CORRECTION OF POTASSIUM DEFICIENCY IN SOYBEAN AND CORN PRODUCTION IN SOUTHEAST KANSAS

by

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Abstract

Over the last decade low (< 130 mg kg^{-1}) soil test potassium (K) levels and increased crop K deficiency have become a major concern in the clay-pan soils of southeast Kansas. The use of more intense crop rotations and the increased production of high K extracting crops (e.g. soybeans (*Glycine max* L.)) has significantly increased K removal from these soils. In addition, the traditional use of the nutrient sufficiency-based fertilizer recommendations has resulted in K application rates being substantially lower than removal rates. Because of these practices, many soils that had naturally elevated K availability 25 years ago have declined in K content. More troubling is the extreme yearly variation of soil test exchangeable K levels reported in the region, which has many producers and consultants concerned about proper K management.

This study was initiated to examine the extent of K soil test variation and to determine if the variability is impacting plant K availability by analyzing soybean leaf K content and crop yield. A major objective of our research is to identify the mechanism(s) driving these changes in soil test K levels and K availability to crops during the growing season. The long-term goal is to be able to design a soil sampling system and develop alternative K fertilizer recommendation strategies that could alleviate K deficiency impacts on crop yield. Evaluation of different K fertilizer application practices including rate of application and broadcast or surface band methods of application were studied as tools to correct soybean K deficiency. The direct and residual impacts of K fertilization and placement were also evaluated on corn (*Zea mays* L.) grown in the rotation with the soybeans.

Results observed from this research showed that monthly soil samples taken during three crop years at multiple locations have ammonium acetate exchangeable K levels that indeed change dramatically. The data we collected together with data accumulated by farmers and crop consultants showed significant fluctuation in exchangeable K levels of up to 50% on a yearly and even on a monthly basis. Levels seem to demonstrate seasonal changes: higher in the spring months and then decline in the summer and fall. Potassium soil test levels also appear to follow a similar trend as monthly precipitation and soil moisture status. During wet months soil levels tend to increase and then decline during drier months, however, this is not a perfect relationship and other factors are likely to be involved in regulating soil test K levels. No clear effect of K fertilization or method of placement on soybean or corn yields was observed during the study.

However, soybean leaf samples revealed that on very low (< 90 mg kg^{-1}) soil test sites surface band applied fertilizer increased leaf K concentrations compared to broadcasted applications. Furthermore, the corn study revealed no distinct difference between using a split annual or biannual fertilizer application system.

Maintaining soil test K levels above 130 mg kg^{-1} using a spring soil test appears to be a successful strategy for avoiding K deficiency. Traditionally most soil sampling occurs in late summer or fall when soil conditions are dry. Our data has demonstrated that during this period one should expect to encounter low soil test results that may not be true indicators of soil K levels during the spring planting months. With that said, spring soil sampling can be difficult to do in a timely fashion due to weather, as well as potential labor restrictions. Another critical point is to not switch back and forth between spring and fall sampling dates. Staying consistent with your sample timing will minimize the seasonal variability that is frequently experienced. Additionally, adopting a build and maintain fertilizer recommendation philosophy rather than a nutrient sufficiency-based recommendation approach is a better nutrient budgeting method to avoid having removal rates exceeding nutrient additions. The best K management proposal would be to consider using a build and maintain approach in combination with basing fertilizer rates on spring soil test K levels.

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Dedication

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"Don't tell me the sky is the limit when there are footprints on the Moon" - Unknown

Chapter 1 - Literature Review

Introduction

In 2010, Kansas production of soybeans (*Glycine max* L.) was 3.8 million metric tons (MT) and corn (*Zea mays* L.) was 14.8 million MT of harvested grain (USDA, 2011). Assuming an average grain potassium (K) concentration of 20 g K kg^{-1} for soybean and 3.5 g K kg^{-1} for corn, an estimated 127,800 MT of K was removed from the soil just through soybean and corn production. The net loss of K from Kansas soils used to produce soybean and corn grains indicates that eventually, if not already, K supplementation will be a necessity. Many soils in Kansas are inherently high in K and fertilization is uncommon. The one exception is the older and highly weathered soils of southeastern Kansas, where K deficiency symptoms are becoming increasingly widespread. The increased occurrences of K deficiency are caused by inadequate fertilization in combination with continuous cropping. With ever increasing costs of inputs involved in crop production, especially K fertilizer, and higher grain prices in 2011, having a sound K management plan is essential to a producer's profitability in the future.

Potassium's Role in Plant Growth

Potassium (K) is an essential macronutrient involved in regulating many processes that are vital to plant growth and reproduction. Specifically, K plays a vital role in plant-water relations, photosynthesis, enzyme activation, sugar and starch transport, lignification, plant growth mechanisms and many other important functions (Marschner, 1995). Potassium is absorbed by plants in larger amounts than any other nutrient except nitrogen (Havlin et al., 2005). In fact, many plant species will absorb more K than they actually need when it is readily available. This is commonly referred to as luxury consumption. Unlike nitrogen, phosphorus and most other nutrients, K is not a component of biochemical compounds in the plant (Havlin et al., 2005). Potassium ions exist either solely in plant cellular solution or bound to negative tissue surfaces within plants. As a result, K strongly influences the ionic strength of solutions and charge balance inside plant cells (Havlin et al., 2005). The ionic balance in plant cells helps regulate plant-water relations and provides much of the osmotic pull that draws water into plants.

Potassium ions are the major osmotic component involved with stomatal movement. Early work done by Fischer (1968) and Fischer and Hsiao (1968) demonstrated how K flux into and out of stomatal guard cells controlled stomatal aperture by affecting osmotic potential of the guard cells. Further research conducted by Talbott and Zeiger (1996) found that K and sucrose both play a key role in guard cell osmoregulation. During the course of a day K promotes stomatal opening early in the day and then gives way to sucrose as the principle osmotic force around mid-day (Talbott and Zeiger, 1996). Due to the close relationship between K guard cell concentration and stomatal aperture, insufficient leaf levels of K can lead to decreased stomatal conductance (Huber, 1985; Longstreth and Nobel, 1980). As a result, certain K-deficient plants have higher transpiration losses due to delayed stomatal resistance (Huber, 1985; Graham and Ulrich, 1972). Additionally, accumulation of K in plant roots produces a gradient of osmotic pressure that draws water into plant roots. When K is deficient plants are less able to absorb water and are more subject to drought stress when water is in short supply (Huber, 1985; Graham and Ulrich, 1972).

The decrease in stomatal conductance also leads to decreased photosynthesis per unit leaf area (Huber, 1985; Wolf et al., 1976). Potassium maintains stomatal aperture which not only influences plant water use efficiency, but also subsequent inflow movement of carbon dioxide (CO_2) into plant leaves. When K supply is limited photosynthetic fixation of CO_2 is repressed, whereas photorespiration and respiration are stimulated (Jackson and Volk, 1968). However, the reduction in stomatal conductance only partial accounts for the decline in photosynthetic activity. Biochemical factors also contribute to reduced photosynthesis, especially when K deficiency becomes severe (Bednarz et al., 1998; Tester and Blatt, 1989; Huber, 1985). Biochemical limitations under low K conditions are partly related to the need of K for the photosynthetic transfer of radiant energy into chemical energy through the production of ATP (Havlin et al., 2005). Shingles and McCarty (1994) further demonstrated the importance of an adequate K supply for optimal activity of ATP. The energy that is derived from ATP is required to power metabolic processes in plants that produce carbohydrates, proteins and other compounds essential for crop productivity and quality.

In addition to reduced photosynthesis under plant K starvation, the transport of photosynthetic assimilates away from source tissue is also restricted (Mengel, 1980; Ashley and Goodson, 1972). The accumulation and translocation of newly synthesized carbohydrates, especially during grain fill, requires K (Mills and Jones, 1996). In K-deficient plants the lack of translocation of carbohydrates creates a mass build-up of sugars that can indirectly limit plant photosynthesis (Jackson and Volk, 1968).

Potassium plays a major role in plant metabolism by activating several key enzymes. Potassium either directly controls or stimulates the activation of over 60 different enzymes involved in plant growth (Marschner, 1995). Enzymes are proteins that serve as catalysts for chemical reactions that occur in plants. Potassium changes the physical shape of enzyme molecules, exposing the appropriate chemically active sites for reaction (Evans and Wilde, 1971). The amount of K in the plant determines how many of the enzymes can be activated and the rate at which the chemical reactions can proceed (International Plant Nutrition Institute, 2006). Potassium activates enzymes involved with starch synthesis, nitrogen metabolism, photophosphorylation glycolysis and oxidative phosphorylation (Liebhardt, 1968; Evans and Sorger, 1966).

Potassium plays significant roles in helping plants adapt to environmental stresses, resulting in improved crop quality. High levels of available K improves crop physical condition, disease resistance, drought tolerance, harvestability and feeding value of grain. Potassium deficient soybeans are highly susceptible to pod and stem blight and studies have shown that with high rates of K fertilizer disease incidence is dramatically reduced (Havlin et al., 2005). Adequate K levels in soybeans enhances seed size, produces less shriveled and moldy seed, and improves grain oil content. Application of K, in conjunction with more resistant varieties, has provided practical control of Stewart's wilt (Spencer and McNew, 1938) and Stalk rot (Ellett, 1973; Hooker 1966) of corn. Studies have also shown that when supplemental K fertilization was applied, corn plants produced grain with increased protein and amino acid content (Usherwood, 1985). Additionally, K fertilization of corn produces earlier silking, uniform maturity, improved stalk quality and higher grain test weight (Welch and Flannery, 1985).

Potassium in Soils

Potassium (K) is a primary nutrient that is often found in large quantities in most agricultural soils. Total K content ranges between 0.5 and 2.5% in most soils, or approximately 11 to 56 Mg K ha^{-1} (Mills and Jones, 1996). It is the seventh most abundant element of the earth's crust (Sheldrick, 1985). However, just a small percentage, often less than 2%, of total soil K is available to plants over the growing season (International Plant Nutrition Institute, 2006). Soil K is often described as existing in three forms: unavailable, slowly available and readily available. Unavailable K accounts for 90-98% of the total K, whereas slowly available and readily available represents 1 to 10% and 0.1 to 2%, respectively (Havlin et al., 2005). These three forms of K give a general representation of the potential sources for plant-available K, but no distinct boundaries exist among them.

The unavailable form of K is found in primary aluminosilicate minerals in soil. Primary aluminosilicates include muscovite micas, K-feldspars and biotite (Bertsch and Thomas, 1985). Over very long periods of time K is released from these structural minerals through physical and chemical weathering. The break down and conversion of K from mineral forms to a soluble available K form is a very slow process. It could take years to add significant amounts of available K to a given soil, however, the weathering of these minerals based on the long-term is vital in replenishing readily available soil K. The amount of K that is made available is dependent on intensity of weathering, time of deposition and the proportion and type of clay minerals that are present in the soil (Sparks and Huang, 1985).

