intervals: 0-10, 10-20 and 20-40 cm. These were sent to an independent laboratory and analyzed for organic matter, available phosphorus (using Mehlich 3), exchangeable potassium, magnesium, soil pH, Mg and Ca. Table 3-1 shows the mean soil chemical properties for the experimental sites in 2002, 2003 and 2004.

Table 3-1. Summary of soil chemical properties in 2002, 2003 and 2004.

Depth	OM (%)	pH	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})
			2002			
0-10 cm	3.5	6.5	46 (24.2)	181 (26.4)	671	2481
10-20 cm	3.5	6.3	26 (32.0)	134 (14.8)	610	2451
20-40 cm	--	--	13 (35.8)	129 (10.8)	663	2621
			2003			
0-10 cm	4.0	6.6	40 (36.8)	209 (28.3)	702	2821
10-20 cm	3.9	6.7	24 (40.6)	129 (16.9)	720	2913
20-40 cm	--	--	18 (44.3)	119 (17.2)	748	2990
			2004			
0-10 cm	3.7	6.9	32 (34.0)	192 (24.1)	731	2531
10-20 cm	3.6	6.5	23 (32.6)	115 (15.4)	645	2480
20-40 cm	--	--	14 (54.2)	109 (18.3)	670	2580

Organic matter and pH values were obtained only for the first two depth intervals. Values in parenthesis are coefficients of variation.

Soybean measurements

Plant measurements include R1-stage leaf nutrient concentrations, seed yield, seed moisture, oil content, protein content, and seed nutrient concentrations.

Leaf nutrient concentrations were sampled when 50% of the plants were at the first reproductive stage (R1). Twenty fully expanded trifoliolate leaves were taken to make a composite sample in each plot. These composite samples were then dried in a 40ºC oven and subsequently ground through a 1 mm sieve by a rotary blade grinder (Thomas Wiley Mill Model ED-5, Arthur H. Thomas Co. Phila, PA. USA). The ground samples were then sent to an independent laboratory and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, manganese, copper and zinc.

Seed yield was obtained using a plot combine. The four central soybean rows of each plot were harvested and then weighted. Seed yield values were then adjusted to the standard moisture content of 130 g kg^{-1}.

Seed moisture was measured by collecting a sample from each plot. This sample was subsequently run through a Motomco Moisture Meter (Motomco Inc., Electronics Div., Cark N.J.) to obtain moisture values used in subsequent yield calculations and statistical analyses.

Seed quality (oil and protein content) was also determined on the soybean samples collected from each plot. Seed concentrations were obtained through near infrared analysis via an InfratecR 1229 Whole Grain Analyzer. Near infrared (NIR) analysis is extensively used for routine compositional testing of seed. The standard analyses given by the InfratecR analysis are moisture, oil, fiber, and protein content. These values were then adjusted to the standard moisture content of 130 g kg^{-1} for oil and protein by using the formula CDB = 100*(CM/100-M) or CM = (CDB (100-M))/100, where CM=current moisture, M=percent moisture desired and, CDB=percent component (oil or protein) (Maier and Briggs, 1997). Seed oil and protein concentration values were available for the last two years of the study (i.e. 2003 and 2004).

Seed nutrient concentrations were derived for each of the samples from each plot. A subsample of approximately 50 grams was taken from each seed quality sample and dried in an oven at 60ºC. The sample was then ground using a rotary blade grinder (Thomas Wiley Mill Model ED-5, Arthur H. Thomas Co. Phila, PA, USA) and forced through a 2 mm sieve. The ground samples were then sent to an independent laboratory and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, manganese, copper and zinc.

Statistical analysis

The statistical analyses were accomplished using Statistical Analysis Software (SAS) version 9.1 (SAS Institute, Inc., Cary, North Carolina). Analysis of variance for the split-split plot was performed for both available P and exchangeable K from soil at three depths (0-10, 10-20 and 20-40 cm) and for two positions (in the previous corn row and between the previous corn row). The same split-split plot analysis – but without regard for corn row position - was performed for R1 leaf K content, R1 leaf P content, seed yield, seed K content, seed P content, seed oil content and seed protein content.

Comparisons across years were done when possible. Mean separation tests were performed according to Tukey (α=0.05)

Results and Discussion

Soil fertility concentrations

Soil available P at two different positions and at three different depths was analyzed as a response variable across prior fertility treatments. Prior hybrid had no significant effect on the soil available P at either of the two sampling positions, nor at any of the three different depths (data not shown, Appendix C-2).

Table 3-2 shows soil available P concentrations measured at the in-row position as affected by prior corn fertility treatments in 2002, 2003 and 2004. In 2002, prior corn fertility treatment had no effect on soil available P at any of the three depth intervals. In 2003, differences were found at the 0 to 10 and at the 20 to 40 cm depth intervals. Within the first depth interval, the broadcast treatment resulted in the highest P concentration and it was significantly different from the rest of the treatments. At the 20 to 40 cm depth interval, the shallow band and the shallow plus deep treatment resulted in the highest P concentration. The shallow plus deep band was significantly different from the control, the broadcast and the deep band treatment. However, the shallow band treatment was only different from the control.

In 2004, soil P concentration differences were found for all three depth intervals. At the 0 to 10 cm depth interval, the broadcast treatment resulted in the highest P value and it was significantly different from the rest of the treatments. At the 10 to 20 cm depth interval, the shallow band treatment was the highest and significantly different from the rest of the treatments. Finally, for the 20 to 40 cm depth interval, the deep band treatment resulted in the highest P concentration and it was significantly different from the rest of the treatments.

Table 3-2. Soil available P concentrations measured at the in-row position as affected by prior corn fertility treatments in 2002, 2003 and 2004.

Year	Fertility treatment	Depth 0-10 cm	10-20 cm	20-40 cm
		-------Soil P concentration (mg kg^{-1})-------		
2002	Control	46	26	13
	Broadcast P&K	52	24	13
	Shallow band P&K	46	29	13
	Deep band P&K	46	27	13
	Shallow+Deep	45	27	14
2003	Control	39 b	23	14 c
	Broadcast P&K	48 a	26	19 bc
	Shallow band P&K	37 b	24	22 ab
	Deep band P&K	35 b	21	19 bc
	Shallow+Deep	39 b	25	25 a
2004	Control	29 b	20 b	11 b
	Broadcast P&K	41 a	20 b	11 b
	Shallow band P&K	28 b	31 a	12 b
	Deep band P&K	31 b	23 b	21 a
	Shallow+Deep	29 b	22 b	15 b

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Soil available P at the between-row position and measured at the 0 to 10 cm depth interval was affected by the interaction of prior corn population with prior fertility treatments (Table 3-3). In 2002, and within the low prior corn population (79,000 plants ha^{-1}), the broadcast treatment resulted in the highest P concentration and it was significantly different from all other treatments but the control. Within the high prior corn population (104,000 plants ha^{-1}), the broadcast treatment resulted in the highest P concentration and it was significantly different from all other treatments without exception.

In 2003 no soil available P differences were found within the low prior corn population. Within the high population, the broadcast treatment resulted in the highest P concentration and it was significantly different from the rest of the treatments. Furthermore, the control and the shallow plus deep band treatment were significantly different from the shallow band and the deep band treatment.

In 2004 and within the low prior corn population, the broadcast treatment resulted in the highest P concentration but in this case it was only significantly different from the shallow plus deep band treatment. In contrast, within the high prior corn population broadcasting was significantly different from all the rest of the treatments.

Table 3-3. Soil available P concentrations at the 0 to 10 cm depth interval, measured at the between-row position, as affected by prior corn population and fertility treatments in 2002, 2003 and 2004.

Year	Fertility treatment	Population 79,000 pl ha^{-1}	Population 104,000 pl ha^{-1}
		-------Soil P concentration (mg kg^{-1})-------	
2002	Control	44.5 ab	44.6 b
	Broadcast P&K	51.9 a	56.0 a
	Shallow band P&K	40.4 b	44.6 b
	Deep band P&K	42.5 b	42.5 b
	Shallow+Deep	39.9 b	42.8 b
2003	Control	43.6	35.3 bc
	Broadcast P&K	43.8	50.0 a
	Shallow band P&K	40.0	32.8 c
	Deep band P&K	39.8	32.2 c
	Shallow+Deep	37.0	41.4 b
2004	Control	31.0 ab	30.0 b
	Broadcast P&K	35.9 a	44.3 a
	Shallow band P&K	29.4 ab	29.9 b
	Deep band P&K	28.6 ab	32.4 b
	Shallow+Deep	26.3 b	33.6 b

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Soil available P at the between-row position and measured at the 10 to 20 and at the 20 to 40 cm depth intervals was affected by the interaction of prior corn population with prior fertility treatments but there were no significant year effects at these depths. Table 3-4 shows the soil available P concentration at the 10 to 20 and 20 to 40 cm depth intervals measured at the between-row position as affected by prior corn population and fertility treatments across years. Within the low prior corn population, differences were only apparent at the 20 to 40 cm depth interval. At that depth, the deep band treatment resulted in the highest P concentration, but it was only significantly different from the broadcast treatment.

Within the high prior corn population, differences were observed at both depth intervals. At the 10 to 20 cm depth interval, the broadcast treatment resulted in the highest P concentration but it was only significantly different from the deep band treatment and the control. At the 20 to 40 cm depth interval, the broadcast treatment resulted again in the highest P concentration but in this case it was significantly different from the shallow band treatment and the control.

Table 3-4. Soil available P concentrations at the 10 to 20 and 20 to 40 cm depth intervals, measured at the between-row position, as affected by prior corn population and fertility treatments across years.

Depth	Fertility treatment	Population 79,000 pl ha^{-1}	104,000 pl ha^{-1}
		------Soil P concentration (mg kg^{-1})------	
10-20 cm	Control	23.6	22.6 b
	Broadcast P&K	20.8	28.1 a
	Shallow band P&K	22.7	24.7 ab
	Deep band P&K	23.5	22.1 b
	Shallow+Deep	22.9	26.6 a
20-40 cm	Control	13.1 ab	12.9 b
	Broadcast P&K	12.3 b	16.8 a
	Shallow band P&K	14.4 ab	12.6 b
	Deep band P&K	15.4 a	15.1 ab
	Shallow+Deep	12.7 ab	16.4 a

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Soil exchangeable K at two different positions and at three different depths was also analyzed as a response variable across prior fertility treatments. Prior hybrid had no significant effect on the soil exchangeable K at either of the two different positions, nor at any of the three different depths (data not shown, Appendix C-2).

Soil exchangeable K concentrations measured at the in-row position as affected by prior corn fertility treatments in 2002, 2003 and 2004 are presented in Table 3-5.

In 2002, differences among treatments were significant only at the shallowest depth interval. At that depth, the broadcast treatment resulted in the highest K concentration and it was significantly different from the shallow band treatment and the control.

In 2003, differences among treatments were observed at both the shallowest and at the deepest depth intervals. At the shallowest depth, the broadcast treatment resulted in the highest K concentration and it was significantly different from all the rest of the treatments but the shallow plus deep band treatment. The latter was also different from the rest of the treatments. At the 20 to 40 cm depth interval, the shallow plus deep band treatment resulted in the highest K concentration and it was significantly different from all the rest of the treatments but the shallow band treatment.

In 2004, differences were only found at the 0 to 10 cm depth interval. At that depth, the broadcast treatment resulted in the highest K concentration and it was significantly different from the shallow band treatment and the control, but not from the rest of the treatments. Furthermore, the deep band and the shallow plus deep band were also significantly different from the control.

Table 3-5. Soil exchangeable K concentrations measured at the in-row position as affected by prior corn fertility treatments in 2002, 2003 and 2004.

Year	Fertility treatment	Depth 0-10 cm	10-20 cm	20-40 cm
		-------Soil K concentration (mg kg^{-1})-------		
2002	Control	213 b	137	131
	Broadcast P&K	237 a	140	132
	Shallow band P&K	212 b	145	129
	Deep band P&K	227 ab	142	126
	Shallow+Deep	218 ab	145	133
2003	Control	241 b	133	119 b
	Broadcast P&K	263 a	137	120 b
	Shallow band P&K	224 bc	132	121 ab
	Deep band P&K	220 c	126	119 b
	Shallow+Deep	243 b	132	129 a
2004	Control	180 c	110	100
	Broadcast P&K	222 a	123	108
	Shallow band P&K	199 bc	122	107
	Deep band P&K	220 ab	116	107
	Shallow+Deep	206 ab	119	115

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Soil exchangeable K at the between-row position for the 0 to 10 cm depth interval was affected by the prior fertility treatments (Table 3-6). In 2002, the broadcast treatment resulted in the highest K concentration and it was significantly different from all the rest of the treatments. In 2003, the broadcast treatment resulted again in the highest K concentration and it was significantly different from all the rest of the treatments but the control. In 2004, results were the same as the first year. The broadcast treatment resulted in the highest K concentration and it was significantly different from all the rest of the treatments.

Table 3-6. Soil exchangeable K concentrations at the 0 to 10 cm depth interval measured at the between-row position as affected by prior corn fertility treatments in 2002, 2003 and 2004.

Fertility treatment	2002	2003	2004
	------Soil K concentration (mg kg^{-1})------		
Control	136.7 b	182.1 ab	161.1 b
Broadcast P&K	158.9 a	189.2 a	213.8 a
Shallow band P&K	132.5 b	174.1 bc	168.3 b
Deep band P&K	138.3 b	166.8 c	179.1 b
Shallow+Deep	136.1 b	177.9 bc	167.7 b

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Soil exchangeable K at the between-row position, and measured at the 10 to 20 and at the 20 to 40 cm depth intervals, was affected by the interaction of prior corn population with prior fertility treatments in an apparently similar fashion each year (as there was no significant year interaction effects). Table 3-7 shows the soil exchangeable K concentration at the 10 to 20 and 20 to 40 cm depth intervals measured at the between-row position as affected by prior corn population and fertility treatments across years. Treatment differences were observed at the same depths, and within the same prior corn population, as for available P concentrations. Within the low prior corn population, fertility treatment differences were only found at the 20 to 40 cm depth interval. At that depth, the control treatment resulted in the highest K concentration and it was significantly different from the shallow band and the deep band treatment but not from the broadcast or the shallow plus deep treatment. Within the high prior corn population, differences were found at both depth intervals. At the 10 to 20 cm depth interval, the shallow plus deep band treatment resulted in the highest K concentration (although it was only significantly different from the deep band treatment and from the control). At the 20 to 40 cm depth interval, the shallow plus deep band treatment again resulted in the highest K concentration but in this case it was significantly different from the control, shallow band treatment and the deep band treatments. Lower concentration values for the control at higher populations and at both depth intervals suggests that K loss was more evident, presumably because of more uptake (with expanded leaf area).

Table 3-7. Soil exchangeable K concentrations for the 10 to 20 and 20 to 40 cm depth intervals, measured at the between-row position, as affected by prior corn population and fertility treatments (mean of 2002-2004).

Depth	Fertility treatment	Population	
		79,000 pl ha^{-1}	104,000 pl ha^{-1}
		------Soil K concentration (mg kg^{-1})------	
10-20 cm	Control	124.2	115.9 b
	Broadcast P&K	124.9	125.3 a
	Shallow band P&K	119.4	122.7 ab
	Deep band P&K	121.8	116.2 b
	Shallow+Deep	120.6	126.1 a
20-40 cm	Control	122.4 a	109.3 c
	Broadcast P&K	121.4 ab	118.5 ab
	Shallow band P&K	113.3 c	113.8 bc
	Deep band P&K	115.5 bc	113.1 bc
	Shallow+Deep	117.9 abc	122.3 a

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

For all three years of the study, vertical soil K stratification was evident. Soil K concentrations at the surface layer averaged 1.7 times higher than K levels at the 10 to 20 depth interval. Horizontal stratification was also evident in the near-surface soil samples. At the in-row position, soil exchangeable K concentrations averaged 27 to 81 mg kg^{-1} higher than between-row samples for the 0 to 10 cm depth interval. Horizontal stratification was less evident for soil depth increments below 10 cm.

These higher values of soil-test K in the row sampling position compared to those between rows are in agreement with those reported by Varsa and Ebelhar (2000) and Yin and Vyn (2003b). Both studies found that all fertilizer placement methods including the broadcast treatment (other methods were surface band, surface dribble and starter) resulted in higher soil K levels near the corn row compared to soil near the middle of the row. This was an indication that K was leached near the previous row after corn plants had reached maturity. These results were similar to those reported by Tyler and Howard (1991) for no-till corn.