Slowly available K is trapped between interlayers of certain kinds of clay minerals. It is commonly referred to as fixed K and is of agricultural importance in clay-bearing soils since about 1 to 2 g K may be fixed by 100 g of clay minerals (Mills and Jones, 1996). Fixation of K is associated with 2:1 secondary aluminosilicate minerals such as smectite, vermiculite and illite. Smectite and vermiculite minerals are expanding type clay minerals that shrink and swell during drying and wetting soil conditions (International Plant Nutrition Institute, 2006). Upon wetting, the cleavage planes of the lamellae (stacked plate-like sheets) separate, leaving their interlayer surfaces exposed (Hillel, 2004). Positively charged ions along with water molecules enter the area between the clay layers. In 2:1 layer silicates, isomorphic substitution of lower valence cations for silicate and aluminum in tetrahedral and octahedral sheets causes a net negative charge, or layer charge deficiency. In vermiculite the primary site of isomorphic substitution occurs in the outer most tetrahedral sheet, making its source of negative charge in close proximity to positively charged K ions. Smectite, on the other hand, has most of the negative charge in the octahedral sheet, making the attractive force for K weaker. The residual negative charge is neutralized by K ions and other positively charged cations present within the interlayer spaces and surrounding the clay particles (Sparks and Huang, 1985). The electrostatic forces of attraction between the K ions and the clay surfaces exceeds the hydration forces between individual K ions, resulting in partial collapse of the lamellae which, to varying degrees, traps the K ions (Sparks and Huang, 1985). Non-exchangeable K can also be found on the wedge zones of weathered minerals like vermiculite. Only ions with a similar size to K, like ammonium, can exchange K from these wedge zones (Sparks and Huang, 1985; Rich, 1968).

Illite minerals on the other hand are non-expanding and have a relatively high density of negative charges on its clay sheets. They do not exhibit the shrink-swell behavior, but the tremendous negative charge they possess attracts K ions and fixes them tightly into the ditrigonal holes on the surface of adjacent lamellae (Hillel, 2004). As a result, the layers are bound together, so their separation, and hence expansion of the entire lattice are effectively prevented (Hillel, 2004). Both the fixation and release of K from 2:1 minerals can occur simultaneously under certain conditions (Bates and Scott, 1964; Mortland, 1961). The release of trapped K is influenced by the equilibrium existing between the slowly and readily available K forms, which are dependent on the overall K status of each phase (Bertsch and Thomas, 1985).

Readily available K is made up of K ions in soil solution or is adsorbed as an exchangeable ion at the surface of soil colloids (Mills and Jones, 1996). Exchangeable K is the larger portion of the readily available K that is electrostatically bound to the outer surfaces of clay minerals and organic matter (Sparks and Huang, 1985). As a plant removes solution K, some of the K held on at the exchange sites is released to replenish solution K; the exchange continues until equilibrium is established (Sparks and Huang, 1985). Potassium is continuously supplied to the plant by the exchange sites as long as the soil has enough reserve K at the beginning of the growing season (International Plant Nutrition Institute, 2006). The amount of exchangeable K is highly governed by other cations present both in solution and bound to soil particles. Cations like calcium and ammonium are in constant competition with K for exchange sites on the surface of soil colloids. Calcium is generally the dominant cation in soil solution. Ammonium has the same affinity as K for exchange sites, but when high concentrations are present it can remove K from exchange sites (Sparks and Huang, 1985). When calcium or ammonium fertilizers are added to a soil with a high degree of K saturation on colloidal surfaces, K will be displaced from exchange sites and move into soil solution (Havlin et al., 1999). Fertilization of K may be needed to maintain adequate levels of exchangeable K. Potassium that cannot be held by exchange sites on soil colloids can be lost through leaching. The extent of leaching losses is dependent on soil texture and pH of the soil.

Solution K is dissolved in soil water and is a form of K that is directly taken up by plants (Sparks and Huang, 1985). The concentration of soil solution K varies according to the amount of fertilizer applied and the K availability of the soil. Typically the dissolved K levels are relatively small ranging from around 2 to 10 mg K L^{-1} for most agricultural soils (Schulte and Kelling, 1985). Reportedly, solution K concentrations in no-till fields are the highest in the top 5 cm of the soil profile and decrease with depth (Holanda et al., 1998). In contrast, soil K distribution in mold-board plowed fields is relatively uniform throughout the plow layer (Fink and Wesley, 1974). Under field conditions the amount of K in soil solution varies widely due to the concentration and dilution process brought about by evaporation, precipitation and plant uptake (McLean and Watson, 1985). In general, the relationship between exchangeable and solution K is a good measure of availability of labile K to plants. Soil laboratories use extractants to quantify both solution and exchangeable K when determining K availability in soils (Havlin et al., 2005).

Movement of solution K to root surfaces is orchestrated by two main processes: mass flow and diffusion. Mass flow is dependent upon the water uptake by the plant and the K concentration in soil solution. Mass flow contributes very little to plant K absorption due to the large amount of water that would need to be taken up by the plant at K concentrations much higher than what is normally measured in soil solution. However, in soils that have a naturally higher water soluble K, or where K fertilizer has increased the concentration in soil solution, mass flow can contribute greatly to K uptake (Havlin et al., 1999). Roughly 85% of K movement in the soil to root surfaces is through diffusion – a slow movement of ions in response to concentration gradients through water films surrounding soil particles (Mills and Jones, 1996). This process is limited to short distances, usually around 1 to 4 mm from the root surface (Barber, 1985). Since K diffusion occurs within only a few mm of the plant root, some K that is further away may be in a plant available form, but not in a position to impact plant uptake (Havlin et al., 1999). The diffusion process is highly dependent on several factors including soil water content, soil temperature, K concentration gradient and tortuosity of the diffusion path (Barber, 1985).

Factors Affecting Potassium Availability and Plant Uptake

Many components influence the potassium (K) availability of a soil and, therefore, the uptake of K by plants. The interactions between various soil properties, plant characteristics and environmental conditions are the prime drivers that dictate plant K nutrition. The relationship that is shared between these elements is often what complicates the availability of soil K. Though many of the environmental factors are uncontrollable, having a better understanding of soil K dynamics helps in K fertilization and management decisions.

The ability of soils to retain K is dependent on its cation exchange capacity (CEC). Soil CEC represents the total quantity of negative surface charges on soil particles and organic matter available to hold and exchange cations in solution (Havlin et al., 2005). The CEC of a soil is highly contingent on soil texture and the volume of organic matter present in the soil. However, organic matter particles have a relatively weak attraction for K ions (Schulte and Kelling, 1985). Consequently, the presence of clay in the soil fraction provides the majority of soil K adsorption. Soils high in clay possess the highest CEC and sandy soils typically represent the lowest CEC. Soils with a high CEC have a greater capacity to retain additional K in the exchangeable form (Munson and Nelson, 1963). However, higher exchangeable K does not necessarily result in higher solution K (Havlin et al., 2005). Early in the growing season soil solution K is often lower in high K bearing clay dominate soils as compared to sandy soils. Potassium is bound tighter to the clay colloids and clays have a higher buffering capacity, reducing the release of excess exchangeable K. However, the higher soil K levels found in sandier soils are often not maintained as plants remove the dissolved K from soil solution.

Soil pH indirectly controls the amount of exchangeable K held by the exchange sites. Only extremely acidic soils, pH below 5.2, contain appreciable amounts of exchangeable aluminum. At this low pH, aluminum causes more displacement of K ions into soil solution (Barber, 1995). The excess release of exchangeable K into soil solution by acidic soils and low CEC soils may lead to increased K leaching losses. Loss of K by leaching is one of the reasons sandy and organic soils often test relatively low in available K (Schulte and Kelling, 1985). Soil pH can also affect the amount of K fixation that occurs in the soil. As the pH of a soil increases it causes displacement of hydrogen and hydroxyl aluminum ions making it easier for K ions to move closer to colloidal surfaces, where they are more susceptible to fixation (Brady and Weil, 2004). For these reasons, the optimum pH for K availability is 6.0 to 7.0 on the pH scale.

The amount of K available in clays is highly dependent on the mineralogy of the clays. Soils containing vermiculite, montmorillonite or weathered mica clay minerals typically have elevated levels of exchangeable K compared to soils containing kaolinitic clays, which are more highly weathered (Havlin et al., 2005). However, high K bearing minerals often have a higher K fixing potential resulting in unpredictable K availability. When K is added to soil, some of it goes into exchangeable positions and some of it is fixed (Barber, 1995). In soils that have been intensively cropped and highly K depleted, significant fixation of applied K may occur (Bertsch and Thomas, 1985). The non-exchangeable binding sites in this situation are so exhausted from under fertilization and continuous cropping that it may take years of supplementation with K fertilizer to replenish. Consequently, very costly annual heavy applications of K fertilizer are needed to overcome any adverse effects on yield.

Wetting and drying cycles have been reported to have a big impact on the amounts of K fixed by 2:1 minerals. The degree of K fixation or release due to wetting and drying cycles is dependent on the type of clay minerals present in the soil and the concentration of K in soil solution (Sparks and Haung, 1985). Furthermore, the structural and chemical changes the clay layers undergo during certain soil conditions significantly influences soil K availability. Structural K fixation can occur from drying soils high in exchangeable K or with soils that recently had K fertilizer applied (Laboski, 2005). As the soil dries the clay layers collapse and K is trapped between the clay layers. On the other hand, structural K release can occur when soils low in exchangeable K are dried causing the clay sheets to roll back and release K (Laboski, 2005; McClean and Watson, 1985). Chemical fixation and/or release of K are driven by the oxidative or reductive state of Iron (Fe). Iron is a component of the structural lattice of many clay minerals. When soils are dried Fe is reduced from a 2^+ charge to a 3^+ charge. For smectites, this results in a decrease in K fixation and likely increases K availability. However, for vermiculites and illite, more K fixation is evident (Murrell, 2011). Similarly, freezing and thawing cycles contribute to either fixation or release of K, depending on clay mineralogy. In soils with considerable amounts of mica clays, freezing and thawing cycles release fixed K. In soils containing smaller amounts of mica and having greater amounts of exchangeable K, freezing and thawing has no net effect on K fixation or release (Laboski, 2005).

The availability and plant uptake of K is governed by any factors that impact diffusion rates and plant root growth. Soil moisture influences the diffusive pathway of K supplied to plant roots. With low soil moisture, water films around soil particles are thinner and discontinuous; resulting in a more complex path for K diffusion to roots (Havlin et al., 2005). Research by Johnson and Wallingford (1983) showed that corn and soybeans take up K less efficiently in dry periods. This can be an especially important issue in no-till cropping practices. In no-till systems much more crop debris is left at the soil surface. As nutrient concentrations start to build up at the soil surface from crop residue breakdown and surface fertilizer application with limited soil mixing, vertical stratification develops. Nutrient vertical stratification is a gradient of soil test levels with depth (Murrell, 2011). Under dry soil conditions this could lead to K positional unavailability. Soil temperature strongly affects both plant K uptake by the root and K diffusion through the soil (Barber, 1995). Low soil temperature impairs root growth and drastically slows K diffusion rates. In compacted, or under extraordinarily high soil moisture conditions, root growth can be restricted due to the reduced supply of oxygen (Havlin et al., 2005). When the oxygen content is low, respiration in the roots is lowered, and nutrient absorption is decreased (Hanway and Johnson, 1985). Active plant root K absorption is most effective in moist, warm, well-aerated soils.

Potassium Deficiency Diagnostic Techniques

Plant potassium (K) status can be evaluated using several diagnostic tools. Assessing the visual appearance of plants is a good initial indicator of plant nutrient deficiencies. There are several key visual signs to look for when specifically diagnosing K deficiency. Soybean K deficiency first appears as an irregular chlorotic mottling around the edges of the leaflets. The yellow areas may eventually form a continuous, irregular yellow border. Under more severe K shortages, the leaf margin will be necrotic while leaving only the center and base of the leaf green. Since K is mobile in the plant, visual deficiency symptoms usually first appear on the older, lower leaves and progresses toward the top leaves as severity increases (Bissonnette et al., 2010). Severe K-deficient soybeans will be stunted and can be slow to reach physiological maturity. Potassium deficient soybean grain is often shriveled with low oil content.

Corn that is K-deficient results in visual symptoms including yellowing of lower leaf margins while the midrib of the leave remains green. Under severe conditions leaf tips will begin to die and if the plant doesn’t overcome the deficiency, necrosis will eventually move along the leaf margins. Potassium deficient corn plants are more prone to lodging due to insufficient stability of the stalk tissue. Corn roots and nodal tissue are poorly developed and ears may be small with under developed tips (Bissonnette et al., 2010).

Though visual symptoms alert an individual of a problem, diagnosing the problem solely off of visual appearance in some instances can be difficult. Misidentification of K deficiency is not uncommon. Plant tissue analysis is a reliable way to confirm K deficiency when specific symptoms arise. Plant analysis can play a major role in diagnosing mineral nutrition problems and for solving field crop problems (Jones, 2001). Being able to identify a nutrient deficiency before visual symptoms appear is one of the biggest advantages in conducting plant tissue analysis. In some situations plants can be deficient and show no visual symptoms. This crop behavior is known as hidden hunger. If deficiency problems are detected before plant stress is evident then reduction in grain yield and/or crop quality could be avoided if appropriate actions are administered (Havlin et al., 2005).

When taking a sample there are a number of important components to consider. The amount of K in plants varies depending on growth stage and between plant part locations on individual plants. Plants usually absorb most of their K during the first half of their growth cycle (Mills and Jones, 1996). As the plant matures the amount of K in plants decreases; therefore it is important to know the plant's stage of growth to properly interpret the results of a leaf K analysis (Schulte and Kelling, 1985). Potassium concentration usually decreases from the top to the bottom of plants, thus the portion of the plant sampled can affect K interpretation. Gathering samples from the correct portion of the plant at the appropriate time are important when trying to obtain a representative field sample. To determine whether plant nutrient concentrations are adequate for plant growth and development, measured concentrations from plant samples from the field are compared with recommended critical ranges (Plank, 1979). Table 1.1 lists the K sufficiency range, recommended sample size, plant part and growth stage for soybeans and corn.

Table 1.1 Critical K sufficiency range with sampling criteria for soybeans and corn (Mills and Jones, 1996)

Crop	*Sample Size*	*Plant Part Sampled*	*Growth Stage*	*Sufficiency Range*
Soybean	25-30	Top mature trifoliate	Prior to pod set	17.0 - 25.0 g kg^{-1}
Corn	12-15	Ear-leaf	Initial silk	17.0 - 30.0 g kg^{-1}

Unfortunately, plant tissue analysis is often used when visual deficiencies appear late in the season. Depending on the situation, this may limit options for economically effective treatments for that year's crop. One cannot rely on leaf diagnosis alone to give an accurate picture of fertilizer requirements needed to overcome K deficiency (Mallarino, 2005). While there are many environmental and soil nutrient interactions that affect soil K availability, soil sampling is the most useful tool in assessing the relative availability of soil K for crop nutrition.

A major advantage of soil sampling is that producers have the ability to evaluate soil productivity and address K shortages before the crop season begins. When collecting soil samples, it's important to understand that soils are naturally variable horizontally as well as vertically (Jones, 2001). Since most fields are not homogeneous, naturally or from past and/or current cultural practices, the challenge for the sampler is to obtain a sample that is representative of the field under test (Woodruff, 1994). The test results will only be as reliable as the sample collected from the field.

The first step in conducting soil samples is to establish sampling areas. Some individuals may choose to break fields into small uniform grid sampling areas while others may choose larger sampling areas. Either way, a common procedure is to divide a field into uniform sampling areas based on soil consistency and/or past cropping history. Once sampling areas are established, 10-15 random individual cores are taken from specific areas to form a single composite sample. Several studies have shown that collecting more than 8 cores per composite sample does not provide any more accuracy of soil test results. Better information could be obtained by a fewer number of cores per sample and more than one composite sample from a specific field (Jones, 2001). The number of sampling areas and/or cores per sample is based on individual preferences. When taking individual cores one should pay strict attention to sampling depth. Appropriate sampling depth is influenced by one of several aspects: horizontal characteristics, depth of soil mixing during tillage and rooting depth of the crop to be grown (Jones, 2001). Potassium is relatively immobile so samples are generally taken at 15-20 cm depth. In reduced till or no-till systems taking addition samples at the 5-10 cm depths could be useful in determining the degree of K stratification. When using any sample depth it is important to remain consistent.

Potassium Management and Fertilization

Soils can provide much of the potassium (K) that is needed by plants, but when supply becomes limiting, there is a need for supplemental fertilization. The dominant fertilizer K source in the United States is potassium chloride (KCl); accounting for more than 90% of total K sold (Young, 1968). Potassium chloride is popular among producers given that it provides the highest percent of K of any readily available K supplying compound (60 to 62% K_2O) (Adams, 1968). Other K sources are commercially available including potassium sulfate (K_2SO_4), potassium nitrate (KNO_3), and potassium-magnesium sulfate ($K_2Mg(SO_4)_2$) (Mills and Jones, 1996). The rates and placement methods in which these K sources are applied to agricultural land depends on various soil and crop conditions. Research conducted with corn and soybean production across the Midwest has revealed mixed results in response to the addition of K fertilizer and the different methods of application.

Throughout the Midwest direct K fertilization of soybeans is rarely practiced. In a corn-soybean rotation, biannual application of K fertilizer before corn has become a popular management choice. The idea is to apply high enough rates to satisfy the K requirements of corn and the subsequent soybean crop. Many producers consider soybeans to be far less responsive to fertilizers in the year of application than corn, even though they were perhaps relatively efficient in recovering residual fertilizer from the soil (deMooy et al., 1973). Numerous studies have determined that soybeans responsiveness to direct fertilization with K is significantly less than corn (deMooy et al., 1973; Norman 1946; Pierre, 1944; Lang and Miller, 1942). Corn typically requires more K than soybeans, which could help explain the increased K responsiveness (Ebelhar and Varsa, 2000). Buah et al. (2000) and Rehm and Lamb (2004) found that residual and direct fertilization resulted in similar soybean yields. Research in Ontario, Canada (Yin and Vyn, 2002a) concluded that subsequent no-till soybeans responded more to residual fertilizer than to application timing, tillage and K fertilizer placement in preceding corn. However, in further research by Yin and Vyn (2002b) they found that no-till soybean response to residual K fertilizer management varied depending on the tillage system utilized in corn.

It seems the volume of response from either crop is highly dependent on soil test K levels. Relevant research has shown that soybeans demonstrate positive responses to added K on relatively low (91 – 130 mg kg^{-1}) K testing soils (Yin and Vyn, 2003; Yin and Vyn, 2002a; Randall et al., 1997; Rehm, 1995). Two studies (Borges and Mallarino, 2003; Ebelhar and

Varsa, 2000) showed that on medium to high K soils (131 – 274 mg kg^{-1}), as K rate increased soybean K uptake increased as well, however, no yield responses were documented. Other investigations in Iowa (Borges and Mallarino, 2000; Buah et al., 2000) showed that no-till soybean yield response to K fertilization was rarely significant on optimum to very high testing soils. Gelderman et al. (2002) found corn yield responses on relatively low testing soils with the addition of K in South Dakota. Ebelhar and Varsa (2000) reported that corn responses were found in Illinois soils even when soil test K levels were in the high range of 210 to 280 mg kg^{-1}, showing that as the rate of K increased so did K uptake.

The placement of K fertilization can play a huge role in how rapidly K will be available and utilized by plants. The selection of the appropriate application technique for a particular field depends in part on the intensity of soil fertility management, the crop to be grown and the tillage system being practiced. Soybean and corn producers primarily practice three principle fertilizer placement methods. The most popular and convenient application method is broadcast fertilization. Broadcasting is simply the spreading of nutrients on the soil surface and can either be left on the surface or incorporated. The second application method is deep banding of K fertilizers. Deep banding consists of injecting nutrients 15-25 cm below the soil surface, typically the fertilizer is placed below the intended crop row area. Lastly, row fertilizer applications or commonly known as "starter" fertilization. Starter fertilizer is usually surface applied or placed 5 cm below and 5 cm to the side of the seed during planting. It can also be in-furrow applied, but salt injury to germinating seed can be a major concern at high K rates.

Broadcast application of fertilizers is a low cost way to supply large quantities of nutrients. However, broadcasting K fertilizers can lead to more accumulation of K in the upper soil layer than banded applications. Furthermore, broadcast applications have a higher potential for K fixation which can reduce the immediate efficiency of K fertilizer (International Plant Nutrition Institute, 2006). When fertilizer is placed in a band it is concentrated which allows for less exposure to K fixing clay minerals.

Research conducted by Yin and Vyn (2002a) and Ebelhar and Varsa (2000) concluded that there were no significant difference of soybean leaf K concentrations at early reproductive growth stages between broadcast and banded treatments. Other research (Hudak et al., 1989) also showed no K placement effect on yield of no-till soybeans grown on a silt loam soil in Ohio. However, Hairston (1990) and Yin and Vyn (2003) showed that deep-banded fertilizer had an advantage over surface broadcast placement at the same rates in terms of leaf K and yield on low to medium testing K soils. Work done by Eckert and Johnson (1985) and Yibirin et al. (1993) also showed that shallow sub-surface banding can significantly increase P and K fertilizer use efficiency compared with broadcast fertilizer applications for no-till soybean and corn. Research in Iowa (Borges and Mallarino, 2000) reported that both deep-band and starter K fertilizer in no-till systems produced slightly higher soybean yields than surface applications on optimum to very high testing soils. Rehm et al. (1988) found similar results with corn where the greatest yield responses generally resulted from a combination of sub-surface banding with starter fertilization. Gordon (1999) found that starter fertilizer (7-21-7) increased corn and soybean yields even though levels of P and K were high and very high, respectively. However, no soybean yield advantage with starter K placement alone versus surface broadcast was seen by Buah et al. (2000) on high K testing soils.

Summary

Potassium (K) is often referred to as the "regulator" in crop production. It has earned this distinction due to its important role in protein and starch synthesis, as well as the regulation of over 60 enzyme systems that assist in the development of improved quality and production of crops. Potassium is also well known to positively interact with nitrogen and phosphorus in soil, serving to improve their nutrient use efficiency. Improved K management systems are needed to achieve optimum productivity of many economically important crops and to be able to optimize fertility inputs. When soil test K levels are not maintained at sufficient levels, the outcome may result in potential economic losses.

Concerns about K fertility management have increased significantly in southeast Kansas corn and soybean production. Potassium availability limitations have led to increased K deficiency incidences in both crops, especially for no-till systems in the area. Long and short-term limitations of K availability depends upon types and amounts of clay present in soil, soil pH, soil moisture conditions, soil temperature, degree of soil compaction and extent of vertical and/or horizontal soil K stratification. During hot, dry summers K availability can be significantly reduced, this is especially true in no-till systems where compaction and vertical stratification can be significant. Proper rates and placement of K fertilizer in this situation can become extremely important.

Previous research done on K fertilization of corn and soybeans has been exceptionally variable. In general K uptake for both corn and soybeans is generally increased with increasing K fertilization rates. However, soybean yield increases are less likely to added K fertilization. It seems increased K uptake and yield responses are more common in soils with very low to optimum (> 170 mg kg^{-1}) soil test K levels, however, response variation in the optimum (130 – 170 mg kg^{-1}) category is more erratic. Research has demonstrated that corn seems to be more responsive to direct K fertilization at varying rates. Some research regarding K fertilizer placement techniques have shown that when soil test K levels were in the low range, a positive response to banded K fertilization was seen. However, in soils with high (> 171 mg kg^{-1}) soil test K levels, responses to either broadcast or banded K fertilization were minimal. In no-till systems deep banding K has been an effective K placement alternative. Conversely, other studies have also revealed no significant differences in plant K uptake or yield due to K placement strategies regardless of soil test K. Responses to starter fertilizer have been variable as well. Most often corn seems to be more responsive to starter K fertilization then soybean, especially early in the growing season. The use of deep-banding K fertilizer in combination with starter fertilizer has shown positive responses for both corn and soybeans in no-till systems.