With regards to vertical soil P stratification, the ratio between soil-test P at the 0 to 10 cm depth interval with the concentration at the 10 to 20 cm depth interval was similar to the K ratio (i.e. surface concentrations 1.6 times higher that the subsurface values). However in this case, horizontal stratification was not evident in the near-surface soil samples. At the in-row position, soil available P concentrations averaged 39.4 mg kg^{-1} while at the between-row position they averaged 38.9 (i.e. ratio almost equal to 1).

This study introduced an issue that may not have been reported before. This study's soil results showed a significant interaction effect of previous fertility treatments with previous corn populations on P and K availability measured at the between-row position. However, results were not consistent between P and K. With regards to soil-test P, results showed that the broadcast treatment resulted in higher values with high prior corn populations compared to those of lower corn populations. In contrast, that doesn't seem to be the case for soil-test K. With regards to this nutrient, lower concentration values at deeper depth intervals (10-20 and 20-40 cm) for the control at higher populations, compared to those for lower populations, suggests that K loss was more evident, presumably because of more uptake (with expanded leaf area and, perhaps, higher shoot dry matter).

Broadcasting almost always resulted in higher levels of surface P and K concentrations compared to banding, measured in the prior corn row position and in the between-row position. Phosphorus and potassium availability in the surface soil layer for the subsequent no-till soybeans might be higher the following year when fertilizers were previously broadcast applied and if water deficient-periods do not occur.

R1 nutrient analysis

Leaf P and K concentrations at the R1 growth stage indicates the levels of soybean P and K nutrition at early growth stages. Comparisons among treatments and across years were performed when possible.

Table 3-8 shows the effects of prior fertility treatments on leaf P concentrations measured at the R1 growth stage in 2002, 2003 and 2004. For all three years, there was no significant effect of either the previous corn hybrid or the previous corn population on leaf P concentrations. Previous fertility treatments were significantly different for leaf P concentrations only in 2003, when the broadcast P&K treatment and the shallow plus deep band treatments resulted in highest leaf P concentrations. These two treatments were significantly different from the control, the shallow band and the deep band treatments. No prior fertility effects on leaf P were observed in 2002 or 2004. In general, results in 2003 are in agreement with those reported by Buah et al. (2000) who found that banding and direct application of P generally increase leaf P concentrations at early bloom. However, in their study fertilizer application was directly to the soybean crop, whereas only residual P fertilizer placement effects were measured in the present study.

Table 3-8. Leaf P concentration at the R1 growth stage as affected by prior fertility treatments in 2002, 2003 and 2004.

Fertility treatment	2002	2003	2004
	------------Leaf P concentration (g kg^{-1})------------		
Control	4.2	3.6 b	4.6
Broadcast P&K	4.2	4.1 a	4.7
Shallow band P&K	4.2	3.7 b	4.5
Deep band P&K	4.2	3.6 b	4.7
Shallow+Deep	4.2	4.1 a	4.6

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Table 3-9 shows the effect of prior corn hybrid and prior fertility treatments on leaf K concentrations measured at the R1 growth stage. Significant treatment effects were found in all three years of the experiment. However, in 2002, effects of prior fertility treatments were found only within prior corn hybrid Pioneer 34B24. Within that hybrid, all the fertility treatments were significantly different from the control but not different from each other. In 2003, effects of prior fertility treatments were significant following both prior corn hybrids. Within hybrid Pioneer 34B24, the broadcast P&K treatment was significantly different from the control and the shallow plus deep band treatment. However, it was not different from the shallow band or from the deep band treatment. Within hybrid Pioneer 34M95, the broadcast P&K treatment, the shallow band and the shallow plus deep band resulted in the highest leaf K concentrations. Those treatments, except for the shallow band, were significantly different from the control and from the deep band treatment.

In 2004, and within hybrid Pioneer 34B24, the broadcast P&K and the deep band treatments resulted in the highest leaf K concentrations. These treatments were significantly different from the control, the shallow band and the shallow plus deep band treatments. Within hybrid Pioneer 34M95, the broadcast P&K and the shallow plus deep band were significantly different from the control, but the shallow band and the deep band were not.

Table 3-9. Leaf K concentration at the R1 growth stage as affected by prior corn hybrids and prior fertility treatments in 2002, 2003 and 2004.

Fertility treatment	2002	2003	2004
	Previous Corn Hybrid		
	Pioneer 34B24		
	------------Leaf K concentration (g kg^{-1})------------		
Control	17.0 b	18.9 b	22.8 b
Broadcast P&K	19.2 a	21.1 a	26.8 a
Shallow band P&K	17.8 a	20.0 ab	22.8 b
Deep band P&K	18.0 a	19.7 ab	25.2 a
Shallow+Deep	18.0 a	18.6 b	23.0 b
	Pioneer 34M95		
	------------Leaf K concentration (g kg^{-1})------------		
Control	18.6	17.6 b	22.3 b
Broadcast P&K	18.4	19.7 a	24.5 a
Shallow band P&K	18.3	19.0 ab	23.6 ab
Deep band P&K	18.3	17.8 b	23.6 ab
Shallow+Deep	17.7	19.6 a	24.2 a

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Results of this experiment are generally in agreement with those reported by Yin and Vyn (2003a) who found that 15-cm band and surface broadcast placements in prior corn were similar in their residual effects on soybean leaf K at the initial flowering stage. Furthermore, leaf concentration differences between banding depths were apparent only for 1 year out of 3, and then only within just one of the prior corn hybrids.

In previous research Small and Ohlrogge (1973) determined that plant sufficiency ranges were 2.6 to 5 g kg^{-1} for P and 17.1 to 25 g kg^{-1} for K. More recent research by Yin and Vyn (2004) suggested that critical leaf K concentration for no-till soybean was 24 g kg^{-1}. Leaf P and K concentrations in this study were generally within the accepted sufficiency range even when significant differences in leaf P and K concentrations were observed among previous fertility treatments. Thus it is unlikely that the differences observed were likely to affect soybean yield. However, if overall soil P and K concentrations had been lower, there may have been significant leaf deficiencies for the control treatment that would have been a factor in yield reductions.

Furthermore, there might be a benefit from broadcast compared to band placement of fertilizers with regards to P and K nutrition at those early growth stages. Banding tended to result in lower R1 leaf P and K concentrations in some years, but not all. That might be a potential disadvantage of banding even though it was no worse after 30 cm banding than with 15-cm banding.

Soybean yield

Overall soybean yields were very high (well above comparable state averages) in all 3 years. Previous corn hybrid, previous corn population and previous P and K fertility treatments had no significant influence on no-till soybean yield response in any of the three years of the study. Table 3-10 shows mean seed yields for different previous fertility treatments in all three years.

Table 3-10. Seed yield as affected by prior fertility treatments in 2002, 2003 and 2004.

Fertility treatment	2002	2003	2004
	-----------------Seed yield (Mg ha^{-1}) -----------------		
Control	4.65	4.40	5.11
Broadcast P&K	4.68	4.62	5.22
Shallow band P&K	4.69	4.52	5.11
Deep band P&K	4.63	4.57	5.16
Shallow+Deep	4.70	4.48	5.12

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

These results were expected for two main reasons. First, soil available P and soil exchangeable K were, for the three years of the study, generally above the critical soil test levels for soybeans reported in the Tri-state Fertilizer Recommendations bulletin for corn, soybeans, wheat and alfalfa (Extension Bulletin E-2567, Rep. August 1996). Those critical soil test levels are 15 mg kg^{-1} for P and 150 mg kg^{-1} for K for a soil with a CEC of 30 meq 100 g^{-1} or above. Second, leaf P and K concentrations at early bloom were within the sufficiency range reported by Small and Ohlrogge (1973). Those ranges were 2.6 to 5 g kg^{-1} for P and 17.1 to 25 g kg^{-1} for K. At the R1 growth stage, leaf P and K concentrations in this study were always within the sufficiency range even when differences among previous fertility treatments were found to have statistically significant effects on leaf P and K concentrations.

Still the results also suggest that there were no negative yield effects associated with very deep banding of P and K even when soybeans are planted in 38-cm narrow rows.

Seed nutrient and composition analysis

Table 3-11 and 3-12 show the effects of the prior corn hybrid by prior population interaction and the effects of prior fertility treatments on seed P concentration. The prior corn hybrid by prior population interaction effect was only apparent in 1 year out of 3. Within corn hybrid Pioneer 34M95 the low corn population resulted in a significantly higher value of seed P concentration. No significant seed P differences were observed for the other hybrid or during the other 2 years of the experiment.

Table 3-11. Seed P concentration as affected by prior corn hybrids and prior corn population in 2002, 2003 and 2004.

Prior corn population	2002	2003	2004
	Previous Corn Hybrid		
	Pioneer 34B24		
	-----------Seed P concentration (g kg^{-1})------------		
79,000 pl ha^{-1}	4.9	5.2	5.1
104,000 pl ha^{-1}	5.1	5.1	4.9
	Pioneer 34M95		
	-----------Seed P concentration (g kg^{-1})------------		
79,000 pl ha^{-1}	5.2 a	5.2	5.1
104,000 pl ha^{-1}	4.9 b	5.3	5.3

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

With regards to the effect of previous fertility treatments on seed P concentration, results across years show that both the broadcast P&K treatment and the shallow band treatment resulted in significant higher seed P concentrations compared to the control, the deep band treatment and the shallow plus deep treatment.

Table 3-12. Seed P concentrations as affected by prior fertility treatments across years.

Fertility treatment	---- Seed P concentration (g kg^{-1})----
Control	5.1 b
Broadcast P&K	5.2 a
Shallow band P&K	5.2 a
Deep band P&K	5.1 b
Shallow+Deep	5.1 b

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Table 3-13 and 3-14 show the effects of the prior corn hybrid by prior population interaction and the effects of prior fertility treatments on seed K concentration. As for seed P concentration, the prior corn hybrid by prior population interaction effect was only apparent in 1 year out of 3. In 2003 and within corn hybrid Pioneer 34B24 the low corn population resulted in a significantly higher value of seed K concentration. No differences were found for the other hybrid or for the other 2 years of the experiment.

Table 3-13. Seed K concentration as affected by prior corn hybrids and prior corn population in 2002, 2003 and 2004.

Prior corn population	2002	2003	2004
	Previous Corn Hybrid		
	Pioneer 34B24		
	------------Seed K concentration (g kg^{-1})------------		
79,000 pl ha^{-1}	18.9	17.3 a	18.9
104,000 pl ha^{-1}	19.2	16.8 b	18.4
	Pioneer 34M95		
	------------Seed K concentration (g kg^{-1})------------		
79,000 pl ha^{-1}	19.3 a	16.9	18.8
104,000 pl ha^{-1}	18.7 b	17.3	19.1

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

With regards to the effect of previous fertility treatments on seed K concentration, differences were apparent only in 1 year out of 3. In 2004, results showed that all fertility treatments were significantly different from the control, but no differences were apparent among them.

Table 3-14. Seed K concentration as affected by prior fertility treatments in 2002, 2003 and 2004.

Fertility treatment	2002	2003	2004
	------------Seed K concentration (g kg^{-1})------------		
Control	18.9	17.1	18.3 b
Broadcast P&K	19.2	17.2	18.9 a
Shallow band P&K	19.0	17.1	18.9 a
Deep band P&K	18.9	17.0	18.9 a
Shallow+Deep	19.0	17.1	18.9 a

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

In general these results are in agreement with those reported by Yin and Vyn (2002a) who showed that there was a frequent increase on seed K concentrations due to residual effects of K fertilizer applied to the previous corn. For this study, broadcast fertilizer application was never superior to shallow band. Differences between deep band and shallow band were only apparent on seed P content but then the difference was very small (0.1 g kg^{-1}).

Table 3-15 shows the effect of prior fertility treatment on seed oil concentration. Seed oil concentration was not affected by prior corn hybrid or by prior corn hybrid population. Comparisons across years were not possible in this analysis. In 2003, the control and the shallow band treatment resulted in the highest seed oil concentrations. Furthermore, they were significantly different from all the rest of the treatments. In 2004, no differences were found among previous fertility treatments. The slight differences found in 2003 were too small to be of commercial significance.

Table 3-15. Seed oil concentration as affected by prior fertility treatments in 2003 and 2004.

Fertility treatment	Year	
	2003	2004
	---Seed oil concentration (g kg^{-1})---	
Control	179.5 a	169.3
Broadcast P&K	177.8 b	169.8
Shallow band P&K	179.5 a	168.9
Deep band P&K	178.2 b	169.6
Shallow+Deep	178.2 b	169.2

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Table 3-16 shows the effect of prior fertility treatment on seed protein concentration. Seed protein concentration was not affected by prior corn hybrid or by prior corn hybrid population. Comparisons across years were not possible in this analysis. In 2003, no differences were found among previous fertility treatments. In 2004, the control resulted in the highest seed protein concentrations. However, this treatment was only significantly different from the broadcast P& K but not from the rest of the treatments.

Table 3-16. Seed protein concentration as affected by prior fertility treatments in 2003 and 2004.

Fertility treatment	Year 2003	Year 2004
	---Seed protein concentration (g kg^{-1})---	
Control	344.9	368.7 a
Broadcast P&K	346.7	365.4 b
Shallow band P&K	344.9	367.2 ab
Deep band P&K	346.9	366.5 ab
Shallow+Deep	346.9	366.9 ab

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Results in 2003 for seed oil concentration and in 2004 for seed protein concentration agree in direction of response, but to a lesser extent, with those reported Yin and Vyn (2003a) who found that although both seed oil and protein concentrations were affected by K fertilizer applications, the range of changes in those quality parameters with K fertilization was small.

The results obtained in this study are also in agreement with more recent research by Mallarino et al. (2005) that reported that the application of fertilizer P and K seldom affected soybean seed oil and protein concentrations. Even when there was a significant fertilization effect on seed oil and protein concentration, the responses were small.

Conclusions

The results of this 3-year study show that previous corn hybrid, previous corn population and previous P and K fertility treatments had no influence to little influence on no-till soybean yield and quality parameters. At least one of the band applications of P and K fertilizers (i.e. shallow band, deep band or the combination of both) was not significantly different from the broadcast application in any of the soybean parameters measured. Ultra-deep placement (30cm) was neither worse nor better than broadcast or shallow band placement for soybean response parameters. Band placement of P and K at either 15-cm or 30-cm depth was never inferior to broadcast P and K placement with regards to seed yield or seed quality (i.e. oil and protein content) even when soil P and K concentrations near the surface (especially between-row) were lower with banded treatments. However, it is equally true that P and K banding at either depth was not beneficial to soybean production even when vertical K stratification was evident and pronounced (i.e. stratification ratios above 1.7). It won't be fair to generalize from this to all soil environments in Indiana. Since overall soybean yields were well above normal at this site, it is possible that P and K placement effects may have had more influence at less productive sites, or if there had been more drought stress during the growing seasons.

With regard to seed quality, both protein and oil concentrations were significantly affected by the previous fertility treatments at least in one year of the study but only to a very small degree that may have little commercial relevance.

Soil exchangeable K concentrations at the 0 to 20 cm depth were greater in the previous corn rows than those between previous corn rows, regardless of previous fertility treatment (even when no fertilizer was previously applied), but this doesn't seem to be an issue when soybean are planted in 38 cm row widths. In contrast, when narrower rows are planted (i.e. 19 cm) this horizontal stratification might be a concern for soybean K nutrition. Horizontal differences in soil K concentration might be more evident particularly when corn rows are continuously planted close to previous rows and when nutrients are banded instead of broadcast applied.

The similar responses of band nutrient placement compared to broadcast placement suggest that no-till soybean growers should not be concerned about which placement method (i.e. broadcast, 15-cm band or 30-cm band) they select for the preceding corn in corn-soybean rotations in soils similar to those of this study. It appears to be little merit in future testing of residual fertility placement options following multiple corn hybrids and plant populations.

Furthermore, attempts to overcome soil K vertical stratification with deep banding was never beneficial to soybean responses in this study on soils with high organic matter levels and high water holding capacity.

CHAPTER FOUR
NO-TILL SOYBEAN RESPONSES TO BROADCAST K FERTILIZER FOLLOWING BANDED VS. BROADCAST P AND K COMBINATIONS IN PRIOR CORN

Abstract

Biannual broadcast fertilizer application of P and K fertilizer prior to corn in a corn–soybean rotation has been a common practice in conventional tillage systems in the Corn Belt states. This nutrient management approach may no longer be appropriate for narrow-row no-till soybean production, particularly if P and K fertilizers are deep banded.

In 2003, a field study was initiated to determine no-till soybean responses to broadcast K fertilizer following banded versus broadcast P&K combinations in prior corn. The experiment was repeated in 2004 at the same Agronomy Research Farm near West Lafayette, IN. Soil available P concentrations ranged from very high in 2003 to medium in 2004, while soil exchangeable K concentrations were medium in both years. Treatments included two previous corn hybrids and previous five fertility treatments including a control (no added P or K other than starter), Broadcast P and K (applied on the surface), Band P and K (applied at a 15 cm depth), Band P (applied at a 15 cm depth) and Band K (applied at a 15 cm depth). Fall strip tillage on 76-cm centers took place on prior to corn for all five fertility treatments. Before soybean planting, no tillage operations occurred, but each split plot was subdivided in two. One half received broadcast fertilizer K and the other half did not.

The results of this 2-year study show that previous corn hybrid and previous P and K fertility treatments had little influence or no influence on no-till soybean response parameters. Band placement of P and K together was never superior to broadcast P and K placement with regards to seed yield or seed quality (i.e. oil and protein content) even when soil K stratification in the upper 20 cm was evident and pronounced (i.e. stratification ratios above 1.5).

Direct broadcast application of K fertilizer before soybean planting had no effect on soybean parameters when both P and K were applied to the prior corn crop. These results suggest that the biannual application of K fertilizer seems to be adequate on these soils, and that there was little benefit from a pre-planting broadcast K application.

Previous application of K fertilizer without any addition of P fertilizer resulted in yield values similar to the control (no added P or K). Lower seed yield results from the banded K treatment might show the importance of balanced nutrition (i.e. balanced between available P and exchangeable K in the rooting profile).

With regard to seed quality, both protein and oil concentrations were significantly affected by the previous fertility treatments but only to a very small degree that may have little commercial relevance.

Soil exchangeable K concentrations at the 0 to 20 cm depth were greater in the previous corn rows than those between previous corn rows, regardless of previous fertility treatment (even when no fertilizer was previously applied), but this doesn’t seem to be a concern when soybean are planted in 38 cm row widths.

Similar soybean responses to banded nutrient placement compared to broadcast placement suggest that no-till soybean growers should not be concerned about which placement method they select for the preceding corn crop in corn-soybean rotations.

Introduction

Phosphorus and potassium fertilizer application to corn in a 2-year cropping sequence (corn–soybean rotation) has been common in conventional tillage systems in North America. However, because the area of no-till soybean in the Corn Belt has increased markedly since the late 1980s, new questions have been raised concerning the success of applying the nutrient management systems which were originally designed for conventional-till soybean to no-till soybean production. Traditional P and K management recommendations designed for soybean under conventional tillage may need to be revised to ensure that P and K nutrition, yield and quality of soybeans will not be restricted under conservation tillage systems.

Conservation tillage systems may have more vertical nutrient stratification due to continual broadcast application of soil nutrients on the surface without subsequent incorporation (Vyn and Janovicek, 2001; Crozier et al., 1999). Without mechanical incorporation of the fertilizer, relatively immobile nutrients such as P and K remain concentrated in about the upper 5 cm of soil (Cruse et al., 1983; Ketcheson et al., 1980). This stratification of nutrients is a concern because if the upper 5 cm of soil becomes dry, the surface-applied P and K will become less available to plants.

Published research comparing deep-banding with other placements for no-till soybean is somewhat limited and inconsistent. Previous research (Eckert and Johnson, 1985; Yibirin et al., 1993) showed that shallow subsurface banding (5 cm beside and below the seeds) can significantly increase P and K fertilizer use efficiency compared with broadcast fertilizer application for no-till soybean. This result agrees with long known effects of banding in minimizing retention of these nutrients by soil constituents and in increasing fertilizer use efficiency by crops.

Hairston et al. (1990) showed that deep injection (15-cm depth) of P and K fertilizer gave yield responses superior to broadcast fertilizer applications on no-till soybean in some Mississippi soils testing low in P and K. Other research (Hudak et al., 1989) showed no K placement effect on yield of no-till soybean grown in a silt loam soil in Ohio. Research in Iowa by Borges and Mallarino (2000) reported that both deep-banded and planter-banded K fertilizer in no-tillage systems produced slightly higher soybean yield than surface application on optimum to very high-testing soils although the positive response was only significant at 2 locations out of 20. These authors also reported that the positive yield response to banding was not related to soil K levels or degree of soil K stratification. Another investigation in Iowa (Buah et al., 2000) showed that no-till soybean responded to surface application at least as well as to planter-banded application, even though significant soil K stratification was evident when soil K levels were in the optimum, high, or very high ranges. More recent research in Ontario, Canada Yin and Vyn (2002a) showed that direct subsurface banding of K fertilizer in soybeans often resulted in similar leaf K and seed yield to surface broadcast, across all tillage systems used in that study (zone-till, fall disk and no-till).

Most of the published research has been devoted to the effects of direct P and K applications and placement to soybeans, but fewer reports are available concerning the residual effects of P and K fertilization and placement for corn on subsequent no-till soybean in corn-soybean rotations. Relevant research showed that no-till soybean yield response to residual fertilizer K (102 kg ha^{-1}) was negligible on high-testing soils with at least ten years of no-tillage management (Buah et al., 2000). However, on fields after six years in ridge till with evident vertical soil K stratification, soybean response to residual deep-banded (10-cm depth) K was evident on a high-testing soil at a high rate (148 kg ha^{-1}) of fall K fertilizer (Rehm, 1995). Research in Ontario, Canada (Yin and Vyn, 2002b; Yin and Vyn, 2004) concluded that subsequent no-till soybean responded more to residual K fertilizer rate than to application timing, tillage, and K fertilizer placement method in preceding corn.

With regards to P fertilizer management residual effects, research in South Dakota (Bly et al., 1997) concluded that fertilizer P applied as a band to corn was identifiable two years later. The residual fertilizer in these bands increased soybean shoot dry matter weight, shoot P uptake, and seed yield compared to the control treatment (0 kg ha^{-1} of P). However, the authors found that the distance of the band from the soybean row was more important that the band P concentration or previously applied P rate.

More recent research in Ontario, Canada, by Yin and Vyn (2003b) reported that the extent of soybean responses to direct or residual K application in a corn-soybean rotation may depend on the relative proximity of soybean rows to previous corn rows. They concluded that soybean responses to residual K fertilizer may be greater in those soybean rows that were planted where K fertilizer was banded for the prior corn.

None of the reports on soybean response to residual P or K fertilizers applied to the prior corn crop have investigated applying more broadcast K fertilizer directly before planting soybean. That might be more beneficial following deep-banded versus broadcast P and K treatments. Few reports are available concerning the effects of direct application of K fertilizer to no-till soybean following different fertilizer application methods for the previous corn crop in a corn-soybean rotation.

The primary objective of this study was to evaluate the no-till soybean yield and quality responses to direct broadcast application of K fertilizer following banded versus broadcast P and K fertilizer combinations in prior corn.

Materials and Methods

Site description

In the spring of 2003 a study was initiated at the Purdue Agronomy Center for Research and Education (ACRE) located near West Lafayette, Indiana (40° 28’ N Lat., 86° 59’ W Lon.). The research was conducted across a Raub-Brenton complex (fine, silty, mesic Aquic Argiudoll) that is classified as being a somewhat poorly drained, deep, silt loam soil.

In 2004, the study was located at a different site at the ACRE. The soil at that location is a mix of Toronto-Millbrook complex (fine, silty, mesic Udollic Ochraqualf) and Drummer soils (fine, silty, mesic Typic Haploquoll). The Toronto-Millbrook complex is classified as being somewhat poorly drained, deep soil with a silt loam texture. Drummer soils are nearly level, very deep, poorly drained with a silty clay loam texture.

Cultural practices

Soybeans were no-till planted in 38.1 cm rows using a John Deere 1780 row-crop planter at a seeding rate of 432,000 plants ha^{-1}. Pioneer variety 93B67 was planted in 2003. In 2004 the soybean variety was changed to Pioneer 93M80.

During the growing season, weed and insect control products were applied as necessary. In 2003, glyphosate (Round-up) was applied at 2.3 liters ha^{-1}. In August of that year λ-cyhalothrin (Warrior) was aerially applied at 270 g ha^{-1}. In 2004 glyphosate was applied at 2.3 liters ha^{-1}.

The experiment was designed as a split-split-plot, randomized complete block. There were six replications in 2003 and five replications in 2004. Two previous corn hybrids were randomly assigned to the main plots, and five previous fertility treatments were randomly assigned to the sub-plots. In 2003 each sub-plot was 9.1 m wide and 18.3 m long. In 2004, they were again 9.1 m wide, but 22.9 m long. Each sub-plot was subdivided in two sub-sub-plots. One half received broadcast K fertilizer two weeks before soybean planting and the other half did not. The experimental design is described in more detail below.

Main Plots (prior 2 corn hybrids):

1. Pioneer 34B24: 110 CRM, Bt. This previous corn hybrid was replaced in 2003 by a new hybrid Pioneer 31N28, with a very similar root structure.
2. Pioneer 34M95: 110 CRM, Bt.

Subplots (Prior 5 fertility treatments):

1. Control: no added P or K other than starter
2. Broadcast P and K: applied on the surface and lightly incorporated
3. Band P and K: applied at a 15 cm depth
4. Band P: applied at a 15 cm depth
5. Band K: applied at a 15 cm depth

Sub-subplots (broadcast K):

1. Control: no added broadcast K
2. Broadcast K: applied on the surface prior to soybean planting.

The rates of P and K for the five prior fertility treatments, excluding the control, were 99 kg ha^{-1} of P_2O_5 and 129 kg ha^{-1} of K_2O. Phosphorous fertilizer was applied as 0-46-0 and K was applied as muriate of potash (0-0-60). All banded treatments were applied to a depth of 15 cm in the spring with a Gandy system attached to a DMI Nutriplacr® 2500 strip tillage implement operating at a depth of 20 to 25cm. The application of K fertilizer before soybean planting was spring broadcasted with an air flow applicator at a rate of 134 kg ha^{-1} K_2O.

Soil measurements

Soil samples were taken in mid-June of each year. Sampling was done in two different positions within each sub-sub-plot but only for the plots that did not receive any broadcast K during the soybean year. The reason for this sampling scheme was to accurately compare prior fertility effects on soil P and K availability. Those positions within a plot were in the previous corn rows and between the previous corn rows. Those plots were sampled by bulking 10-12 soil cores per plot per position. These soil cores were sub-divided into three depth-intervals: 0-10, 10-20 and 20-40 cm. Samples were sent to an independent laboratory and analyzed for organic matter, available phosphorus (using Mehlich 3), exchangeable potassium, magnesium, soil pH, Mg and Ca. Table 4-1 shows the mean soil chemical properties for the experimental sites in 2003 and 2004.

Table 4-1. Summary of soil chemical properties in 2003 and 2004.

Depth	OM (%)	pH	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})
			2003			
0-10 cm	4.5	6.5	119	216	881	3264
10-20 cm	4.5	6.7	107	136	931	3441
20-40 cm	--	--	65	115	930	3499
			2004			
0-10 cm	3.9	6.8	20	193	672	2388
10-20 cm	3.5	6.6	22	95	649	2437
20-40 cm	--	--	11	85	659	2522

Organic matter and pH values were obtained for the first two depth intervals.

Soybean measurements

Several plant measurements were taken throughout the growing season. These measures include R1 growth stage leaf nutrient concentrations, seed yield and moisture, seed oil and protein concentrations, and seed nutrient concentrations.

R1 growth stage leaf nutrient concentrations were sampled when 50% of the plants were at the first reproductive stage (R1). Twenty trifoliolate leaves were taken to make a composite sample in each plot. Samples were collected in mid-July each year. These composite samples were then dried in a 40ºC oven and subsequently ground through a 1 mm sieve by a rotary blade grinder (Thomas Wiley Mill Model ED-5, Arthur H. Thomas Co. Phila, PA. USA). The ground samples were then sent to an independent laboratory and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, manganese, copper and zinc.

Seed yield was obtained using a plot combine. The four central soybean rows of each plot were harvested and then weighted. Seed yield values were then adjusted to the standard moisture content of 130 g kg^{-1}.

Seed moisture was measured by collecting a sample from each plot. This sample was subsequently run through a Motomco Moisture Meter (Motomco Inc., Electronics Div., Cark N.J.) to obtain moisture values used in subsequent yield calculations and statistical analyses.

Seed quality (oil and protein concentrations) was also analyzed on the soybean samples collected from each plot. Seed oil and protein concentrations were obtained through near infrared analysis via an InfratecR 1229 Whole Grain Analyzer. Near infrared (NIR) analysis is extensively used for routine compositional testing of seed. These values were then adjusted to the standard moisture content of 130 g kg^{-1} for oil and protein by using the formula CDB = 100*(CM/100-M) or CM = (CDB (100-M))/100, where CM=current moisture, M=percent moisture desired and, CDB=percent component (oil or protein) (Maier and Briggs, 1997).

Seed nutrient concentrations were derived for each of the samples from each plot. A subsample of approximately 50 grams was taken from each seed quality sample and dried in an oven at 60ºC. The sample was then ground using a rotary blade grinder (Thomas Wiley Mill Model ED-5, Arthur H. Thomas Co. Phila, PA. USA) and forced through a 2 mm sieve. The ground samples were then sent to an independent laboratory and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, manganese, copper and zinc.

Statistical analysis

The statistical analyses were accomplished using Statistical Analysis Software (SAS) version 9.1 (SAS Institute, Inc., Cary, North Carolina). Analysis of variance for a split-split plot was performed for each year separately for soil exchangeable K at three depths (0-10, 10-20 and 20-40 cm) and at two positions (in the previous corn row and between the previous corn row), and for soil available P at three depths (0-10, 10-20 and 20-40 cm) and at two positions (in the previous corn row and between the previous corn row). The same analysis was perform for R1 growth stage leaf K content, R1 growth stage leaf P content, seed yield, seed K content, seed P content, seed oil content and seed protein content but across years when possible. Mean separation tests were performed according to Tukey (α=0.05).

A linear regression model was also adjusted using Statistical Analysis System, SAS (version 9.1, SAS Institute, Cary, NC) between soybean leaf K concentrations and soybean seed and leaf manganese concentrations with initial soil K concentration (measured at the 0 to 10 cm depth intervals) on a split-split-plot basis. A regression model was adjusted between soil P concentration and leaf and seed P concentration. A total of 60 and 50 samples were used in the regression analysis in 2003 and 2004, respectively. Levels of significance less than P=0.05 were declared significant.

Results and Discussion

Soil fertility concentrations

Analysis of variance of a split-split-plot design was performed for each year separately due to high variability in soil available P between years (Table 4-1). In 2003 the concentrations of available P were approximately 5 times as high (for all 3 depth intervals) as they were in 2004. Mean soil K values were also higher in 2004 (Table 4-1) but differences were not dramatic. Soil available P and soil exchangeable K were, for both years, above the critical soil test levels for soybeans reported in the Tri-state fertilizer recommendations bulletin for corn, soybeans, wheat and alfalfa (Extension Bulletin E-2567, Rep. August 1996). Those critical soil test levels are 15 mg kg^{-1} for P and 150 mg kg^{-1} for K for a soil with a CEC of 30 meq 100 g^{-1} or above.

Soil available P at two different positions and at three different depths was analyzed as a response variable across prior fertility treatments. Prior hybrid had no significant effect on the soil available P at either of the two sampling positions, nor at any of the three different depths (data not shown, Appendix D-2).

In 2003, differences in soil available P among previous fertility treatments were significant only at the in-row sampling position, and then only for the 0 to 10 cm depth interval (Table 4-2). Broadcast application of P and K resulted in higher available P concentrations compared to the other fertility treatments. No significant differences were found among the rest of the treatments. Even though no significant differences were found at the 10 to 20 cm depth, the banded P&K and the banded P resulted in higher P concentrations than other treatments.

Table 4-2. Soil available P concentration measured at different positions as affected by prior corn fertility treatments in 2003.

Position	Fertility treatment	Depth 0-10 cm	10-20 cm	20-40 cm
		-------Soil P concentration (mg kg^{-1})-------		
In-row	Control	116 b	104	58
	Broadcast P&K	130 a	106	68
	Band P&K	111 b	121	58
	Band P	118 b	113	60
	Band K	117 b	106	64
In-row mean		117	110	62
Btn-row	Control	116	104	60
	Broadcast P&K	122	106	76
	Band P&K	120	101	65
	Band P	123	102	69
	Band K	124	108	75
Btn-row mean		121	104	69

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05). In-row = samples taken in previous corn rows, Btn-row = samples taken in between previous corn rows.