The decision on proper K rate and placement is going to depend on a producer's tillage system and soil test K levels prior to the growing season. It seems the most important aspect of K management is for producer's to maintain soil K levels above the optimum (130 mg kg^{-1}) level. Addition of fertilizer may be required to achieve this, but once it is established applying K at sufficient levels to replenish crop removal rates becomes crucial.

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Chapter 2 - Changes in Potassium Soil Test Levels over Time

Abstract

Kansas soils have long been-recognized for containing naturally high levels of available potassium (K) for crop production. As a result, in a big portion of the state the practice of supplemental K fertilization is practically non-existent. The one exception is in southeast Kansas where large numbers of very low to low (< 130 mg kg^{-1}) exchangeable K soil tests are being reported. Annual K applications in the region have become essential to growing healthy, productive crops. Producers have relied on soil tests to guide their K application rates. However, in recent years as farmers and advisers have intensified their collection of individual field soil data, noticeable and at times dramatic variability in soil test K levels over time have been observed. The objective of this study was to measure the degree of variability in soil test K levels over time in cropped fields in southeast Kansas and try to identify mechanisms driving these changes.

This study was conducted at eleven locations in southeast Kansas during the 2009, 2010 and 2011 cropping seasons. Selected sites varied in soil test K levels, but all initially tested below the optimum level of 130 mg kg^{-1} exchangeable K, based on samples collected in the fall or winter. Multiple K treatments were applied in the spring, but only two were regularly soil sampled to track exchangeable K levels, the unfertilized K control and a single broadcast application of 202 kg K_2O ha^{-1} applied at the initiation of the study. Soil samples were collected on a one to two month basis during the growing seasons at each location throughout the duration of the study.

Results observed from this research showed that monthly soil samples taken during the past three cropping years at multiple locations had ammonium acetate exchangeable K levels that indeed changed significantly over time. The data we collected together with data accumulated by farmers and crop consultants shows fluctuation in exchangeable K levels of up to 50% on a yearly and even on a monthly basis. Levels seem to demonstrate seasonal changes: generally higher in the spring months when a crop is not actively growing and then declining in the summer and fall. The decline in soil K was documented during most growing seasons from crop establishment up to crop maturity. The drastic decrease observed can be partially attributed to removal of K from the soil by the crop. Between growing seasons soil test K levels seem to

build back up, which can be partially explained by K being released from crop residues. Additionally, variations in soil test K level appear to follow a similar trend as monthly precipitation and soil moisture status. During many wet months soil test K levels tended to increase and then decline during drier months, however, the relationship was inconsistent over time and other factors are likely involved in regulating changes in soil test K over time.

Introduction

In addition to a guide for fertilizer rate information, regular soil test information can be used as a crop diagnostic tool to identify trends over time that allow producers to evaluate their nutrient management practices. However, many producers in southeast Kansas are dealing with some puzzling soil test potassium (K) variability that has made soil K management over time an enormous challenge. Several individuals' soil test K histories have displayed tremendous yearly fluctuations that cannot be explained with K fertilization additions and standardized crop removal rates. The unpredictable changes have many questioning the true value of soil tests, how to interrupt soil test K and the effect it has on K recommendations.

A portion of K variability can be clarified with a simple understanding of soil K dynamics. The exchange of K between soil solution and exchangeable forms of K determine whether applied K will be leached, taken up by plants, converted into unavailable forms or released into available forms of K (Sparks, 2001). Studies have shown that the reaction rate between these two phases of K is strongly dependent on the mineralogy of the soil (Sparks and Jardine, 1984; Sparks et al., 1980). All minerals vary drastically in their ionic preferences, ion binding affinities and types of ion exchange reactions (Sparks, 2001). The elemental differences that exist between clay minerals account for the varying soil K exchangeability and otherwise unexplainable K variation in soils over time. The exchange of K on kaolinite and montmorillonite is usually quite rapid (Sparks and Jardine, 1984; Malcolm and Kennedy, 1969), however, the exchange of K on vermiculite and mica minerals tends to be extremely slow (Sparks, 2001).

The relationship between exchangeable and non-exchangeable K also has a big influence on soil K dynamics. Soils high in 2:1 type clay minerals have the ability to fix or release K depending on the soil test K level and the current environmental conditions (Goulding, 1987). Potassium that is fixed becomes part of the non-exchangeable pool. Vermiculite and hydrous mica minerals are known to be the main minerals that contribute to K fixation (Murashkina et al., 2007). Smectite minerals possess the ability to fix K as well, but their K fixing potentials are generally lower. However, smectite minerals that possess a high layer charge have been found to fix high quantities of K (Singh and Heffernan, 2002; Weir, 1965). The K fixed by these minerals is not readily released, however, if exchangeable K is excessively depleted or when specific environmental conditions change, a release of K can result.

Wetting and drying cycles have been reported to have a big impact on the amount of K fixed or released by 2:1 minerals. The degree of fixation and/or release is impacted by structural and chemical changes that clay layers undergo during certain soil conditions. Structural K fixation can occur from drying soils high in exchangeable K or with soils that recently had K fertilizer applied (Laboski, 2005). As the soil dries the clay layers collapse and K is trapped between the clay layers. On the other hand, structural K release can occur when soils low in exchangeable K are dried, causing the clay sheets to roll back and release K (Laboski, 2005; McClean and Watson, 1985). Chemical fixation and/or release of K are driven by the oxidative or reductive state of Iron (Fe). Iron is a component of the structural lattice of clay minerals. When soils are dried Fe is reduced from a 2^+ charge to a 3^+ charge. For smectite minerals, this results in a decrease in K fixation and likely increases K availability. However, for vermiculite and mica minerals, more K fixation is evident (Murrell, 2011). Similarly, freezing and thawing cycles contribute to either fixation or release of K, depending on clay mineralogy. In soils with considerable amounts of mica clays, freezing and thawing cycles release fixed K. In soils containing smaller amounts of mica and having greater amounts of exchangeable K, freezing and thawing has no net effect on K fixation or release (Laboski, 2005). The response of soil K to environmental conditions can differ widely among different soils, therefore it is important to evaluate how southeast Kansas soils react to such situations.

Management practices can have big impacts of soil K variability within soils. In no-till systems much more crop debris is left at the soil surface, than in tilled systems. As nutrient concentrations start to build up at the soil surface from crop residue breakdown and surface fertilizer applications with limited soil mixing, vertical stratification develops. Nutrient vertical stratification is a gradient of soil test levels with depth (Murrell, 2011). In long-term no-till, soil K levels can be significantly higher at the soil surface compared to lower shallow depths. In situations where severe K stratification exists, depth control during soil sampling becomes crucial. Soil samples taken at an inconsistent soil sampling depth can show significant K variability over time.

A representative soil sample not only depends on depth control, but also a sufficient number of soil cores being collected from a sampling area. Soil K can be highly variable within a given field. Causes of variability include differences in landscape position, erosion and management history (Woodruff, 1994). Taking a small number of cores can result in reduced chances that the sample represents the average fertility of the area. Consequently, taking too few cores per sample can contribute significantly to observed year to year K variability in soil test K results, producing random increases or decreases.

Collectively, an increase in the number of wetting and drying and/or freezing and thawing cycles in a given period in combination with soil clay mineral composition can have a big impact on the magnitude of K fixation or release. When you add these uncontrollable factors with the use of improper soil sampling methods, the accumulative affect could result in extreme seasonal soil test K variability over time.

The objectives of this study were to:

1. Document variability in soil test K levels occurring in cropped fields in southeast Kansas.
2. Identify the mechanism(s) driving the changes in soil test K levels and K availability to crops.
3. Design an appropriate soil sampling system that will help minimize soil test K variability.

Materials and Methods

This project was conducted in southeast Kansas. The area, generally defined as east of the Flinthills and south of the Kansas River, is a major corn (*Zea mays* L.) and soybean (*Glycine max* L.) producing area in Kansas. The region has a humid continental climate with 30 year (1981-2010) average annual rainfall amounts of 1143 mm in Cherokee County and 1092 mm in Wilson County (National Climatic Data Center, 2011). Research was conducted on-farm in cooperation with local producers from 2009-2011. Four research sites were initially established near Hallowell, Kansas in 2009. Four additional sites were added near Hallowell, KS in 2010.

In 2011, two additional field experiments near Columbus, KS and one near Buffalo, KS were added. Buffalo, KS is located in Wilson County while all other locations are located in Cherokee County. Field site locations, study years, soil classification and initial ammonium acetate exchangeable K levels are given in Table 2.1. The soils that make up each series are all very deep clay-pan soils that are poorly drained with very slow to moderate permeability. The soils are very susceptible to flooding and drought due to a restrictive sub-clay layer that impedes vertical flow of water and the relatively shallow surface horizon that reduces the amount of plant-available water.

Study plots were arranged in the field using a randomized complete block design with four replications. Individual plots were 15.2 meters long and 6.2 meters (or 8 rows) wide at all locations in 2009 to 2011 except at Pringles in 2011, where plots were 15.2 meters long and 4.6 meters (or 6 rows) wide. Ten different combinations of K rates and fertilizer application methods were applied to the plots in 2009 to 2011 (Table 2.2) except at North Leeper. At North Leeper, only eight different combinations of K rates and fertilizer application methods were applied to the plots because of space restrictions (Table 2.3). All treatments were surface applied after planting and granular potassium chloride (0-0-62) was used as the K fertilization source. A month after fertilization soil samples were taken from the unfertilized K control (treatment 1) and the biannual broadcasted 202 kg K_2O ha^{-1} (treatment 7) plots at each location to evaluate soil K levels. This process continued on a one to two month basis during the duration of each cropping season at every location. The plots monitored for soil test K levels received no additional K fertilizer following the year of study initiation. Monthly precipitation amounts were collected for each area from the nearest local weather station to compare changes in precipitation with fluctuations in soil test K (National Climatic Data Center, 2011). For the Hallowell, Columbus and Buffalo locations, weather data was taken from the Oswego, Columbus and Yates Center weather stations, respectively. Predicted changes in soil test K levels were determined using standardized crop removal rates and a soil K buffering capacity of 10 kg K_2O ha^{-1} per 1 mg kg^{-1} change in STK level. Additionally, best crop and pest management practices were followed at each location.