In 2004, previous fertility treatments were significantly different both in the row sampling position and the between-row sampling position (Table 4-3). At the in-row sampling position between 0 and 10 cm, broadcast P&K resulted in higher available P concentrations compared to the control, the banded P&K treatment and the banded K treatments. The banded P treatment was not significantly different from any of the treatments. At the 10 to 20 cm depth interval, the banded P treatment resulted in the highest available P concentration. However, it was not significantly different from the banded P&K treatment or from the broadcast P&K treatment. These last two treatments were not significantly different from the rest of the treatments. At the between-row sampling position, differences among previous fertility treatments were only significant at the 0 to 10 cm depth interval. The broadcast P&K treatment resulted in the highest available P concentration and this treatment was significantly different from all the other treatments but the banded P. Furthermore, the banded P treatment was found to be significantly different compared to the control but not to the rest of the treatments.

Table 4-3. Soil available P concentration measured at different positions as affected by prior corn fertility treatments in 2004.

Position	Fertility treatment	Depth 0-10 cm	10-20 cm	20-40 cm
		----Soil P concentration (mg kg^{-1})----		
In-row	Control	19 b	19 b	10
	Broadcast P&K	24 a	22 ab	11
	Band P&K	18 b	22 ab	13
	Band P	21 ab	29 a	11
	Band K	18 b	19 b	9
In-row mean		20	23	11
Btn-row	Control	18 c	20	11
	Broadcast P&K	25 a	23	11
	Band P&K	19 bc	18	10
	Band P	23 ab	21	10
	Band K	19 bc	20	10
Btn-row mean		21	20	10

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05). In-row = samples taken in previous corn rows, Btn-row = samples taken in between previous corn rows.

Soil exchangeable K at two different positions and at three different depths was also analyzed as a response variable across prior fertility treatments. Prior hybrid had no significant effect on soil exchangeable K in either sampling position, nor at any of the three different depths (data not shown).

Table 4-4 shows the effects of previous fertility treatments on the soil exchangeable K sampled at different positions and depth intervals in 2003. Significant effects were found at the in-row sampling position but not at the between-row sampling position. For the in-row sampling position, a significant effect of the previous fertility treatment was found at the 0 to 10 and at the 10 to 20 cm depth intervals but not at the deeper depth. At the 0 to 10 cm depth interval, the broadcast P&K treatment resulted in significantly higher soil exchangeable K concentration than all other fertility treatments but the banded P&K treatment. The latter was not significantly different from the control, the banded P or the banded K treatment. At the 10 to 20 cm depth interval, the banded P&K treatment resulted in the highest exchangeable K concentration, but then it was only significantly different from the control.

Table 4-4. Soil exchangeable K concentration measured at different positions as affected by prior corn fertility treatments in 2003.

Position	Fertility treatment	Depth		
		0-10 cm	10-20 cm	20-40 cm
		----Soil K concentration (mg kg^{-1})----		
	Control	234 b	129 b	109
	Broadcast P&K	291 a	146 ab	114
In-row	Band P&K	245 ab	150 a	121
	Band P	232 b	139 ab	112
	Band K	225 b	147 ab	122
In-row mean		245	142	115
	Control	175	129	104
	Broadcast P&K	205	137	123
Btn-row	Band P&K	190	134	115
	Band P	190	128	109
	Band K	175	126	124
Btn-row mean		187	131	115

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05). In-row= samples taken in previous corn rows, Btn-row= samples taken in between previous corn rows.

Table 4-5 shows the effects of previous fertility treatment on the soil exchangeable K sampled at different positions and depth intervals in 2004. Significant effects were found at the in-row sampling position but not at the between-row sampling position. For the in-row sampling position, a significant effect of the previous fertility treatment was found at the 0 to 10 cm interval but not at deeper depth intervals. The banded K treatment resulted in the highest soil exchangeable K concentration but it was only significantly different from the control. Furthermore, no significant differences were found among the control, the broadcast P&K treatment, the banded P&K treatment and the banded P treatment.

Table 4-5. Soil exchangeable K concentration measured at different positions as affected by prior corn fertility treatments in 2004.

Position	Fertility treatment	Depth 0-10 cm	10-20 cm	20-40 cm
		----Soil K concentration (mg kg^{-1})----		
In-row	Control	188 b	100	87
	Broadcast P&K	209 ab	97	86
	Band P&K	210 ab	104	92
	Band P	198 ab	100	87
	Band K	236 a	106	89
In-row mean		216	101	88
Btn-row	Control	177	90	80
	Broadcast P&K	167	86	81
	Band P&K	170	92	85
	Band P	160	87	85
	Band K	174	92	79
Btn-row mean		169	89	82

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05). In-row= samples taken in previous corn rows, Btn-row= samples taken in between previous corn rows.

Vertical soil K stratification was evident in both years. Soil K concentrations at the surface layer were 1.4 to 2.1 times higher than K levels at the 10 to 20 cm depth interval. Horizontal stratification was also evident. At the in-row position, soil exchangeable K concentrations averaged 47 to 58 mg kg^{-1} higher than between row for the 0 to 10 cm depth interval. In row soil-test K was still 11 to 12 mg kg^{-1} higher than between row at the 10 to 20 cm depth interval. Horizontal stratification was also evident in the control treatment but to a lesser extent compared to the broadcast treatment. Soil K ratios in the in-row sampling position and across all previous fertility treatments averaged 1.7 and 2.1 in 2003 and 2004, respectively. Those ratios were 1.4 and 1.8 at the between sampling position for those same years.

These higher values of soil-test K in the row sampling position compared to those in the between sampling position are in agreement with those reported by Varsa and Ebelhar (2000), and Yin and Vyn (2003b). Both studies found that all fertilizer placement methods including the broadcast treatment (other methods were surface band, surface dribble and starter) resulted in higher soil K levels near the corn row compared to soil near the middle of the row. This was an indication that K was leached near the previous row after corn plants had reached maturity. These results were similar to those reported by Tyler and Howard (1991) for no-till corn.

R1 nutrient analysis

Leaf P and K content at the R1 growth stage indicates the levels of soybean P and K nutrition at early growth stages. Comparisons among treatments and across years were performed when possible.

Prior corn hybrid and prior fertility treatments were found to have a significant effect on the leaf P concentration measured at the R1 growth stage. Table 4-6 shows the effects of the interaction between previous corn hybrid and previous fertility treatment on the leaf P concentration at the R1 growth stage in 2003 and 2004. Comparisons across years were not possible due to a significant year effect on the leaf P concentration at the R1 growth stage. In 2003, and within each prior corn hybrid, leaf P concentrations were not affected by the prior fertility treatment. These results were expected because of very high levels of soil available P (Table 4-2). In contrast, in 2004 a significant effect of prior fertility treatment was found within prior corn hybrids. Comparisons within hybrid Pioneer 31N28 show that the broadcast P&K and the banded P treatments resulted in the highest leaf P concentrations. Comparisons within hybrid Pioneer 34M95 were more complex. The broadcast P&K resulted in the highest leaf P concentration and this treatment was significantly different from all other treatments but the control. Furthermore, the control was significantly different from the banded K treatment.

In 2003 results were as expected (no difference among previous fertility treatments) since levels of soil-test P were well above the sufficiency range. Soybean leaf P concentrations were also well above the accepted critical level of 3.0 g kg^{-1} in 2003. In 2004, where levels of soil-test P were closer to the critical value (15 mg kg^{-1}, Tri-State Fertilizer Recommendations, 1996) differences among previous fertility treatments were more apparent. In general, results in 2004 are in agreement with those reported by Buah et al. (2000) who found that banding and direct application of P generally increase leaf P concentrations at early bloom. However, in their study fertilizer application was directly to the soybean crop, whereas only residual P fertilizer placement effects were measured in the present study.

Table 4-6. Leaf P concentration at the R1 growth stage as affected by prior corn hybrids and prior fertility treatments in 2003 and 2004.

Fertility treatment	Previous Corn Hybrid	
	2003	
	Pioneer 34B24	Pioneer 34M95
	----Leaf P concentration (g kg^{-1})----	
Control	4.9	5.0
Broadcast P&K	5.0	5.1
Band P&K	4.9	4.9
Band P	5.1	5.2
Band K	4.9	5.0
	2004	
	Pioneer 31N28	Pioneer 34M95
	---Leaf P concentration (g kg^{-1})----	
Control	3.7 b	4.2 ab
Broadcast P&K	4.1 a	4.4 a
Band P&K	3.6 b	3.9 bc
Band P	4.0 a	4.0 bc
Band K	3.4 b	3.7 c

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Previous fertility treatments and direct K fertility treatments were the factors that were found to have a significant effect on the leaf K concentration but only as an interaction effect with year and prior corn hybrid. Tables 4-7 and 4-8 show the effects of the previous fertility treatment and direct K fertility treatment on the leaf K concentrations in 2003 and 2004, respectively. Comparisons were performed within years and within prior corn hybrid. In 2003, no differences were found among previous fertility treatments within hybrid Pioneer 34B24. For the same year but within hybrid Pioneer 34M95, prior fertility differences were found only with the no K fertility sub-sub-treatment. The broadcast P&K treatment resulted in the highest leaf K concentration although broadcast P and K was only significantly different from the banded P or banded K alone treatments. In 2004, differences among previous fertility treatments were found within both hybrid Pioneer 31N28 and hybrid Pioneer 34M95, but then only at the no K fertility sub-sub-treatment. Within hybrid Pioneer 31N28, banded P&K and banded K treatments were different from the banded P treatment. Within hybrid Pioneer 34M95, a similar trend was found but then only banded K was significantly different from the banded P treatment.

With regards to the effects of direct K fertility treatments (i.e. no K or broadcast K), significant differences were found only in 2004. For that year, and for both hybrid Pioneer 31N28 and Pioneer 34M95, the direct broadcast K treatment resulted in higher leaf K concentration compared to the No K treatment only within the prior banded P fertility treatment (Table 4-8). Broadcast K application directly before planting soybean did not enhance leaf K concentrations if K fertilizer had been applied (whether broadcast or deep-banded) to the prior corn crop.

Results in 2004 are in agreement with those reported by Buah et al. (2002) who found significant higher levels of leaf K at early bloom with the direct addition of fertilizer K. Yin and Vyn (2002b) also reported higher levels of leaf K at early bloom with the direct broadcast addition of fertilizer K compared to the control treatment. These results are also in agreement with those reported by Yin and Vyn (2003a) who found that deep band and surface broadcast placements were similar in their residual effects on soybean leaf K at initial flowering stage.

Table 4-7. Leaf K concentration at the R1 growth stage as affected by prior corn hybrids, prior fertility treatments and K fertility treatments in 2003.

Fertility treatment	Direct K fertility: No K	Direct K fertility: Broadcast K
	------Leaf K concentration (g kg^{-1})------	
	Pioneer 34B24	
Control	22.1	21.9
Broadcast P&K	21.9	24.0
Band P&K	22.7	23.3
Band P	23.0	21.4
Band K	24.3	24.1
	Pioneer 34M95	
Control	22.5 ab	23.1
Broadcast P&K	24.3 a	22.1
Band P&K	22.0 ab	21.0
Band P	21.0 b	22.7
Band K	20.3 b	22.3

Means followed by the same letter, or no letter, within a column or means followed by the same capital letter, or no letter, within a row are not significantly different according to Tukey (α=0.05).

Table 4-8. Leaf K concentration at the R1 growth stage as affected by prior corn hybrids, prior fertility treatments and K fertility treatments in 2004.

Fertility treatment	Direct K fertility	
	No K	Broadcast K
	------Leaf K concentration (g kg^{-1})------	
	Pioneer 31N28	
Control	24.0 ab	27.0
Broadcast P&K	23.2 ab	22.3
Band P&K	25.1 a	23.1
Band P	20.7 b B	24.3 A
Band K	26.8 a	25.4
	Pioneer 34M95	
Control	23.2 ab	21.7
Broadcast P&K	24.1 ab	22.9
Band P&K	23.1 ab	24.2
Band P	20.9 b B	24.0 A
Band K	24.3 a	22.5

Means followed by the same letter, or no letter, within a column or means followed by the same capital letter, or no letter, within a row are not significantly different according to Tukey (α=0.05).

In previous research Small and Ohlrogge (1973) determined that plant sufficiency ranges were 2.6 to 5 g kg^{-1} for P and 17.1 to 25 g kg^{-1} for K. More recent research by Yin and Vyn (2004) suggested that critical leaf K concentration for no-till soybean was 24 g kg^{-1}. At the R1 growth stage, leaf P and K concentrations in this study were generally within the sufficiency range even when differences among previous fertility treatments were found to have statistically significant effects on leaf P and K concentrations.

Soybean yield

Table 4-9 shows the effects of previous fertility treatments with and without a direct K fertility treatment on seed yield in 2003 and 2004. In 2003, there were no significant differences among previous fertility treatments at any fixed level of direct K fertility (i.e. No K or Broadcast K). In 2004, differences among previous fertility treatments were found at both fixed levels of direct K fertility. Within the No K treatment, the broadcast P&K and the banded P treatments were significantly higher than the control and the banded K treatments. Within the broadcast K treatment, a similar trend was found. The broadcast P&K and the banded P treatments were significantly different from the control, the banded K treatment and also the banded P&K treatment.

Direct K fertility treatment benefited yield significantly only in the control sub-treatment (2003) or the broadcast P&K sub-treatment (2004).

Table 4-9. Seed yield as affected by direct K fertility treatments in 2003 and 2004.

Fertility treatment	Direct K fertility No K	Direct K fertility Broadcast K
	------Seed yield (Mg ha^{-1})------	
	2003	
Control	4.43 B	4.58 A
Broadcast P&K	4.58	4.59
Band P&K	4.42	4.50
Band P	4.41	4.52
Band K	4.55	4.50
	2004	
Control	3.85 b	3.88 b
Broadcast P&K	4.34 a B	4.53 a A
Band P&K	4.17 ab	4.01 a
Band P	4.53 a	4.46 a
Band K	3.77 b	3.65 b

Means followed by the same letter, or no letter, within a column or means followed by the same capital letter, or no letter, within a row are not significantly different according to Tukey (α=0.05).

In 2003 results were as expected (no difference among previous fertility treatments) since levels of soil P and K were within the sufficiency range. In 2004, where levels of soil P were closer to the critical value (15 mg kg^{-1}, Tri-State Fertilizer Recommendations, 1996) differences among previous fertility treatments were more apparent. The band application of P&K was never superior to the broadcast application of those same nutrients. Lower yield results after the banded K treatment in 2004 may reflect the significantly lower soil P concentrations both between and in-row (Table 4-3) when K alone was banded, and may also suggest the importance of balanced nutrition (i.e. balanced between P and K) in achieving higher soybean yields. Soil available P concentrations (Table 4-3) and soybean yields (Table 4-9) were never different from each other in the banded K and the control treatments.

Seed nutrient and composition analysis

Table 4-10 shows the effect of prior fertility treatment on seed P concentration. Seed P concentration was not affected by prior corn hybrids or by direct K fertility treatments in either year (data not shown). Comparisons across years were invalid because of a significant year effect on seed P concentration. Those year effects were expected because of the difference in soil available P between 2003 and 2004 (Table 4-2). Effects of prior fertility treatments were significant only in year 2004. In that year, the broadcast P&K and the banded P treatments resulted in the highest seed P concentrations. Furthermore, those concentrations were significantly different from the control, the banded P&K and the banded K treatments. It is interesting that the banded P treatment resulted in a much higher seed P concentration than banded P and K when overall P rates were similar. This may also be the first report of increasing soybean seed P concentrations due to residual effects of fertilizer P application to the previous corn.

Table 4-10. Seed P concentration as affected by prior fertility treatments in 2003 and 2004.

Fertility treatment	Year 2003	Year 2004
	----Seed P concentration (g kg^{-1})----	
Control	5.5	3.7 bc
Broadcast P&K	5.5	4.5 a
Band P&K	5.6	4.0 b
Band P	5.5	4.4 a
Band K	5.5	3.5 c

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Tables 4-11 and 4-12 show the effect of prior fertility treatment and the effect of direct K fertility treatments on seed K concentration, respectively. Seed K concentration was not affected by prior corn hybrid and had no interaction effect with year (data not shown).The broadcasted P&K treatment had slightly higher seed K concentrations. For the broadcasted P&K, banded P&K, and banded K treatments, the broadcast K application in the soybean year resulted in higher seed K concentrations. All increases were relatively small.

Table 4-11. Seed K concentration as affected by prior fertility treatments across years.

Fertility treatment	---Seed K concentration (g kg^{-1})--
Control	17.3 b
Broadcast P&K	17.6 a
Band P&K	17.5 ab
Band P	17.4 b
Band K	17.3 b

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

In general these results are in agreement with those reported by Yin and Vyn (2002a) who showed that there was a frequent increase in seed K concentrations due to residual effects of K fertilizer applied to the previous corn.

Table 4-12. Seed K concentration as affected by direct K fertility treatments across years.

Fertility treatment	Direct K fertility	
	No K	Broadcast K
	---Seed K concentration (g kg^{-1})---	
Control	17.2	17.4
Broadcast P&K	17.4 B	17.8 A
Band P&K	17.4 B	17.7 A
Band P	17.3	17.4
Band K	17.2 B	17.5 A

Means followed by the same letter, or no letter, within a row are not significantly different according to Tukey (α=0.05).

Previous research by Coale and Grove (1991) and by Terman (1977) already reported the fact of soybean seed K concentration being increased by direct application of K fertilizer.

Table 4-13 shows the effect of prior fertility treatment on seed oil concentration. Seed oil concentration was not affected by prior corn hybrid or by direct K fertility. Comparisons across years were not possible in this analysis. In 2003, no differences were found among previous fertility treatments. In 2004, the banded K treatment and the control resulted in the highest seed oil concentrations. However, they were only significantly different from the banded P treatment but not from the rest of the treatments. In addition, these slight differences were too small to be of commercial significance.

Table 4-13.Seed oil concentration as affected by prior fertility treatments in 2003 and 2004.

Fertility treatment	Year	
	2003	2004
	---Seed oil concentration (g kg^{-1})---	
Control	181.4	191.1 a
Broadcast P&K	181.7	189.9 ab
Band P&K	181.4	190.2 ab
Band P	182.8	188.9 b
Band K	181.0	191.7 a

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

Table 4-14 shows the effect of prior fertility treatment on seed protein concentration. Seed protein concentration was not affected by prior corn hybrid or by direct K fertility. Comparisons across years were not possible in this analysis. In 2003, no differences were found among previous fertility treatments. In 2004, the banded P treatment and the broadcast P&K treatment resulted in the highest seed protein concentrations and they were not different from each other. The banded P treatment was significantly different from the control, and the banded K but not from the banded P&K.

Table 4-14.Seed protein concentration as affected by prior fertility treatments in 2003 and 2004.

Fertility treatment	Year 2003	Year 2004
	---Seed protein concentration (g kg^{-1})---	
Control	353.3	349.5 c
Broadcast P&K	353.0	353.3 a
Band P&K	352.9	351.0 bc
Band P	352.9	352.7 ab
Band K	353.0	348.3 c

Means followed by the same letter, or no letter, within a column are not significantly different according to Tukey (α=0.05).

These results agree in direction of response, but to a lesser extent, than those reported by Gaydou and Arrivets (1983) that showed that the addition of potassium resulted in a significant oil content increase but also resulted in a highly significant protein decrease. In another experiment in Australia (Sale et al., 1986), seed produced by K deficient plants contained low oil and high crude protein concentrations compared with seed from plants supplied with adequate K. In more recent research Yin and Vyn (2003a) reported that although both seed oil and protein concentrations were affected by K fertilizer applications, the range of changes in those quality parameters with K fertilization was small.

The results obtained in this study are also in agreement with more recent research by Mallarino et al. (2005) that reported that the application of fertilizer P and K seldom affected soybean seed oil and protein concentrations. Even when there was a significant fertilization effect on seed oil and protein concentration, the responses were small.

Regression analysis

Linear regression models were developed to examine the relationships of soybean nutrient response parameters such as leaf K concentrations, seed manganese concentration, and leaf manganese concentrations with initial soil K concentration (measured at the 0 to 10 cm depth intervals) on an individual split-split-plot basis. Figures 4-1 and 4-2 show the results of the regression analysis of leaf K concentration and initial soil K concentration measured at the 0 to 10 cm depth intervals in 2003 and 2004, respectively. In 2003 the model was not significant. However, in 2004 the regression model was significant, and leaf K concentrations were positively related to initial soil K concentrations with a meaningful R^2 value. For that year, the model explained the 58% of the variation in leaf K concentrations.

Figure 4-1. Regression of leaf K concentration with initial soil K concentration at 0 to 10 cm depth in year 2003.

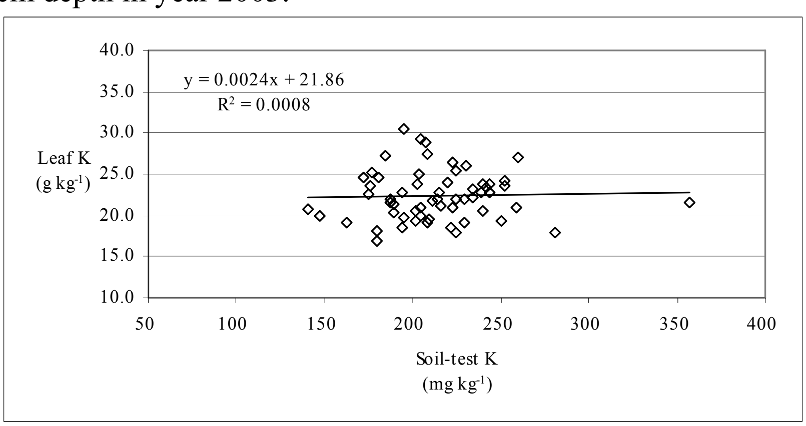
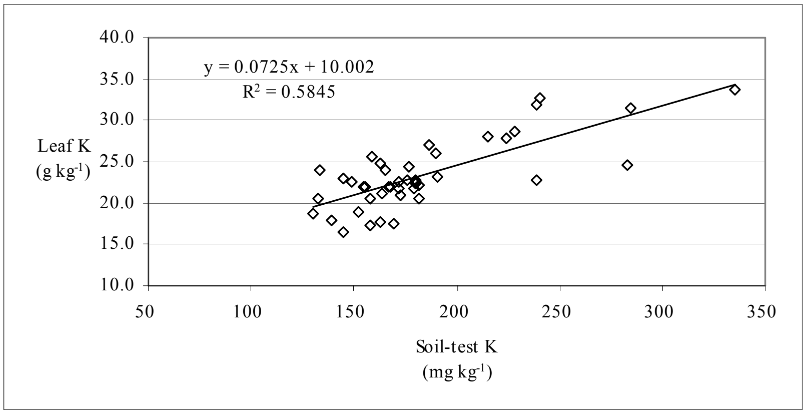


Figure 4-2. Regression of leaf K concentration with initial soil K concentration at 0 to 10 cm depth in year 2004.



Figures 4-3 and 4-4 show the results of the regression analysis of leaf manganese concentration and initial soil K concentration measured at the 0 to 10 cm depth intervals in 2003 and 2004, respectively. Positive results were found again only in 2004. For that year, the regression model was significant, and leaf manganese concentrations were positively related to initial soil K concentrations with a meaningful R^2 value. In 2004, the model explained the 35% of the variation in leaf Mn concentrations.

Even though the relationship between soil K concentration and leaf manganese differed significantly for one year to the next, for both 2003 and 2004 leaf manganese concentrations at initial flowering (R1 growth stage) were within the sufficiency range reported on the Tri-State Fertilizer Recommendations (1996). That sufficiency range is 21 to 100 mg kg^{-1} for soybeans sampled prior to initial flowering.

Figure 4-3. Regression of leaf Mn concentration with initial soil K concentration at 0 to 10 cm depth in year 2003.

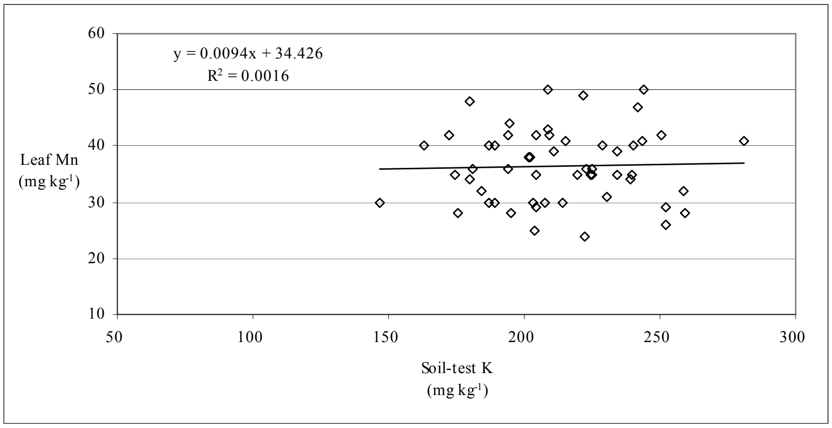
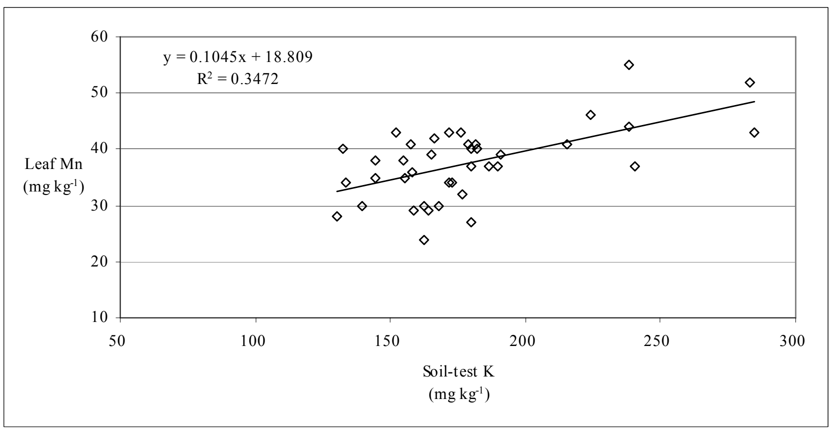


Figure 4-4. Regression of leaf Mn concentration with initial soil K concentration at 0 to 10 cm depth in year 2004.



Figures 4-5 and 4-6 show the results of the regression analysis of seed manganese concentration and initial soil K concentration measured at the 0 to 10 cm depth intervals in 2003 and 2004, respectively. The regression model was significant only in 2004. Seed manganese concentrations were positively related to initial soil K concentrations with a meaningful R^2 value. For that year, the model explained the 52% of the variation in seed Mn concentrations.

Figure 4-5. Regression of seed Mn concentration with initial soil K concentration at 0 to 10 cm depth in year 2003.

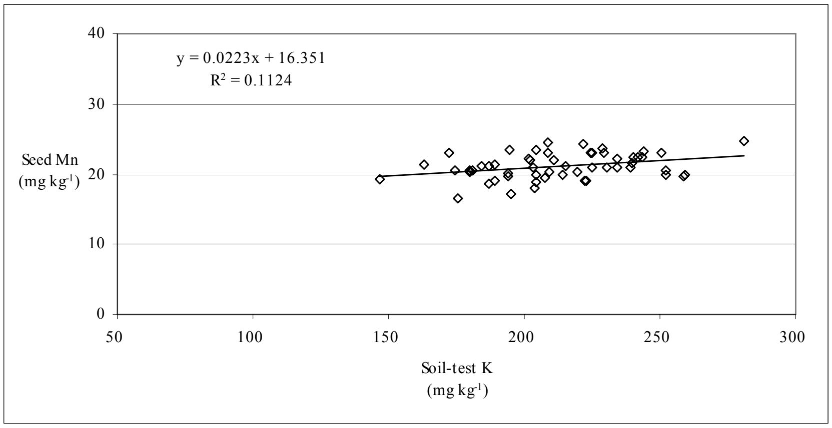
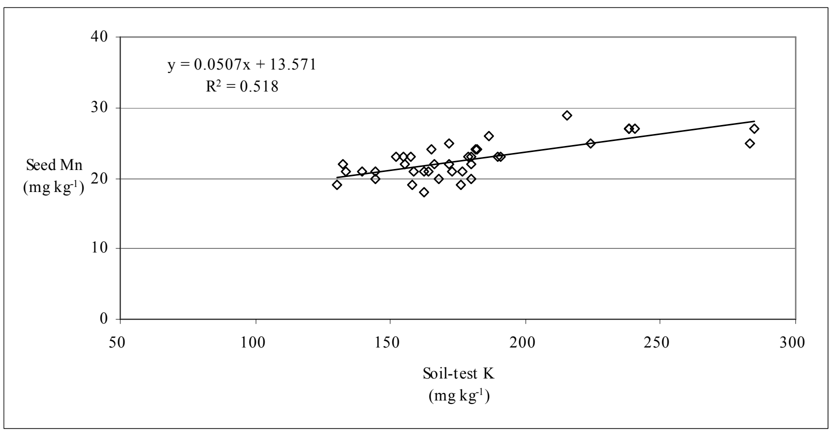


Figure 4-6. Regression of seed Mn concentration with initial soil K concentration at 0 to 10 cm depth in year 2004.



It would be interesting to understand better the environmental factors which lead to strong relationships between soil K concentration and leaf K, leaf Mn and seed Mn in one year, but very poor relationships the next year. Part of the difference may have been associated with cultivars since soybean variety Pioneer 93B67 was planted in 2003 but Pioneer 93M80 was planted in 2004.

The interest in studying manganese results from some recent studies that have shown that some glyphosate-resistant soybean varieties have a reduced capacity to either take up or translocate manganese (Huber et al., 2004), and this micronutrient is thought to be one of the most important in developing resistance in plants to root and foliar diseases (Graham and Webb, 1991). Plant tissues susceptible to fungal, viral, and bacterial pathogen usually have lower manganese concentrations than resistant tissues (Huber and Wilhelm, 1988).

A linear regression model was also developed to understand possible relationships between soybean leaf and seed P concentrations and initial soil P concentration (measured at the 0 to 10 cm depth intervals) on a split-split-plot basis. Figures 4-7 and 4-8 show the results of the regression analysis of leaf and seed P concentration and initial soil P concentration measured at the 0 to 10 cm depth intervals in 2004, respectively. The regression model was significant for both leaf and seed P in 2004 but not in 2003. In 2004, leaf P concentrations were positively related to initial soil P concentrations but the R^2 was only 15%. In contrast, seed P concentrations were not only positively related to initial soil P concentrations but also showed a meaningful R^2 value. For that year, the model explained the 34% of the variation in seed P concentrations (Fig. 4-8).

Figure 4-7. Regression of leaf P concentration with initial soil P concentration at 0 to 10 cm depth in year 2004.

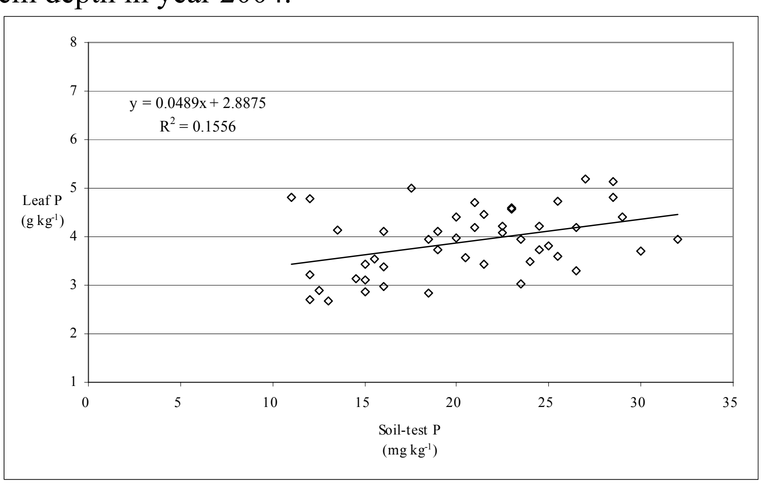
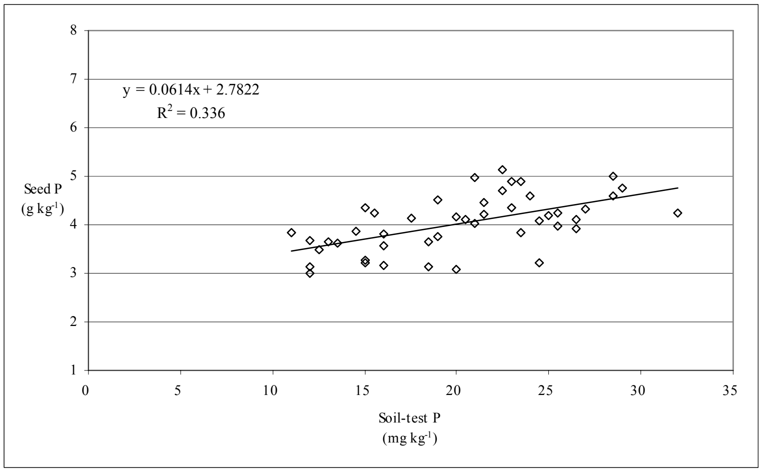


Figure 4-8. Regression of seed P concentration with initial soil P concentration at 0 to 10 cm depth in year 2004.