Table 2.1 Field site county, study years, soil classification and ammonium acetate exchangeable K levels by location

Location	*County*	*Study Years*	*Soil Series*	*Soil Texture*	*Soil Classification*	*NH_4OAc Exchangeable K Levels (mg kg^{-1})*
SW Jennings	Cherokee	2009-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	147
SE Brown	Cherokee	2009-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	154
SW Brown	Cherokee	2009-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	149
Delmont	Cherokee	2009-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	139
NW of Dads	Cherokee	2010-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	114
East Marks	Cherokee	2010-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	108
Krantz	Cherokee	2010-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	110
Spieth	Cherokee	2010-2011	Cherokee	Silt loam	Fine, mixed, active, thermic Typic Albaqualfs	122
Pringle	Wilson	2011	Lanton	Silt loam	Fine, mixed, superactive, thermic Cumulic Epiaquolls	82
North Leeper	Cherokee	2011	Dennis	Silt loam	Fine, mixed, active, thermic Aquic Argiudolls	57
South Leeper	Cherokee	2011	Dennis	Silt loam	Fine, mixed, active, thermic Aquic Argiudolls	55

Table 2.2 Potassium fertilizer rate and placement method

Treatment No.	*Treatment Abv.*	*Treatment Description*
1	CK	Unfertilized check **
2	BC Rec (A)	Annual broadcast K rate based on sufficiency rec.
3	BC 34 (A)	Annual broadcast 34 kg K_2O ha^{-1}
4	BC 67 (A)	Annual broadcast 67 kg K_2O ha^{-1}
5	BC 67 (BA)	Biannual broadcast 67 kg K_2O ha^{-1}
6	BC 134 (BA)	Biannual broadcast 134 kg K_2O ha^{-1}
7	BC 202 (BA)	Biannual broadcast 202 kg K_2O ha^{-1} **
8	SB 67 (BA)	Biannual surface band 67 kg K_2O ha^{-1}
9	SB 134 (BA)	Biannual surface band 134 kg K_2O ha^{-1}
10	SB 202 (BA)	Biannual surface band 202 kg K_2O ha^{-1}

** Indicates treatments that were soil sampled to monitor soil test K levels

Table 2.3 Potassium fertilizer rate and placement method for the study at North Leeper

Treatment No.	*Treatment Abv.*	*Treatment Description*
1	CK	Unfertilized check **
4	BC 67 (A)	Annual broadcast 67 kg K_2O ha^{-1}
5	BC 67 (BA)	Biannual broadcast 67 kg K_2O ha^{-1}
6	BC 134 (BA)	Biannual broadcast 134 kg K_2O ha^{-1}
7	BC 202 (BA)	Biannual broadcast 202 kg K_2O ha^{-1} **
8	SB 67 (BA)	Biannual surface band 67 kg K_2O ha^{-1}
9	SB 134 (BA)	Biannual surface band 134 kg K_2O ha^{-1}
10	SB 202 (BA)	Biannual surface band 202 kg K_2O ha^{-1}

** Indicates treatments that were soil sampled to monitor soil test K levels

Cultural Practices

In 2009 the study was conducted at four locations near Hallowell, Kansas. Each site initially had double crop soybeans (*Glycine max* L.) no-till planted into wheat (*Triticum aestivum* L.) stubble in 2009. In 2010 the study areas were conventionally tilled and planted to corn (*Zea mays* L.). In late 2010 the study areas were once again conventionally tilled and planted to wheat followed by no-till double crop soybeans in 2011. All fertilizer treatments were applied on June 30, 2009 at SW Jennings and on July 1, 2009 at the other three locations to recently emerged soybeans. The plots soil sampled during the study did not receive any additional K fertilization during the corn and wheat growing seasons. The annual application rates (treatments 2 – 4) of K were re-applied in 2010 to corn, and in late 2010 to wheat.

In 2010 the study was expanded to four new locations also near Hallowell, KS. The sites were again initially double crop soybeans no-till planted into wheat stubble, except for the study at NW of Dads, it was tilled and full season soybeans were planted following corn. In 2011 the study areas were conventionally tilled and planted to corn. All treatments were applied on June 24, 2010 at NW of Dads and on July 19, 2010 at the other three locations to soybeans. The plots soil sampled during the study did not receive additional K fertilization during the 2011 corn growing season. However, the annual applications (treatments 2 – 4) were re-applied. The Krantz and Spieth locations were dropped from the study in 2011 due to the local fertilizer dealer spreading K fertilizer over the study areas and contaminated the plots we were monitoring.

In 2011 two additional locations near Columbus, KS and one new location near Buffalo, KS were added. The sites were all full season soybeans following corn. The location at Pringles was no-tilled while the other two locations had been conventionally tilled prior to planting. Fertilizer treatments were applied on June 3, 2011 at Pringles and on June 7, 2011 at the Leeper locations.

Soil Sampling and Analysis

Soil samples consisted of 0-15 cm depth cores collected at random from the unfertilized K control and biannual broadcast high rate plots. Soil samples were taken using a manual soil probe and samples consisted of 10 to 12 individual cores mixed together to form a single composite sample from each plot. Soil samples were always taken on the same day at the locations that were initiated in the same year. Soil samples were oven dried at 60^{o}C and then ground to pass through a 2-mm sieve by a Dyna-Crush 5 flail grinder (Custom Laboratory Equipment Inc., Orange City, FL). A 2 gram sub-sample of each finely ground plot sample was weighted out and extracted with 20 mls of 1.0 N ammonium acetate. The samples were agitated for 5 minutes and filtered for analysis. Potassium analysis was conducted using a Perkin Elmer Model 200 AAnylyst Atomic Absorption Spectrometer.

Statistical Analysis

Ammonium acetate exchangeable K levels were analyzed by location using the PROC MIXED procedure at alpha level 0.05, with blocks as a random affect and date as a fixed affect, in SAS version 9.2 (SAS Institute, 2008). Data was also analyzed by study year for an overall analysis and run in the same PROC MIXED procedure, but with blocks and locations as random affects and date as a fixed affect. Determination of significance of difference between fall and spring soil test K levels were determined using Fishers LSD. *T*-tests were used to determine significance of difference between actual and predicted net changes in soil test K levels.

Results and Discussion

2009-2011 Sites

Soil test potassium (K) levels at all locations for both treatments were found to be significantly ($P<0.05$) affected by time of soil sampling (Figure 2.1). Potassium fertilization dramatically increased exchangeable K levels at all locations. The decrease in soil test K (STK) from the initiation of the study until the conclusion was more pronounced with the addition of K fertilizer (Table 2.4). On average the no K treatment exhibited a 22% net change in STK, while the average change of the high K rate treatment reached 43%. The SE Brown no K treatment actual change in STK was very close to the predicted change based on crop removal rates over the three year period (Table 2.4). The Delmont no K treatment and the high K rate (202 kg K_2O ha^{-1}) treatment at all locations had actual net changes in exchangeable K levels that were significantly higher ($P<0.05$) then the predicted net changes in STK after three years of cropping based on standardized crop removal rates and K buffering factors (Table 2.4).

Soil test K levels for the no K and high K rate treatments were extensively higher ($P<0.05$) in the spring of 2010 than in the fall of 2009 for all locations (Table 2.5). The average increase in STK across all locations was 27 and 26% for the no K and high K rate, respectively.

Both treatments at all locations, except at SW Brown with the high K rate treatment, had fall exchangeable K levels that were below the optimum level (130 mg kg^{-1}) and a specific rate of K fertilizer would have been recommended (Table 2.5). In the following spring all the exchangeable K levels were above the optimum level, except at Delmont with the no K treatment, and thus no K fertilizer would have been recommended (Table 2.5). Soil sample timing greatly influenced exchangeable K levels and consequently the K fertilizer recommendation. In the spring of 2011 the STK levels for the no K and high K rate treatments were substantially lower ($P<0.05$) than in the fall of 2010 at SW Jennings, SE Brown and SW Brown (Table 2.6). At all locations in the fall of 2010 wheat had been planted, so by spring the wheat crop was well established. As a result the decline in exchangeable K from fall (2010) to spring (2011) is likely due to K uptake by the wheat crop.

The change in K levels between the locations followed very similar trends over time, as a result a combined analysis across locations was performed (Figure 2.2). The combined analysis, as expected, displayed significant ($P<0.05$) STK variation over time. During each individual growing season K levels consistently declined from crop establishment to crop harvest. As the crops matured the volume of K uptake increased paralleling the substantial decline in exchangeable K. After harvest, the STK levels went through a build-up period until the next crop was actively growing and taking up K. The post-harvest break-down and decomposition of the crop residue releases K and as a result the soil exchangeable K levels increased.

The relationship of monthly precipitation and fluctuations in soil test K are documented in Figure 2.2. During several wet months STK levels noticeably increased for both treatments. This was observed in March 2010, May 2010 and September 2010, where the average STK level between treatments increased by 26, 14 and 7%, respectively, from the previous sampling date. However, in June 2010, July 2010, April 2011 and May 2011 rainfall was high yet K levels actually decreased. The decrease in exchangeable K levels during these months could be related to the increase in crop K removal, while the increase observed in fall and early spring could have been the return of residue K to the soil by leaching. During several dry months STK levels declined from the previous sampling date. This was observed in October 2009, April 2010 and August 2010, where the average STK level between treatments decreased by 43, 8 and 4%, respectively. Overall, the relationship between STK variability and wetting and drying periods were very inconsistent throughout the three year period. This is likely an indication that multiple mechanisms are involved in the control of STK levels in the field.

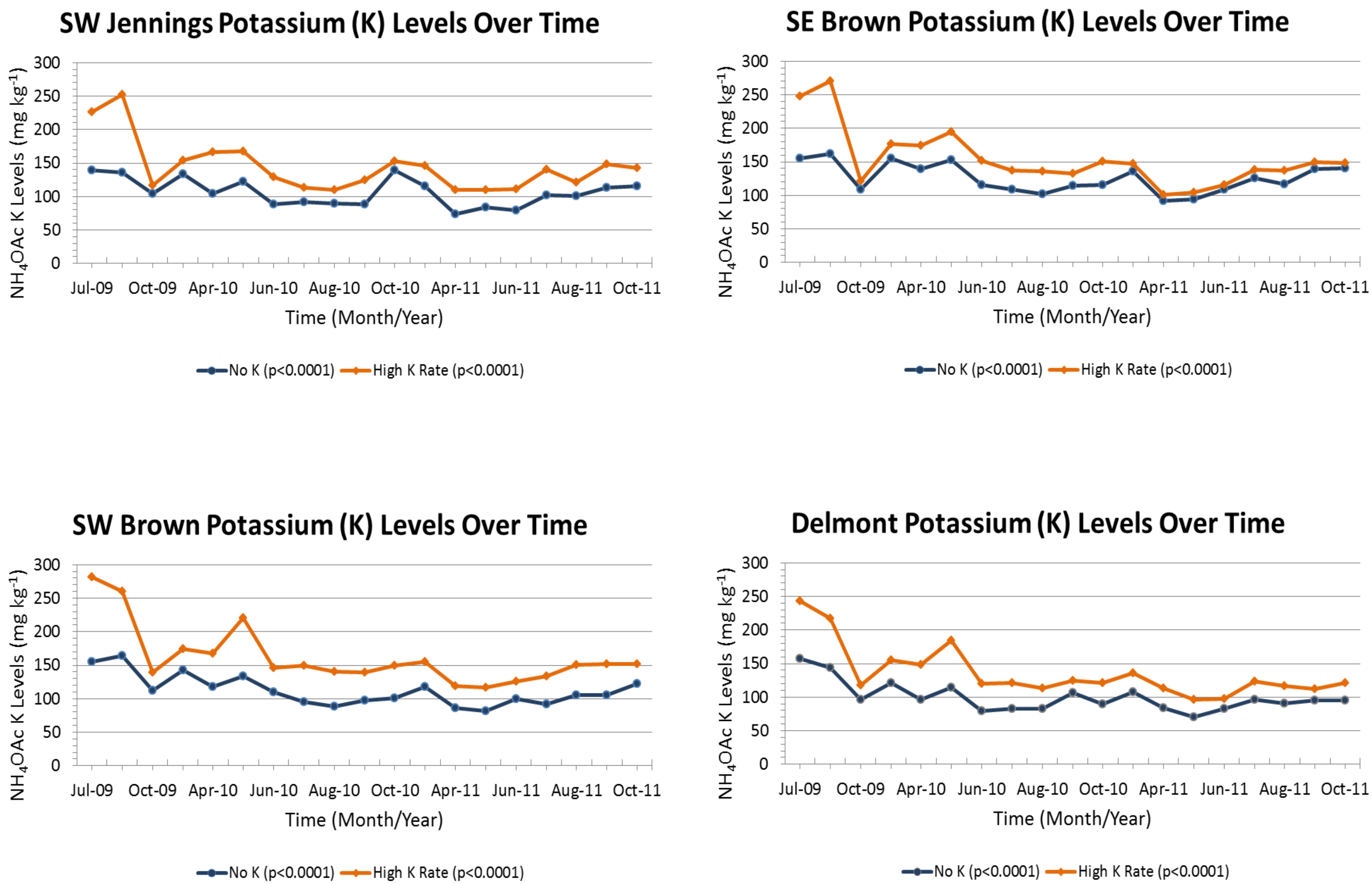

Figure 2.1 Ammonium acetate (NH_4OAc) exchangeable K levels over time by location (2009-2011)