In 2003 results were as expected (no significant relationship among soil P levels and leaf and seed P concentrations) since levels of soil P were very high (mean soil-test P at the 0 to cm depth interval was 119 mg kg^{-1}). In 2004, where levels of soil P were lower (averaged 20 mg kg^{-1} measured at the 0 to 10 cm depth interval) the relationships were more apparent.

Conclusions

The results of this 2-year study show that previous corn hybrid and previous P and K fertility treatments had little influence to no influence on no-till soybean response parameters. Deep-band application of P and K fertilizers was not significantly different in any of the soybean parameters measured except leaf P concentration and seed P concentration, and then only in 2004 (where the broadcast application resulted in both higher leaf and seed P concentrations compared to the band applications). Band placement of P and K together was never superior to broadcast P and K placement with regards to seed yield or seed quality (i.e. oil and protein content) even when soil K stratification was evident and pronounced (i.e. stratification ratios above 1.5).

For the 2 years of the study, direct broadcast application of K fertilizer before soybean planting seems to have no effect on soybean parameters when both P and K fertilizers were applied (whether broadcast or band) to the prior corn crop. Only in 2004, and when P was previously banded without addition of K fertilizer, direct application of K resulted in significantly higher values of leaf K concentration at the R1 growth stage. These results suggest that the biannual application of K fertilizer seems to be adequate on these soils and that there was little benefit from a pre-planting broadcast K application.

In 2004, where levels of soil P were closer to the critical value (15 mg kg^{-1}, Tri-State Fertilizer Recommendations, 1996) differences among previous fertility treatments were more evident. Previous application of K fertilizer without any addition of P fertilizer resulted in yield values similar to the control (no added P or K). Lower seed yield results from the banded K treatment might show the importance of balanced nutrition (i.e.

balanced between available P and exchangeable K in the rooting profile). The high seed yields with banded P in 2004 were interesting in that they suggested more benefit associated with banding P alone than with banding K alone.

With regard to seed quality, both protein and oil concentrations were significantly affected by the previous fertility treatments but only to a very small degree that may have little commercial relevance. In general, treatments that involved broadcast or band applications of K fertilizer were associated with a small decrease in seed protein concentration and an increase in oil concentration.

Soil exchangeable K concentrations at the 0 to 20 cm depth were greater in the previous corn rows than those between previous corn rows, regardless of previous fertility treatment (even when no fertilizer was previously applied), but this doesn't seem to be a concern when soybean are planted in 38 cm row widths. However, when narrower rows are planted (i.e. 19 cm) this horizontal stratification might be an issue for soybean K nutrition. The difference in soil K concentration might be more pronounced particularly when corn rows are continuously planted close to previous rows and when nutrients are banded instead of broadcast applied.

The similar soybean responses to band nutrient placement compared to broadcast placement suggest that no-till soybean growers should not be concerned about which placement method they select for the preceding corn in corn-soybean rotations. Soil K vertical stratification was not an important issue affecting soybean responses in this study on soils with high organic matter levels and high water holding capacity.

Overall, it seems that initial soil exchangeable K and soil available P concentrations in individual plots can play a more important role than the P and K fertility treatments themselves in affecting soybean response. Spatial variability continues to be a dominant concern in trying to demonstrate differences to P and K fertility treatments even when numerous replications and split-split plot designs are used.

CHAPTER FIVE
GENERAL DISCUSSION

Notable Conclusions:

Evaluations of no-till soybean responses following corn over a 3-year period on variable clay soils in Eastern Indiana suggested that the residual effects of K fertilization (fall application of 100 kg ha^{-1}vs. fall plus spring application totaling 156 kg ha^{-1} prior to corn) on soybean yield and seed quality in variable soils were significant only at low to medium-K soil-test levels. Even when soybean yields or seed quality were affected by residual K fertilizer treatments, the effects were small. Effects of the preceding corn tillage system (including No-till, Fall Chisel and Strip-till) on subsequent no-till soybeans yield and quality responses were negligible. Overall initial soil K status was a much more important factor affecting soybean yield and quality responses than the residual effects of the previous tillage system or K fertilization in the prior corn year.

In associated 3-year field experiments on dark prairie soils in West-Central Indiana, no-till soybean responses to the residual effects of deep-banded versus broadcast P and (or) K fertilizers to prior corn were generally similar. No-till soybean yields and seed nutrient, oil and protein concentrations were usually not negatively or positively affected if P and K fertilizers were deep-banded at either 15 or 30 cm versus surface broadcast. Indeed, there were very few significant soybean responses to any P and K fertilizer treatments relative to the control. Furthermore, there was little benefit from additional broadcast K fertilizer application to residual fertilizer treatments in spring before planting soybean. Leaf nutrient concentrations were more often affected by previous fertility treatments than seed yield. However, band placement (15 or 30 cm) was generally neither worse nor better than broadcast for those soybean response parameters. In this high yield environment, and for these soils with at least medium concentrations of available P and exchangeable K, no-till soybean performance in 38-cm row widths was generally not impacted by whether crop-yield-maintenance rates of P and K fertilizers were deep-banded at 76-cm intervals (to match the intended corn rows) or surface broadcast.

Vertical stratification in P and K was evident each spring as soil samples were taken in 0-10, 10-20 and 20-40 cm increments both in and between the former corn rows. Soil K concentrations in the 0-10 cm horizon averaged 1.6 times those in the 10-20 cm depth increment, and were generally not impacted significantly by deep banding versus broadcast application. A deep banding management response to the vertical stratification of essential soil nutrients was not very beneficial in resolving nutrient stratification or in improving no-till soybean yields on these soils with high organic matter levels and high water holding capacity. Horizontal nutrient stratification was also evident in the soybean production year. Soil exchangeable K concentrations at surface and subsurface layers were always greater in the previous corn rows than those between previous corn rows, regardless of previous fertility treatment (even when no fertilizer was previously applied). With regards to vertical soil P stratification, the ratio between soil-test P at the 0 to 10 cm depth interval with the concentration at the 10 to 20 cm depth interval was similar to the

K ratio (i.e. surface concentrations 1.6 times higher that the subsurface values). However in this case, horizontal stratification was not evident in the near-surface soil samples.

Seed quality parameters such as protein and oil concentrations were significantly affected by the previous fertility treatments, but only to a very small degree that may have little commercial relevance. There was a frequent increase in seed P and K concentrations due to residual effects of P and K fertilizers applied to the previous corn but, for this study, band fertilizer application at either 15 or 30 cm depth was never superior to broadcast application.

Implications:

Results of this research project will affect growers in several ways. First, no-till soybean growers should be confident that neither K availability to soybean nor their soybean yield and quality will be improved if conventional tillage or strip tillage systems are adopted for preceding corn. Continuous no-till production, therefore, did not disadvantage soybean growth relative to the more common system of tilled corn alternating with no-till soybean. Second, the generally similar soybean responses to band nutrient placement compared to broadcast placement suggests that no-till soybean growers should not be concerned about which placement method (i.e. broadcast, 15-cm band or 30-cm band) they select for the preceding corn in corn-soybean rotations in soils similar to those of this study. Although oil and protein quality parameters were affected by previous fertility treatments, the responses were so small (and of such little commercial relevance) that no management changes in fertility placement seem warranted to gain improved seed quality. Third, no-till soybean farmers should not get overly concerned about vertical stratification in K since it doesn't seem to be an important issue affecting soybean responses planted at 38 cm row widths on soils with high organic matter levels and high water holding capacity. In contrast, when narrower rows are planted (i.e. 19 cm) horizontal K stratification might be a concern for soybean K nutrition. Horizontal differences in soil K concentration might be more evident particularly when corn rows are continuously planted close to previous rows and when nutrients are banded instead of broadcast applied. Finally, it seems that initial soil exchangeable K and soil available P can play a more important role than the P and K fertility treatments themselves in affecting soybean response.

The overall goal for no-till soybean growers would be not to increase soil P and K concentrations beyond sufficiency ranges but to have enough soil sampling intensity to determine the extent of soil spatial variability and low-testing areas within fields.

Limitations:

The experimental factors of this project were originally designed for a corn study. This study only included a planting row width of 38 cm and a very limited number of soybean varieties (one for the soil variability study at Farmland, IN., and two at West Lafayette). Deep-banded fertilizer treatments may have been more limiting for soybean in 19-cm rows, especially in situations with low soil K (Yin and Vyn. 2003a) Even though each of the experiments were evaluated in multiple years, each experiment was only one conducted at one location.. Particularly for the experiment involving no-till soybean responses to broadcast K fertilizer following banded vs. broadcast P and K combinations in prior corn, it would have been valuable to have more consistent soil nutrient levels from one year to the next (instead, there were very high levels of P in 2003, but only medium P levels in 2002 and 2004).

Plant measurements in this study were limited to above-ground sampling. It would have been interesting to also study treatment effects on soybean root development and distribution. Levels of soil nutrient concentration were generally well above the critical concentrations and that might have played an important role in the lack of soybean responses to previous fertility treatments. Effects might have been more apparent in more stressed conditions with regards to precipitation and disease pressure.

Soil spatial variability in the experimental sites proved to be a dominant concern in trying to demonstrate differences to P and K fertility treatments even when numerous replications and split-split plot designs are used.

With regards to the experimental design chosen for this study, some disadvantages of split-plot designs are that (a) generally a split plot experiment will be less precise than a fully randomized experiment of the same size (the claim that split-plot gives increased precision of information about the split plot factors is usually at the expense of a greater loss of precision of main plot factors), (b) the analysis is more complex, particularly if the data have missing values, covariates are to be used, or the data is used in regression analyses, (c) presentation of results can be more difficult, as several types of variation at multiple main treatment or sub-treatment levels need to represented in graphs and tables when interactions occur.

Future Research:

Future research should be more focused on the role that soil spatial variability plays in no-till soybean responses to direct and residual nutrient rates and placements. There appears to be little merit in future testing of residual fertility placement options following multiple corn hybrids and plant populations. Geo-statistics might be a more reasonable approach for analyzing some of the variable-soil experiments presented in this project.

Evaluation of additional soybean quality responses such as seed isoflavones concentrations and their relationships with yield and seed K concentrations might be of greater interest as soybeans are increasingly grown for nutraceutical markets.

Additional regression analyses between soil nutrient status and plant nutrient levels might be helpful after additional locations and years of investigations with a similar range in treatments. In that regard, the continuity of some of the experiments involved in this project would be useful if sufficient funding is available.

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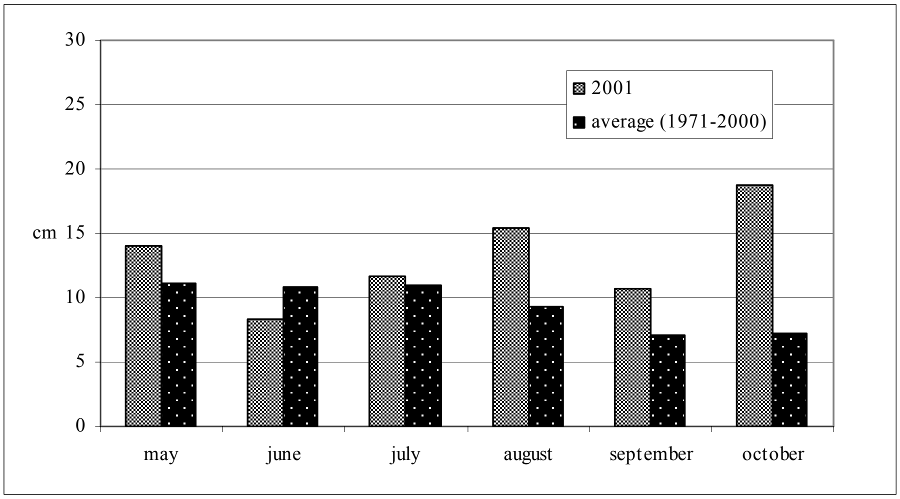
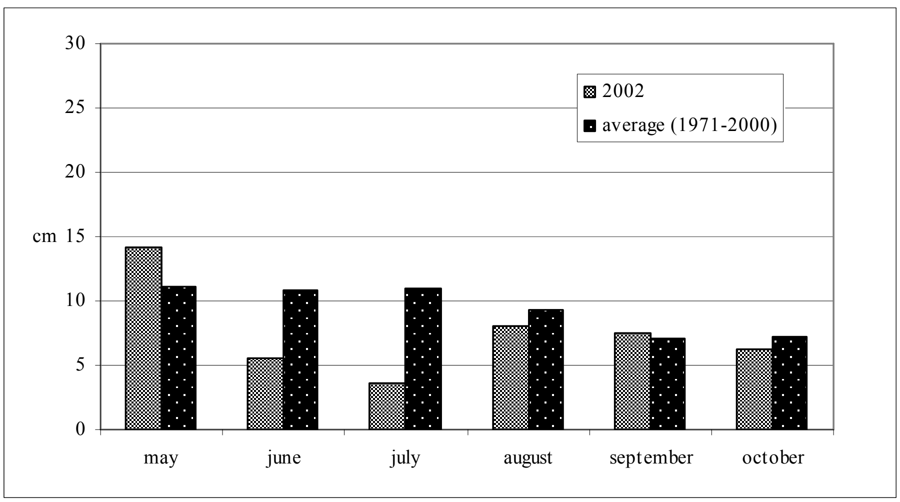
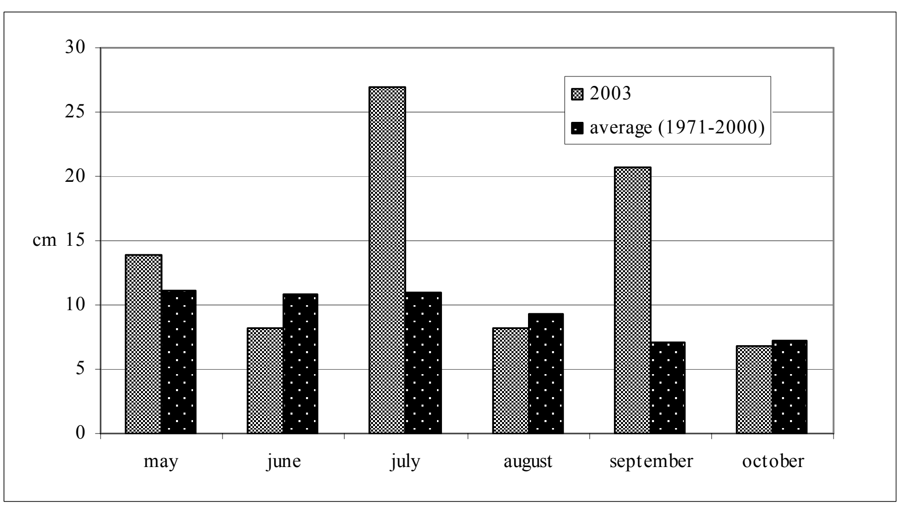
APPENDICES

Appendix A: Seasonal precipitation information

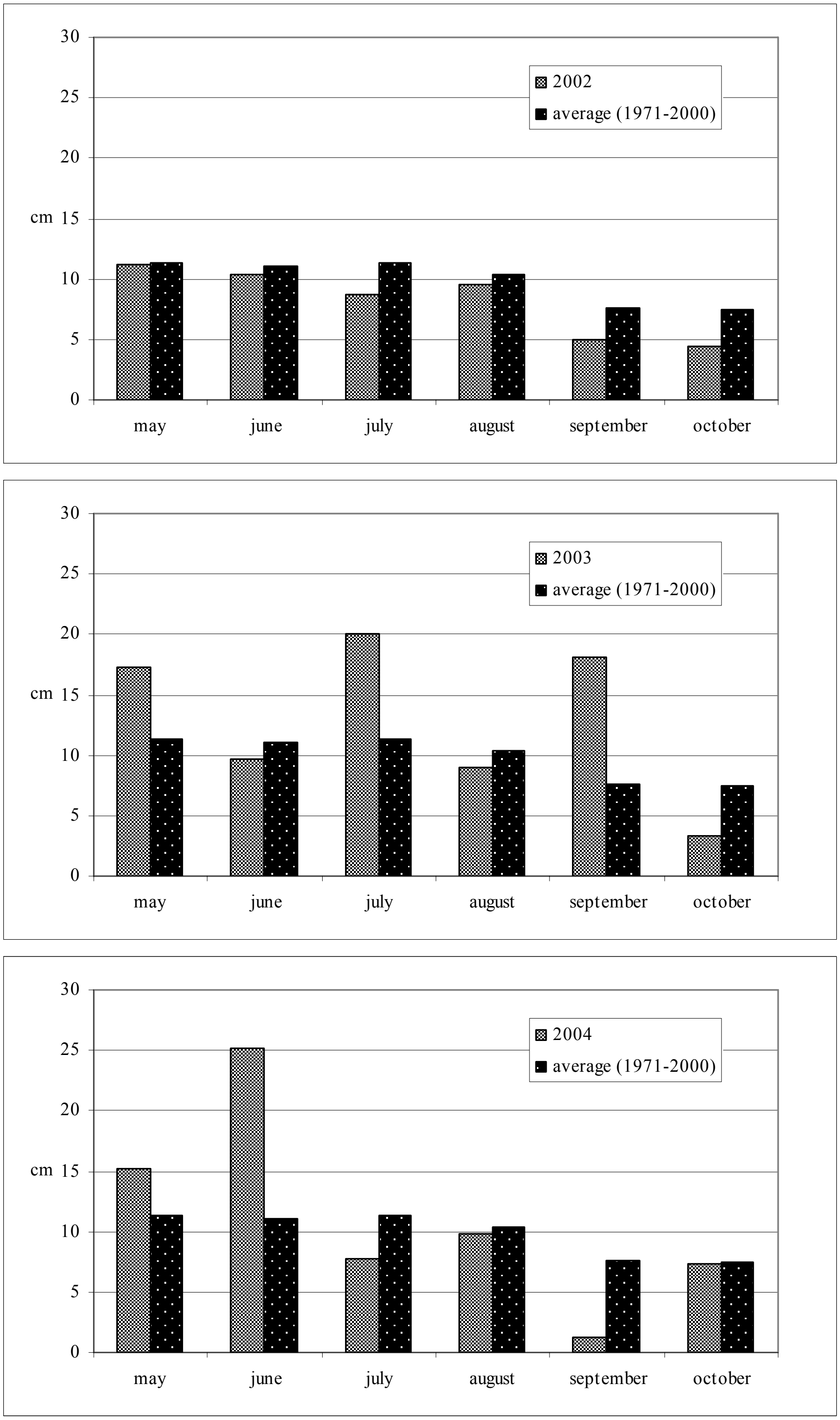
Appendix A-1. Monthly precipitation in 2001, 2002 and 2003 in comparison to the average (1971-2000) at the Davis-Purdue Agronomy Center, Farmland, IN.







Appendix A-2. Monthly precipitation in 2002, 2003 and 2004 in comparison to the average (1971-2000) at the Agronomy Center for Research and Education, West Lafayette, IN.



Appendix B: Combined year ANOVAs for Davis PAC

Appendix B-1: Combined year ANOVAs for plant parameters

Analysis of variance for Seed Yield in 2001

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	2.2	0.1619
K	2	30	1.47	0.2463
Tillage*K	4	30	1.08	0.3822
soil K	1	153	1.87	0.1733
soil K*Tillage*K	8	153	0.66	0.7294

MSE = 45035

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed Yield in 2002

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	1.31	0.3131
K	2	30	0.6	0.5564
Tillage*K	4	30	0.63	0.648
soil K	1	153	53.92	<.0001
soil K*Tillage*K	8	153	0.66	0.7254

MSE = 177741

Levels of significance < 0.05 were declared significant.

Analysis of variance for Leaf K conc. at the R1 growth stage in 2001

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	0.93	0.4251
K	2	30	0.8	0.4606
Tillage*K	4	30	2.39	0.0726
soil K	1	151	30.51	<.0001
soil K*Tillage*K	8	151	0.8	0.6034

MSE = 0.003360

Levels of significance < 0.05 were declared significant.

Analysis of variance for Leaf K conc. at the R1 growth stage in 2002

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	5.55	0.0239
K	2	30	1.98	0.1552
Tillage*K	4	30	2.83	0.0418
soil K	1	143	11.79	0.0008
soil K*Tillage*K	8	143	1.48	0.1711

MSE = 0.004849

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed K concentration in 2001

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	4.27	0.0458
K	2	30	18.48	<.0001
Tillage*K	4	30	1.16	0.35
soil K	1	153	328.65	<.0001
soil K*Tillage*K	8	153	1.66	0.1125

MSE = 0.04285

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed K concentration in 2002

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	0.09	0.9161
K	2	30	14.53	<.0001
Tillage*K	4	30	2.25	0.0869
soil K	1	153	77.09	<.0001
soil K*Tillage*K	8	153	1.19	0.3062

MSE = 0.02290

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed protein concentration in 2001

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	2.01	0.1843
K	2	30	3.34	0.049
Tillage*K	4	30	1.89	0.1381
soil K	1	152	49.63	<.0001
soil K*Tillage*K	8	152	0.84	0.5726

MSE = 0.3064

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed protein concentration in 2002

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	0.34	0.7222
K	2	30	2.33	0.1151
Tillage*K	4	30	1.78	0.1591
soil K	1	153	0.01	0.9188
soil K*Tillage*K	8	153	0.96	0.4659

MSE = 0.4634

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed oil concentration in 2001

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	2.39	0.1416
K	2	30	2.3	0.1177
Tillage*K	4	30	1	0.4226
soil K	1	152	36.82	<.0001
soil K*Tillage*K	8	152	1.08	0.3817

MSE = 0.04189

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed oil concentration in 2002

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	0.08	0.9269
K	2	30	6.46	0.0046
Tillage*K	4	30	2.93	0.0372
soil K	1	152	0.05	0.8244
soil K*Tillage*K	8	152	1.03	0.416

MSE = 0.1073

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed Yield in 2003

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	1.64	0.2422
K	2	30	3.8	0.0338
Tillage*K	4	30	1.88	0.1403
soil K	1	150	7.94	0.0055
soil K*Tillage*K	8	150	1.07	0.3874

MSE = 20711

Levels of significance < 0.05 were declared significant.

Analysis of variance for Leaf K conc. at the R1 growth stage in 2003

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	3.04	0.0931
K	2	30	33.94	<.0001
Tillage*K	4	30	2.65	0.0526
soil K	1	150	94.22	<.0001
soil K*Tillage*K	8	150	1.56	0.1428

MSE = 0.03010

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed K concentration in 2003

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	3.09	0.0899
K	2	30	4.91	0.0143
Tillage*K	4	30	1.33	0.2828
soil K	1	152	5.45	0.0209
soil K*Tillage*K	8	152	0.18	0.9927

MSE = 0.002338

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed protein concentration in 2003

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	1.01	0.4
K	2	30	16.95	<.0001
Tillage*K	4	30	0.46	0.7664
soil K	1	153	0.95	0.3305
soil K*Tillage*K	8	153	0.75	0.6488

MSE = 0.2028

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed oil concentration in 2003

Effect	Num. df	Den. df	F value	Pr >F
Tillage	2	10	1.45	0.2809
K	2	30	21.11	<.0001
Tillage*K	4	30	0.55	0.7036
soil K	1	153	0.65	0.4219
soil K*Tillage*K	8	153	0.32	0.9589

MSE = 0.04949

Levels of significance < 0.05 were declared significant.

Appendix B-2: ANOVAs for soil parameters by year

Analysis of variance for soil available P (0-5cm) in 2001

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.2	0.8205
fert	2	192	1	0.3691
tillage*fert	4	192	0.8	0.5236

MSE = 242.24

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (0-5cm) in 2002

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	6	0.68	0.5426
fert	2	126	0.83	0.4389
tillage*fert	4	126	0.57	0.6836

MSE = 479.02

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (0-5cm) in 2003

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.59	0.5719
fert	2	191	0.16	0.8556
tillage*fert	4	191	0.43	0.7858

MSE = 372.34

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (5-15cm) in 2001

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.24	0.7908
fert	2	192	1.48	0.2308
tillage*fert	4	192	0.26	0.9048

MSE = 50.3477

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (5-15cm) in 2002

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	6	0.66	0.5527
fert	2	125	0.14	0.8703
tillage*fert	4	125	0.19	0.9413

MSE = 89.7377

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (5-15cm) in 2003

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	2.57	0.1255
fert	2	192	0.11	0.8915
tillage*fert	4	192	0.34	0.851

MSE = 96.6923

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (15-25cm) in 2001

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.06	0.9377
fert	2	192	1.86	0.1582
tillage*fert	4	192	0.39	0.8158

MSE = 22.7267

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (15-25cm) in 2002

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	6	0.71	0.5291
fert	2	126	0.28	0.7551
tillage*fert	4	126	0.97	0.4243

MSE = 37.5833

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (15-25cm) in 2003

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.76	0.493
fert	2	192	0.29	0.7465
tillage*fert	4	192	0.63	0.6425

MSE = 37.4819

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-5cm) in 2001

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.23	0.8016
fert	2	192	3.27	0.0402
tillage*fert	4	192	1.44	0.2222

MSE = 573.26

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-5cm) in 2002

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	6	0.14	0.8725
fert	2	126	4.13	0.0183
tillage*fert	4	126	0.8	0.5273

MSE = 1547.93

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-5cm) in 2003

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.17	0.8491
fert	2	190	49.89	<.0001
tillage*fert	4	190	0.7	0.5915

MSE = 1636.32

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (5-15cm) in 2001

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	1.27	0.3215
fert	2	192	0.15	0.8578
tillage*fert	4	192	0.18	0.9463

MSE = 291.90

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (5-15cm) in 2002

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	6	0.96	0.4336
fert	2	126	1.06	0.3499
tillage*fert	4	126	0.27	0.8968

MSE = 588.28

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (5-15cm) in 2003

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	0.76	0.4943
fert	2	191	8.14	0.0004
tillage*fert	4	191	0.78	0.5388

MSE = 637.18

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (15-25cm) in 2001

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	1.45	0.2804
fert	2	192	0.01	0.9863
tillage*fert	4	192	0.61	0.6532

MSE = 264.75

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (15-25cm) in 2002

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	6	2.67	0.1484
fert	2	124	0.27	0.7644
tillage*fert	4	124	0.11	0.9779

MSE = 435.74

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (15-25cm) in 2003

Effect	Num. df	Den. df	F value	Pr >F
tillage	2	10	3.37	0.0759
fert	2	190	2.72	0.0686
tillage*fert	4	190	1.28	0.2807

MSE = 509.28

Levels of significance < 0.05 were declared significant.

Appendix C: Combined year ANOVAs for ASREC

Appendix C-1: Combined year ANOVAs for plant parameters

Analysis of variance for Seed Yield

Effect	Num. df	Den. df	F value	Pr >F
year	2	9.94	29.18	<.0001
hybrid	1	30.1	0.29	0.5921
year*hybrid	2	30.1	2.81	0.0763
population	1	30.1	0.57	0.4566
year*population	2	30.1	0.66	0.5247
hybrid*population	1	30.1	0.4	0.5329
year*hybrid*population	2	30.1	0.42	0.6595
fert	4	175	1.37	0.2455
year*fert	8	175	0.62	0.7618
hybrid*fert	4	175	0.49	0.7441
population*fert	4	175	1.22	0.3056
hybrid*population*fert	4	175	0.37	0.8324
year*population*fert	8	175	0.85	0.5606

MSE = 65656

Levels of significance < 0.05 were declared significant.

Analysis of variance for Leaf P conc. at the R1 growth stage

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	2.47	0.1346
hybrid	1	9.96	0.6	0.4582
year*hybrid	2	9.96	0.58	0.5759
population	1	20.2	1.68	0.2102
year*population	2	20.2	3.11	0.0666
hybrid*population	1	20.2	0.08	0.7865
year*hybrid*population	2	20.2	2.8	0.0845
fert	4	175	2.98	0.0205
year*fert	8	175	3.23	0.0019
hybrid*fert	4	175	0.56	0.6896
population*fert	4	175	0.97	0.4248
hybrid*population*fert	4	175	0.58	0.6805
year*population*fert	8	175	1.41	0.1961

MSE = 0.001623

Levels of significance < 0.05 were declared significant.

Analysis of variance for Leaf K conc. at the R1 growth stage

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	19.89	0.0003
hybrid	1	9.88	1.49	0.2504
year*hybrid	2	9.88	1.1	0.3706
population	1	20.2	0.38	0.5428
year*population	2	20.2	0.75	0.4852
hybrid*population	1	20.2	2.82	0.1087
year*hybrid*population	2	20.2	2.51	0.1065
fert	4	173	8.94	<.0001
year*fert	8	173	1.38	0.2104
hybrid*fert	4	173	3.06	0.0182
population*fert	4	174	2.33	0.0576
hybrid*population*fert	4	174	0.87	0.4808
year*hybrid*fert	8	173	1.29	0.2508

MSE = 0.03174

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed P concentration

Effect	Num. df	Den. df	F value	Pr >F
year	2	9.92	2.72	0.1144
hybrid	1	10.1	0.9	0.3652
year*hybrid	2	10.1	0.5	0.6215
population	1	20.4	0.22	0.6431
year*population	2	20.3	0.12	0.8891
hybrid*population	1	20.4	0.01	0.932
year*hybrid*population	2	20.3	6.54	0.0064
fert	4	157	3.94	0.0045
year*fert	8	157	1.11	0.3584
hybrid*fert	4	157	1.39	0.2399
population*fert	4	157	1.91	0.1106
hybrid*population*fert	4	157	2.05	0.0895
year*hybr*population*fert	24	157	0.93	0.5619

MSE = 0.000411

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed K concentration

Effect	Num. df	Den. df	F value	Pr >F
year	2	20	44.77	<.0001
hybrid	1	20	0.32	0.5791
year*hybrid	2	20	0.22	0.8017
population	1	20.1	0.85	0.3687
year*population	2	20.1	0.04	0.96
hybrid*population	1	20.1	1.6	0.2211
year*hybrid*population	2	20.1	7.44	0.0038
fert	4	159	2.97	0.0211
year*fert	8	159	1.13	0.3471
hybrid*fert	4	159	1.26	0.2871
population*fert	4	159	1.43	0.228
hybrid*population*fert	4	159	0.83	0.5051
year*hybr*population*fert	24	159	0.73	0.8128

MSE = 0.002861

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed oil concentration

Effect	Num. df	Den. df	F value	Pr >F
year	1	14	181.33	<.0001
hybrid	1	14	0.03	0.8691
year*hybrid	1	14	1.59	0.2284
population	1	14	0.01	0.9444
year*population	1	14	1.41	0.2555
hybrid*population	1	14	0.11	0.7452
year*hybrid*population	1	14	3.42	0.0856
fert	4	118	0.9	0.4675
year*fert	4	118	2.75	0.0316
hybrid*fert	4	118	2.66	0.0361
population*fert	4	118	2.76	0.0308
hybrid*population*fert	4	118	1.09	0.3672
year*population*fert	4	118	0.78	0.5402

MSE = 0.03479

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed protein concentration

Effect	Num. df	Den. df	F value	Pr >F
year	1	14.1	291.21	<.0001
hybrid	1	14.1	0.02	0.9017
year*hybrid	1	14.1	2.27	0.1539
population	1	14.1	0	0.9726
year*population	1	14.1	1.83	0.1974
hybrid*population	1	14.1	0.02	0.8985
year*hybrid*population	1	14.1	9.99	0.0069
fert	4	117	0.55	0.7003
year*fert	4	117	3.36	0.0121
hybrid*fert	4	117	1.71	0.1533
population*fert	4	117	1.98	0.1014
hybrid*population*fert	4	117	1.74	0.1462
year*population*fert	4	117	0.68	0.604

MSE = 0.1129

Levels of significance < 0.05 were declared significant.