Table 2.4 Predicted and actual net changes in soil test K (STK) from the initiation to the conclusion of the study by location (2009-2011)

Location	*Est. Crop K Removal*	*Predicted Change in STK*	*Amount of K Applied*	*2009-2011*		
				Initial STK	Final STK	Net Change
	kg K_2O ha^{-1}	mg kg^{-1}	kg K_2O ha^{-1}	------------------------------	mg kg^{-1}	------------------------------
SW Jennings	121	12	0	140	116	-24
	123	12	202	226	142	-84*
SE Brown	101	10	0	155	140	-15
	101	10	202	247	149	-98*
SW Brown	98	10	0	155	123	-32
	98	10	202	282	152	-130*
Delmont	111	11	0	157	95	-62*
	111	11	202	243	121	-122*

- Net change in soil test K calculated as final STK minus initial STK

* Indicates whether actual net change is significantly different than predicted net change in STK at alpha 0.05

Table 2.5 Changes in soil test K (STK) between fall (2009) and spring (2010) soil sampling by location

			Amount of K Applied	*2009-2010*		
				Fall STK	Spring STK	Net Change
Location	*Previous Crop*	*Current Crop*	kg K_2O ha^{-1}	------------------------------	mg kg^{-1}	------------------------------
SW Jennings	Soybean	Fallow	0	104	134	+30*
			202	116	155	+39*
SE Brown	Soybean	Fallow	0	109	155	+46*
			202	121	177	+56*
SW Brown	Soybean	Fallow	0	112	143	+31*
			202	139	174	+35*
Delmont	Soybean	Fallow	0	96	121	+25*
			202	117	156	+39*

- Net change in soil test K calculated as spring STK minus fall STK

* Indicates significant difference between fall and spring STK at alpha 0.05

Table 2.6 Changes in soil test K (STK) between fall (2010) and spring (2011) soil sampling by location

			Amount of K Applied	*2010-2011*		
				Fall STK	Spring STK	Net Change
Location	*Previous Crop*	*Current Crop*	kg K_2O ha^{-1}	------------------------------	mg kg^{-1}	------------------------------
SW Jennings	Corn	Wheat	0	139	74	-65*
			202	153	110	-43*
SE Brown	Corn	Wheat	0	116	92	-24*
			202	150	101	-49*
SW Brown	Corn	Wheat	0	101	87	-14*
			202	150	119	-31*
Delmont	Corn	Wheat	0	90	84	-6
			202	121	113	-8

- Net change in soil test K calculated as spring STK minus fall STK

* Indicates significant difference between fall and spring STK at alpha 0.05

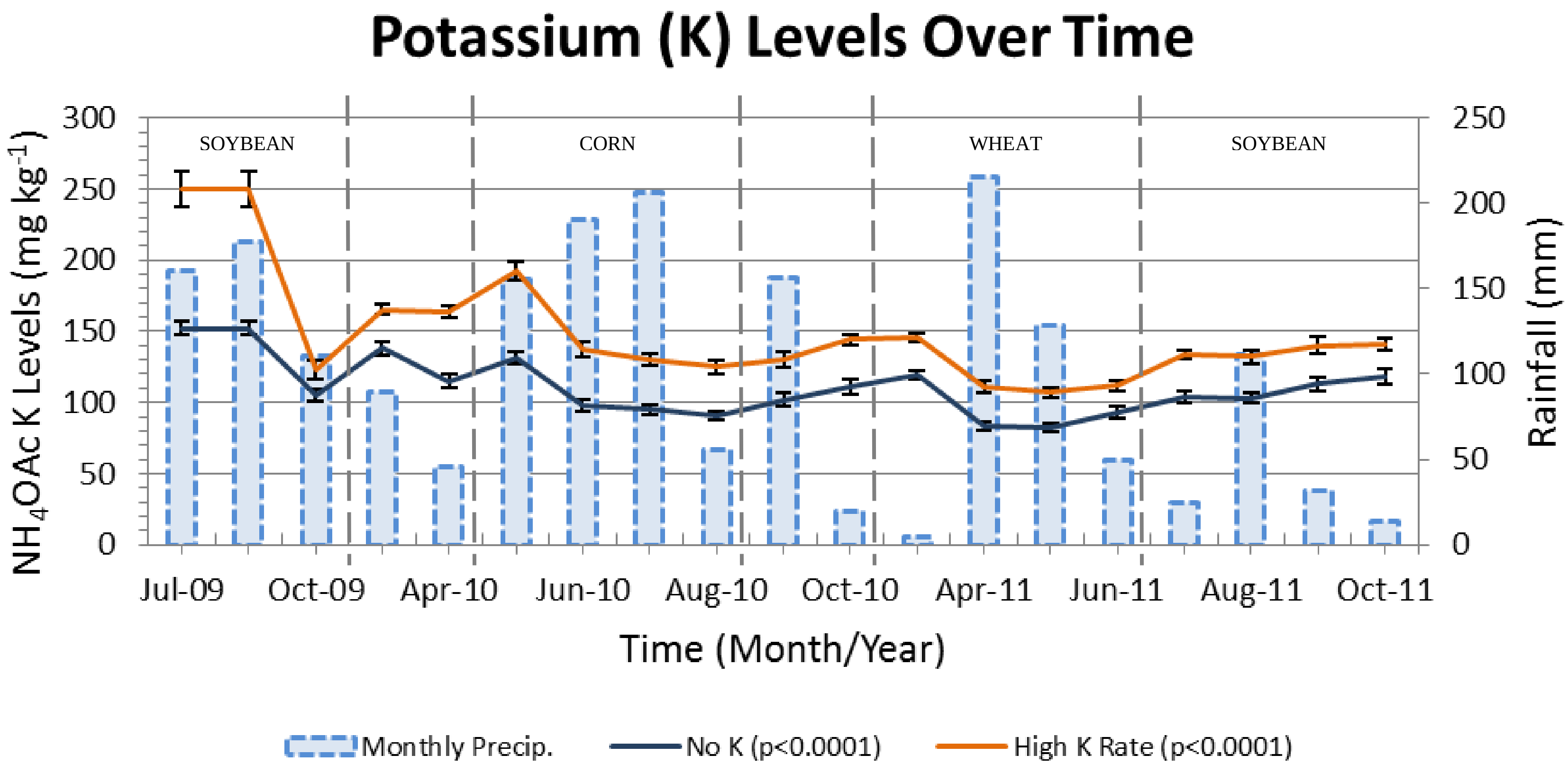

Figure 2.2 Average ammonium acetate (NH_4OAc) exchangeable K over time with standard error bars, monthly precipitation and crop rotation across locations (2009-2011), P-values are given for the effect of time on NH_4OAc exchangeable K levels

2010-2011 Sites

Soil test potassium (K) at these locations for both treatments, except the high rate treatment at Krantz, were also found to be significantly ($P<0.05$) affected by time of soil sampling (Figure 2.3). Potassium fertilization increased exchangeable K levels at all locations. The decrease in soil test K (STK) from the initiation of the study until the conclusion was more pronounced with the addition of K fertilizer at NW of Dads (Table 2.7). Soil test K levels remained higher for the high K rate plots at the end of the study at every location compared to the no K treatment initial STK level, suggesting that some residual fertilizer remained in the soil system. The NW of Dads no K treatment STK level was very close to the predicted value, due to the change in STK based on crop removal rates over the two year period (Table 2.7). The no K treatment and the high K rate (202 kg K_2O ha^{-1}) at East Marks had actual net changes in exchangeable K that were significantly different ($P<0.05$) then the predicted net changes after two years of cropping. A majority of the other locations net change in STK over the course of the study were well above the predicted change based on crop K removal rates but not found to be significant (Table 2.7).

Soil test K levels for the no K treatment at NW of Dads, East Marks and Krantz was significantly higher ($P<0.05$) in the spring of 2011 than in the fall of 2010 (Table 2.8). At the Spieth location the no K treatment STK level decreased ($P<0.05$) 20% from the fall of 2010 to the spring of 2011 (Table 2.8). There were no significant differences between the high K rate STK levels from the fall (2010) to the spring (2011) at any of the locations.

The combined analysis of NW of Dads and East Marks is shown in Figure 2.4. The combined analysis of NW of Dads and East Marks displayed significant ($P<0.05$) STK variation over time. During the soybean growing season in 2010, the no K treatment STK level declined 27% from crop establishment to harvest. The high K rate did not begin to decline until after August, but dropped 10% from that point until harvest. The fertilizer was applied in early July and by August it had dissolved into soil solution. Going into December the no K and high K rate STK levels increased by 17 and 6%, respectively, which is likely due to the release of K from the crop residue. In 2011, from corn planting, after the April soil sampling was conducted, to harvest the K levels once again decreased. As crop K uptake increased during the growing seasons, soil exchangeable K levels declined.

The combined analysis of Krantz and Spieth is shown in Figure 2.5. The Krantz and Spieth data was not analyzed with NW of Dads and East Marks since the two locations were dropped in 2011 due to misapplication of K fertilizer. The combined analysis displayed significant ($P<0.05$) STK variability over time for both the no K and high K rate treatments. During the soybean growing season the no K STK level decreased 18% from planting to harvest. The high K rate STK level increased 24% from July to August, which is due to the addition of K fertilizer between the two sampling dates. From August to September the no K and high K rate STK levels increased 8 and 2%, respectively, but by October, at harvest, the K levels noticeably decreased. By December, the average STK level between the treatments increased 3%, possibly due to the release of K from the soybean residue. By April the level decreased 5% from December, which could be due to the fixation of K into unavailable, or at least not easily measured K forms in the soil.

The relationship of monthly precipitation and fluctuations in STK are documented in Figure 2.4 for NW of Dads and East Mark. During a couple of wet months STK levels increased for both treatments, but only slightly. The no K treatment STK level in September 2010, April 2011 and May 2011 increased 2, 4 and 5%, respectively, from the previous soil sampling date. In May 2011 the high K rate STK level increased 7%. However, in April 2011 and August 2011, rainfall amounts were relatively high, yet K levels dropped for the high K rate treatment. The decrease in exchangeable K levels during these months could be related to the increase in crop K removal. During several dry months STK levels declined, as observed in July 2011 for the no K treatment, October 2010, July 2011 and September 2011 for both treatments. However, the relationship between STK levels and wetting and drying periods were very unpredictable and often times negligible throughout the two year period.

The relationship of monthly precipitation and fluctuations in STK are documented in Figure 2.5 for Krantz and Spieth. The relationship is very minimal, but during September 2010 the high K rate STK level increased 2% with high levels of rainfall and decreased 12% in October 2010 with minimal rainfall. The relationship was not prominent with the no K treatment over the six month period.

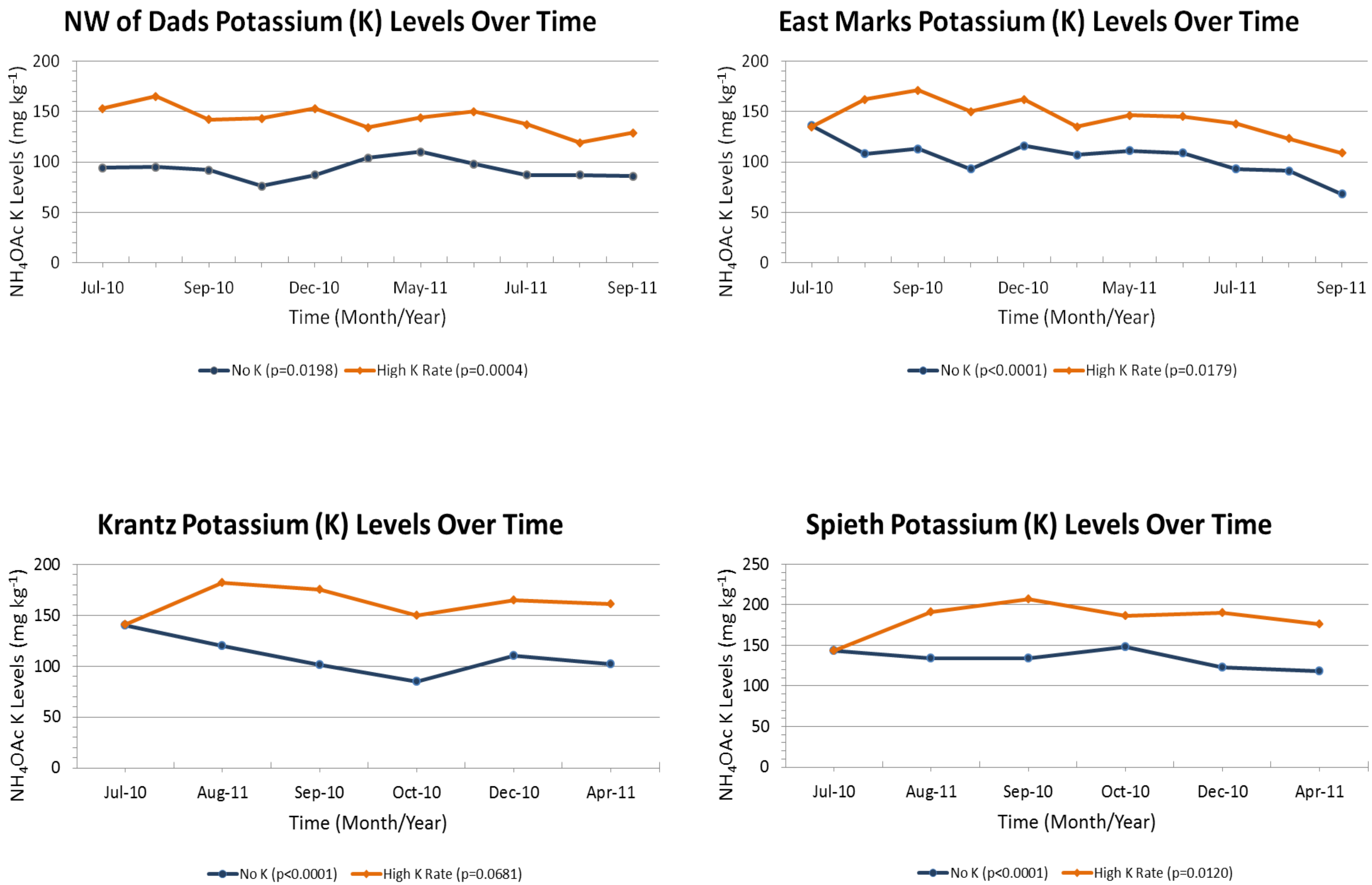

Figure 2.3 Ammonium acetate (NH_4OAc) exchangeable K levels over time by location (2010-2011)

Table 2.7 Predicted and actual net changes in soil test K (STK) from the initiation to the conclusion of the study by location (2010-2011)

Location	*Est. Crop K Removal*	*Predicted Change in STK*	*Amount of K Applied*	*2010-2011*		
				Initial STK	Final STK	Net Change
	kg K_2O ha^{-1}	mg kg^{-1}	kg K_2O ha^{-1}	---------- mg kg^{-1} ----------		
NW of Dads	66	7	0	95	86	-9
	70	7	202	165	129	-36
East Marks	91	9	0	108	68	-40*
	87	9	202	162	109	-53*
Krantz	87	9	0	120	102	-18
	91	9	202	182	161	-21
Spieth	72	7	0	134	118	-16
	67	7	202	191	176	-15

- Net change in soil test K calculated as final STK minus initial STK

* Indicates whether actual net change is significantly different than predicted net change in STK at alpha 0.05

Table 2.8 Changes in soil test K (STK) between fall (2010) and spring (2011) soil sampling by location

Location	*Previous Crop*	*Current Crop*	*Amount of K Applied* kg K_2O ha^{-1}	*2010-2011* Fall STK	Spring STK	Net Change
				------	mg kg^{-1}	------
NW of Dads	Soybean	Fallow	0	76	104	+28*
			202	143	134	-9
East Marks	Soybean	Fallow	0	93	107	+14*
			202	150	135	-15
Krantz	Soybean	Fallow	0	85	102	+17*
			202	150	161	+11
Spieth	Soybean	Fallow	0	148	118	-30*
			202	186	176	-10

- Net change in soil test K calculated as spring STK minus fall STK

* Indicates significant difference between fall and spring STK at alpha 0.05

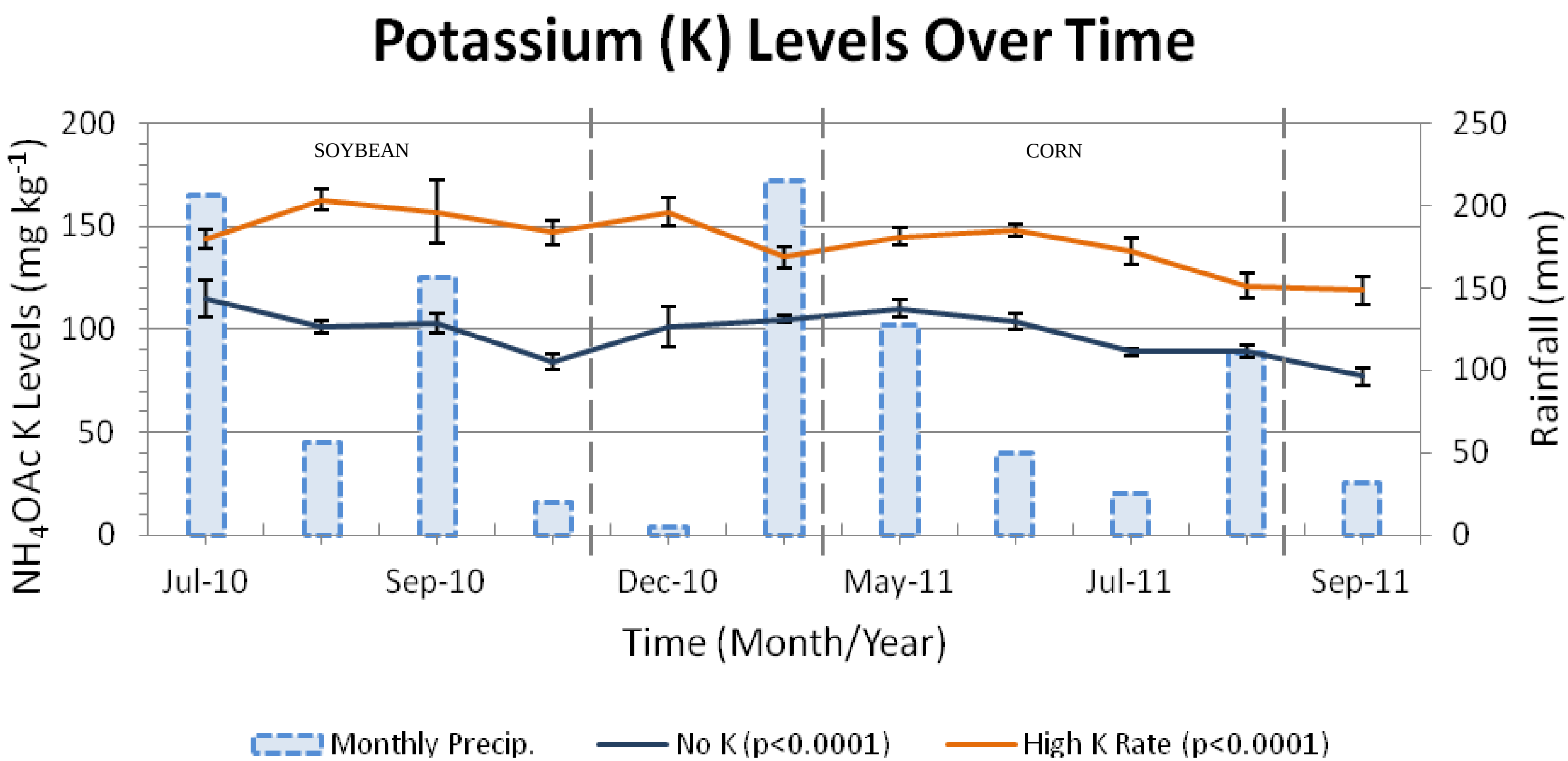

Figure 2.4 Average ammonium acetate (NH_4OAc) exchangeable K over time with standard error bars, monthly precipitation and crop rotation for NW of Dads and East Marks (2010-2011), P-values are given for the effect of time on NH_4OAc exchangeable K

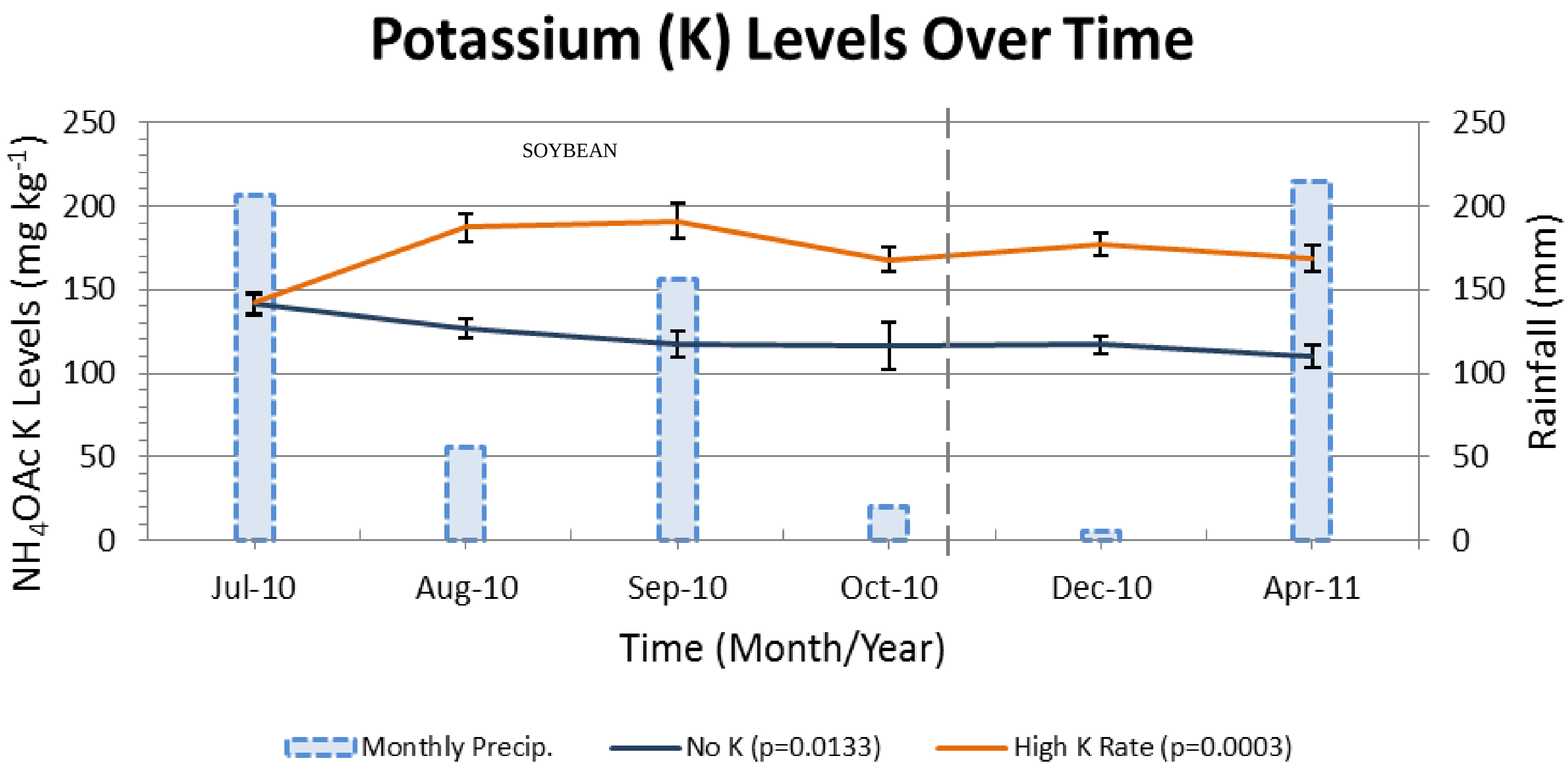

Figure 2.5 Average ammonium acetate (NH_4OAc) exchangeable K over time with standard error bars, monthly precipitation and crop removal for Krantz and Spieth (2010-2011), P-values are given for the effect of time on NH_4OAc exchangeable K levels