Appendix C-2: Combined year ANOVAs for soil parameters

Analysis of variance for soil available P (0-10cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	12.23	0.0021
hybrid	1	10	0.65	0.4403
year*hybrid	2	10	0.85	0.4549
population	1	20	0.19	0.6699
year*population	2	20	1.07	0.3619
hybrid*population	1	20	0.54	0.4728
year*hybrid*population	2	20	2.08	0.1515
fert	4	175	10.19	<.0001
year*fert	8	175	0.76	0.6425
hybrid*fert	4	175	2.02	0.094
population*fert	4	175	2.18	0.0728
hybrid*population*fert	4	175	0.72	0.5826
year*population*fert	8	175	1.66	0.1101

MSE = 87.1206
Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (10-20cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	2.13	0.1693
hybrid	1	10	0.23	0.6428
year*hybrid	2	10	2.15	0.1671
population	1	20	0.75	0.3983
year*population	2	20	1.38	0.2751
hybrid*population	1	20	0.93	0.3457
year*hybrid*population	2	20	0.62	0.5496
fert	4	172	5.48	0.0004
year*fert	8	172	2.86	0.0052
hybrid*fert	4	172	2.45	0.0483
population*fert	4	172	1.57	0.1854
hybrid*population*fert	4	172	1.34	0.2564
year*population*fert	8	172	1.99	0.0503

MSE = 42.4851
Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (20-40cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	24.68	0.0001
hybrid	1	10	0.27	0.614
year*hybrid	2	10	5.45	0.0251
population	1	20	0.23	0.6345
year*population	2	20	0	0.9967
hybrid*population	1	20	0.24	0.63
year*hybrid*population	2	20	0.22	0.8035
fert	4	175	4.99	0.0008
year*fert	8	175	3.64	0.0006
hybrid*fert	4	175	1.16	0.3321
population*fert	4	175	1.45	0.2197
hybrid*population*fert	4	175	0.79	0.5324
year*population*fert	8	175	0.75	0.645

MSE = 49.7798
Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (0-10cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	9.16	0.0055
hybrid	1	10	0.57	0.4659
year*hybrid	2	10	1.13	0.3623
population	1	20	0.44	0.515
year*population	2	20	1.18	0.3276
hybrid*population	1	20	0.29	0.5952
year*hybrid*population	2	20	3.49	0.05
fert	4	173	12.54	<.0001
year*fert	8	173	0.28	0.9725
hybrid*fert	4	173	1.73	0.1449
population*fert	4	173	2.59	0.0382
hybrid*population*fert	4	173	0.33	0.8605
year*population*fert	8	173	0.59	0.7852

MSE = 81.2434

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (10-20cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	1.43	0.2851
hybrid	1	10	0.07	0.8031
year*hybrid	2	10	1.42	0.287
population	1	20	3.84	0.0642
year*population	2	20	1.89	0.1768
hybrid*population	1	20	0.05	0.8191
year*hybrid*population	2	20	1.95	0.1682
fert	4	174	0.68	0.6037
year*fert	8	174	0.74	0.6599
hybrid*fert	4	174	0.99	0.412
population*fert	4	174	3.09	0.0172
hybrid*population*fert	4	174	0.68	0.6059
year*population*fert	8	174	0.71	0.6819

MSE = 52.7694

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (20-40cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	2.15	0.1671
hybrid	1	10	1.73	0.2182
year*hybrid	2	10	3.13	0.088
population	1	20	3.09	0.0943
year*population	2	20	0.34	0.7142
hybrid*population	1	20	0.14	0.7164
year*hybrid*population	2	20	0.01	0.9944
fert	4	175	1.36	0.2487
year*fert	8	175	1.81	0.0783
hybrid*fert	4	175	1.7	0.1517
population*fert	4	175	3.17	0.0152
hybrid*population*fert	4	175	1.8	0.1301
year*population*fert	8	175	0.26	0.9787

MSE = 30.6346

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-10cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	2.38	0.1423
hybrid	1	10	1.55	0.2411
year*hybrid	2	10	0.77	0.4868
population	1	20	2.49	0.13
year*population	2	20	0	0.9986
hybrid*population	1	20	3.87	0.0632
year*hybrid*population	2	20	3.12	0.066
fert	4	170	6.6	<.0001
year*fert	8	170	2.25	0.0261
hybrid*fert	4	170	1.27	0.2826
population*fert	4	170	0.78	0.5373
hybrid*population*fert	4	170	1.83	0.125
year*population*fert	8	170	0.72	0.6739

MSE = 1042.50

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (10-20cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	5.18	0.0286
hybrid	1	10	1.44	0.2578
year*hybrid	2	10	0.34	0.7215
population	1	20	1.84	0.1895
year*population	2	20	0.32	0.7315
hybrid*population	1	20	2.35	0.1406
year*hybrid*population	2	20	0.71	0.5013
fert	4	175	2.02	0.0935
year*fert	8	175	1.14	0.3371
hybrid*fert	4	175	0.24	0.9179
population*fert	4	175	2.15	0.0766
hybrid*population*fert	4	175	2.3	0.0605
year*population*fert	8	175	1.56	0.1412

MSE = 220.63

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (20-40cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	5.04	0.0306
hybrid	1	10	0.4	0.5408
year*hybrid	2	10	0.02	0.9769
population	1	20	0.15	0.7073
year*population	2	20	0.21	0.8158
hybrid*population	1	20	1.05	0.3174
year*hybrid*population	2	20	0.54	0.5916
fert	4	173	3.19	0.0148
year*fert	8	173	0.59	0.7851
hybrid*fert	4	173	0.43	0.7849
population*fert	4	173	1.35	0.2519
hybrid*population*fert	4	173	1.09	0.3645
year*population*fert	8	173	0.62	0.7601

MSE = 192.01

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-10cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	5.28	0.0272
hybrid	1	10	0.81	0.3893
year*hybrid	2	10	0.18	0.8378
population	1	20	0.22	0.6427
year*population	2	20	0.87	0.4327
hybrid*population	1	20	2.96	0.1006
year*hybrid*population	2	20	2.6	0.0994
fert	4	175	17.05	<.0001
year*fert	8	175	3.39	0.0012
hybrid*fert	4	175	1.27	0.2832
population*fert	4	175	2.35	0.0565
hybrid*population*fert	4	175	1.17	0.326
year*population*fert	8	175	1.18	0.3113

MSE = 440.10

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (10-20cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	2.5	0.1317
hybrid	1	10	1.45	0.2562
year*hybrid	2	10	0.04	0.9636
population	1	20	0.1	0.7573
year*population	2	20	0.04	0.9608
hybrid*population	1	20	0.98	0.3331
year*hybrid*population	2	20	1.74	0.2011
fert	4	175	2.06	0.0885
year*fert	8	175	1.01	0.4324
hybrid*fert	4	175	0.53	0.7135
population*fert	4	175	2.82	0.0268
hybrid*population*fert	4	175	2.71	0.0617
year*population*fert	8	175	1.14	0.3368

MSE = 156.17

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (20-40cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
year	2	10	4.04	0.0517
hybrid	1	10	1.85	0.2036
year*hybrid	2	10	0.57	0.583
population	1	20	0.97	0.3353
year*population	2	20	0.15	0.8588
hybrid*population	1	20	0.31	0.5827
year*hybrid*population	2	20	0.06	0.945
fert	4	174	3.18	0.0149
year*fert	8	174	1.06	0.3937
hybrid*fert	4	174	1.46	0.2157
population*fert	4	174	3.51	0.0088
hybrid*population*fert	4	174	1.27	0.2843
year*population*fert	8	174	1.58	0.1347

MSE = 154.74

Levels of significance < 0.05 were declared significant.

Appendix D: Combined year and annual ANOVAs for ACRE

Appendix D-1: Combined year ANOVAs for plant parameter

Analysis of variance for Seed Yield

Effect	Num. df	Den. df	F value	Pr >F
year	1	9	11.93	0.0072
hybrid	1	9	2.7	0.1348
year*hybrid	1	9	2.55	0.1445
fert	4	70	19.44	<.0001
year*fert	4	70	18.6	<.0001
hybrid*fert	4	70	1.84	0.1318
year*hybrid*fert	4	70	2.61	0.0427
K	1	89	0.5	0.4797
year*K	1	89	3.71	0.0572
hybrid*K	1	89	0.09	0.7602
fert*K	4	89	2.62	0.0402
hybrid*fert*K	4	89	1.63	0.1748
year*fert*K	4	89	2.42	0.0543

MSE = 27014

Levels of significance < 0.05 were declared significant.

Analysis of variance for Leaf P conc. at the R1 growth stage

Effect	Num. df	Den. df	F value	Pr >F
year	1	9	30.63	0.0004
hybrid	1	9	7.78	0.0211
year*hybrid	1	9	1.67	0.2286
fert	4	70	7.14	<.0001
year*fert	4	70	4.66	0.0022
hybrid*fert	4	70	1.36	0.2553
year*hybrid*fert	4	70	1.05	0.3872
K	1	91	1.52	0.2215
year*K	1	91	0.26	0.6129
hybrid*K	1	91	0.04	0.8418
fert*K	4	91	1.76	0.1434
hybrid*fert*K	4	91	0.48	0.7509
year*fert*K	4	91	1.12	0.3497

MSE = 0.000687

Levels of significance < 0.05 were declared significant.

Analysis of variance for Leaf K conc. at the R1 growth stage

Effect	Num. df	Den. df	F value	Pr >F
year	1	8.99	0.53	0.4851
hybrid	1	9.17	2.94	0.1199
year*hybrid	1	9.17	0	0.9822
fert	4	71.6	1.4	0.242
year*fert	4	71.6	0.75	0.56
hybrid*fert	4	71.6	1.92	0.1167
year*hybrid*fert	4	71.6	0.44	0.7779
K	1	88.6	0.07	0.7864
year*K	1	88.6	0.14	0.7082
hybrid*K	1	88.6	0.03	0.8702
fert*K	4	88.6	1.69	0.1601
hybrid*fert*K	4	88.6	1.18	0.3256
year*hybrid*fert*K	9	88.4	2.02	0.0457

MSE = 0.05348

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed P concentration

Effect	Num. df	Den. df	F value	Pr >F
year	1	9	102.4	<.0001
hybrid	1	9	1.32	0.2796
year*hybrid	1	9	0.17	0.692
fert	4	70	20.58	<.0001
year*fert	4	70	17.64	<.0001
hybrid*fert	4	70	2.04	0.0976
year*hybrid2*fert	4	70	2.29	0.0678
K	1	89	0.24	0.6251
year*K	1	89	0.22	0.6411
hybrid*K	1	89	0.21	0.6457
fert*K	4	89	1.04	0.3933
hybrid*fert*K	4	89	0.35	0.8442
year*fert*K	4	89	1.37	0.2509

MSE = 0.000445

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed K concentration

Effect	Num. df	Den. df	F value	Pr >F
year	1	9	2.99	0.1177
hybrid	1	9	0	0.9727
year*hybrid	1	9	0.13	0.7294
fert	4	69	3.36	0.0142
year*fert	4	69	1.61	0.1813
hybrid*fert	4	69	1.44	0.2286
year*hybrid*fert	4	69	1.15	0.339
K	1	87	21.5	<.0001
year*K	1	87	0.36	0.5512
hybrid*K	1	87	0.22	0.64
fert*K	4	87	0.29	0.883
hybrid*fert*K	4	87	0.64	0.6374
year*fert*K	4	87	1.46	0.2199

MSE = 0.001507

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed oil concentration

Effect	Num. df	Den. df	F value	Pr >F
year	1	9	226.01	<.0001
hybrid	1	9	1	0.3441
year*hybrid	1	9	4.25	0.0693
fert	4	69	0.81	0.5218
year*fert	4	69	8.24	<.0001
hybrid*fert	4	69	0.65	0.6284
year*hybrid*fert	4	69	1.44	0.2301
K	1	87	0.38	0.5377
year*K	1	87	0.22	0.6389
hybrid*K	1	87	1.72	0.1934
fert*K	4	87	1.16	0.333
hybrid*fert*K	4	87	0.97	0.4295
year*fert*K	4	87	1.44	0.2276

MSE = 0.02707

Levels of significance < 0.05 were declared significant.

Analysis of variance for Seed protein concentration

Effect	Num. df	Den. df	F value	Pr >F
year	1	9	3.89	0.0799
hybrid	1	9	0.01	0.9126
year*hybrid	1	9	0.71	0.4207
fert	4	70	4.98	0.0014
year*fert	4	70	5.71	0.0005
hybrid*fert	4	70	1.02	0.402
year*hybrid*fert	4	70	2.08	0.0929
K	1	89	0.25	0.6175
year*K	1	89	7.19	0.0087
hybrid*K	1	89	2.01	0.1597
fert*K	4	89	0.87	0.4848
hybrid*fert*K	4	89	1.32	0.2703
year*fert*K	4	89	0.43	0.7873

MSE = 0.05521

Levels of significance < 0.05 were declared significant.

Appendix D-2: ANOVAs for soil parameters in 2003

Analysis of variance for soil available P (0-10cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	0.2	0.6761
fert	4	38	5.68	0.0011
hybrid*fert	4	38	0.45	0.7698

MSE = 106.86

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (10-20cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	0.07	0.8042
fert	4	37	0.32	0.8626
hybrid*fert	4	37	0.37	0.83

MSE = 154.67

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (20-40cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	0.12	0.7426
fert	4	39	1.95	0.1206
hybrid*fert	4	39	0.58	0.6777

MSE = 219.79

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (0-10cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	0.42	0.5471
fert	4	39	1.09	0.3735
hybrid*fert	4	39	0.48	0.7508

MSE = 213.74

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (10-20cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	0	0.9714
fert	4	40	0.75	0.5658
hybrid*fert	4	40	0.19	0.9437

MSE = 142.04

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (20-40cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	2.37	0.1844
fert	4	38	0.7	0.5942
hybrid*fert	4	38	0.67	0.6186

MSE = 325.69

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-10cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	2.3	0.1901
fert	4	40	4.15	0.0066
hybrid*fert	4	40	0.99	0.4266

MSE = 2000.52

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (10-20cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	2.74	0.1586
fert	4	40	3.01	0.0293
hybrid*fert	4	40	0.76	0.5555

MSE = 283.57

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (20-40cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	1.47	0.2797
fert	4	39	3.23	0.022
hybrid*fert	4	39	2.06	0.1054

MSE = 150.91

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-10cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	0.27	0.6241
fert	4	39	1.49	0.2227
hybrid*fert	4	39	0.75	0.566

MSE = 572.70

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (10-20cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	2.85	0.1523
fert	4	40	1.68	0.173
hybrid*fert	4	40	0.66	0.62

MSE = 153.55

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (20-40cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	5	0.04	0.8464
fert	4	38	1.57	0.201
hybrid*fert	4	38	0.57	0.6831

MSE = 214.30

Levels of significance < 0.05 were declared significant.

Appendix D-3: ANOVAs for soil parameters in 2004

Analysis of variance for soil available P (0-10cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	0.16	0.7095
fert	4	29	4.57	0.0055
hybrid*fert	4	29	0.32	0.8641

MSE = 11.467

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (10-20cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	0.36	0.5794
fert	4	28	3.1	0.0312
hybrid*fert	4	28	1.94	0.1323

MSE = 46.60

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (20-40cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	1.12	0.3501
fert	4	28	0.66	0.6244
hybrid*fert	4	28	1.56	0.2118

MSE = 12.4971

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (0-10cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	0.1	0.7714
fert	4	29	7.97	0.0002
hybrid*fert	4	29	1.3	0.2919

MSE = 9.5767

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (10-20cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	0.14	0.7275
fert	4	29	1.06	0.395
hybrid*fert	4	29	0.68	0.6091

MSE = 20.6739

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil available P (20-40cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	4.33	0.1059
fert	4	29	0.48	0.7505
hybrid*fert	4	29	2.56	0.0599

MSE = 7.1634

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-10cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	0.26	0.6383
fert	4	27	3.03	0.0348
hybrid*fert	4	27	1.28	0.3034

MSE = 866.85

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (10-20cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	0.14	0.7247
fert	4	27	1.47	0.2397
hybrid*fert	4	27	0.65	0.6306

MSE = 171.93

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (20-40cm) at the in-row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	1.32	0.314
fert	4	26	0.65	0.6295
hybrid*fert	4	26	2.72	0.0513

MSE = 69.8405

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (0-10cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	1.13	0.3468
fert	4	27	0.37	0.8291
hybrid*fert	4	27	2.72	0.0504

MSE = 304.95

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (10-20cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	0.51	0.5151
fert	4	28	1.01	0.4215
hybrid*fert	4	28	1.6	0.2018

MSE = 43.6370

Levels of significance < 0.05 were declared significant.

Analysis of variance for soil exchangeable K (20-40cm) at the between row position

Effect	Num. df	Den. df	F value	Pr >F
hybrid	1	4	2.23	0.2095
fert	4	27	2.23	0.0925
hybrid*fert	4	27	4.35	0.0077

MSE = 46.3975

Levels of significance < 0.05 were declared significant.