2011 Sites

Soil test potassium (K) levels were found to be significantly ($P<0.05$) affected by time of soil sampling at North Leeper and Pringle where no K was applied (Figure 2.6). For the rest of the treatments, fluctuations in soil test K (STK) were obvious, but were not statistically significant ($P>0.05$) due to variability between replicates. Potassium fertilization increased exchangeable K levels at all three locations. The no K treatment exchangeable K level at Pringles increased 38% ($P<0.05$) from the beginning of the cropping season to soybean harvest (Table 2.9). The other treatments either stayed the same or increased over the growing season, however, the actual net change was not found to be statistically significant from the predicted net change (Table 2.9). The North Leeper no K treatment was very close to the predicted change in STK based on soybean crop removal rates over the cropping season (Table 2.9).

The combined analysis of North and South Leeper is shown in Figure 2.7. The combined analysis displayed significant ($P<0.05$) STK level variation over time for the no K treatment. The high K rate was not found to be significant at the 0.05 alpha level. During the soybean growing season the K levels for the no K treatment declined until October. The high K rate decreased 9% from July to August and then increased 2% in September. In September, high rainfall could have contributed to the slight rise in exchangeable K. However, in October STK levels rose 19% even though rainfall amounts for the month were lower than in September.

The analysis of Pringles was done by itself due to the difference in location and rainfall amounts (Figure 2.8). The change in soil exchangeable K over the cropping season was significant ($P<0.05$) for the no K treatment, but not for the high K rate. During the soybean growing season the no K treatment STK level steadily increased from planting to harvest. The high K rate STK levels decreased 21% from July to August and then increased 7% from September to October. The relationship between precipitation and exchangeable K levels was inconsistent. The high K rate decreased in August with high rainfall, but increased the following month with rainfall. In October the rainfall amount was minuscule yet K levels rose from the previous month.

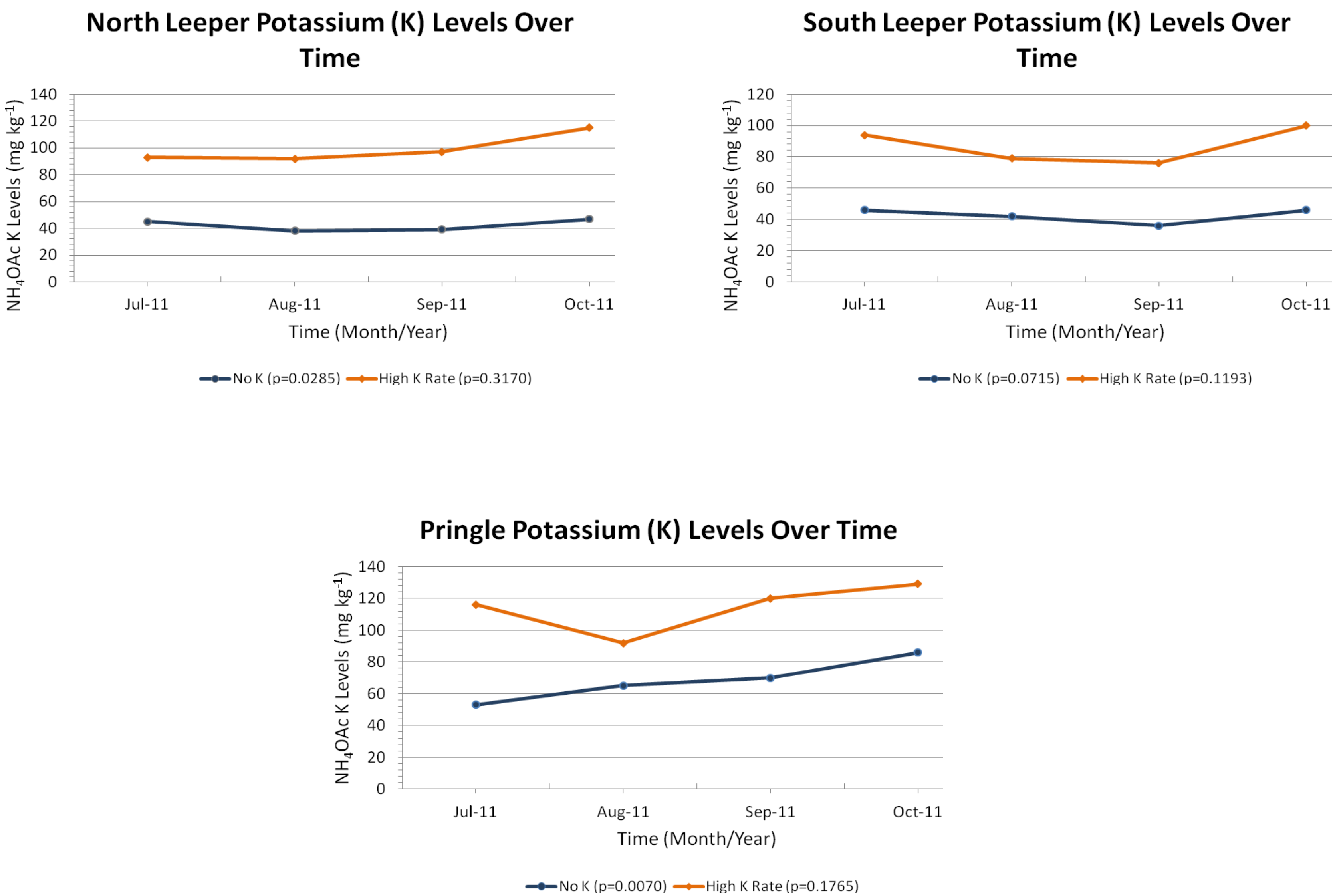

Figure 2.6 Ammonium acetate (NH_4OAc) exchangeable K levels over time by location (2011)

Table 2.9 Predicted and actual net changes in soil test K (STK) from the initiation to the conclusion of the study by location (2011)

Location	*Est. Crop K Removal*	*Predicted Change in STK*	*Amount of K Applied*	*2011*		
				Initial STK	Final STK	Net Change
	kg K_2O ha^{-1}	mg kg^{-1}	kg K_2O ha^{-1}	------------------	mg kg^{-1}	------------------
North Leeper	30	3	0	45	47	+2
	37	4	202	93	115	+22
South Leeper	35	4	0	46	46	0
	41	4	202	94	100	+6
Pringle	49	5	0	53	86	+33*
	57	6	202	116	129	+13

- Net change in soil test K calculated as final STK minus initial STK

* Indicates whether actual net change is significantly different than predicted net change in STK at alpha 0.05

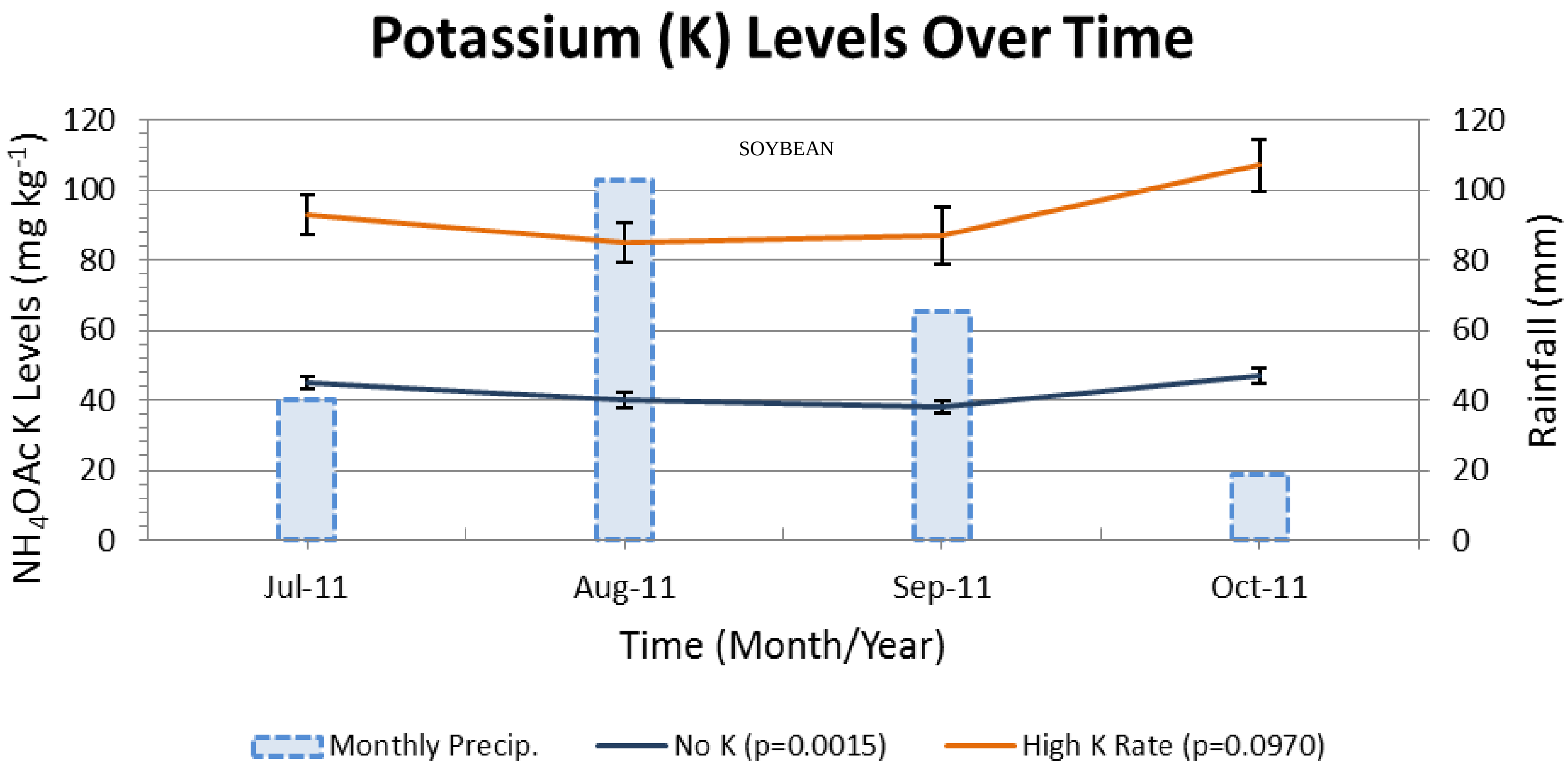

Figure 2.7 Average ammonium acetate (NH_4OAc) exchangeable K over time with standard error bars, monthly precipitation and crop for North and South Leeper (2011), P-values are given for the effect of time on NH_4OAc exchangeable K levels

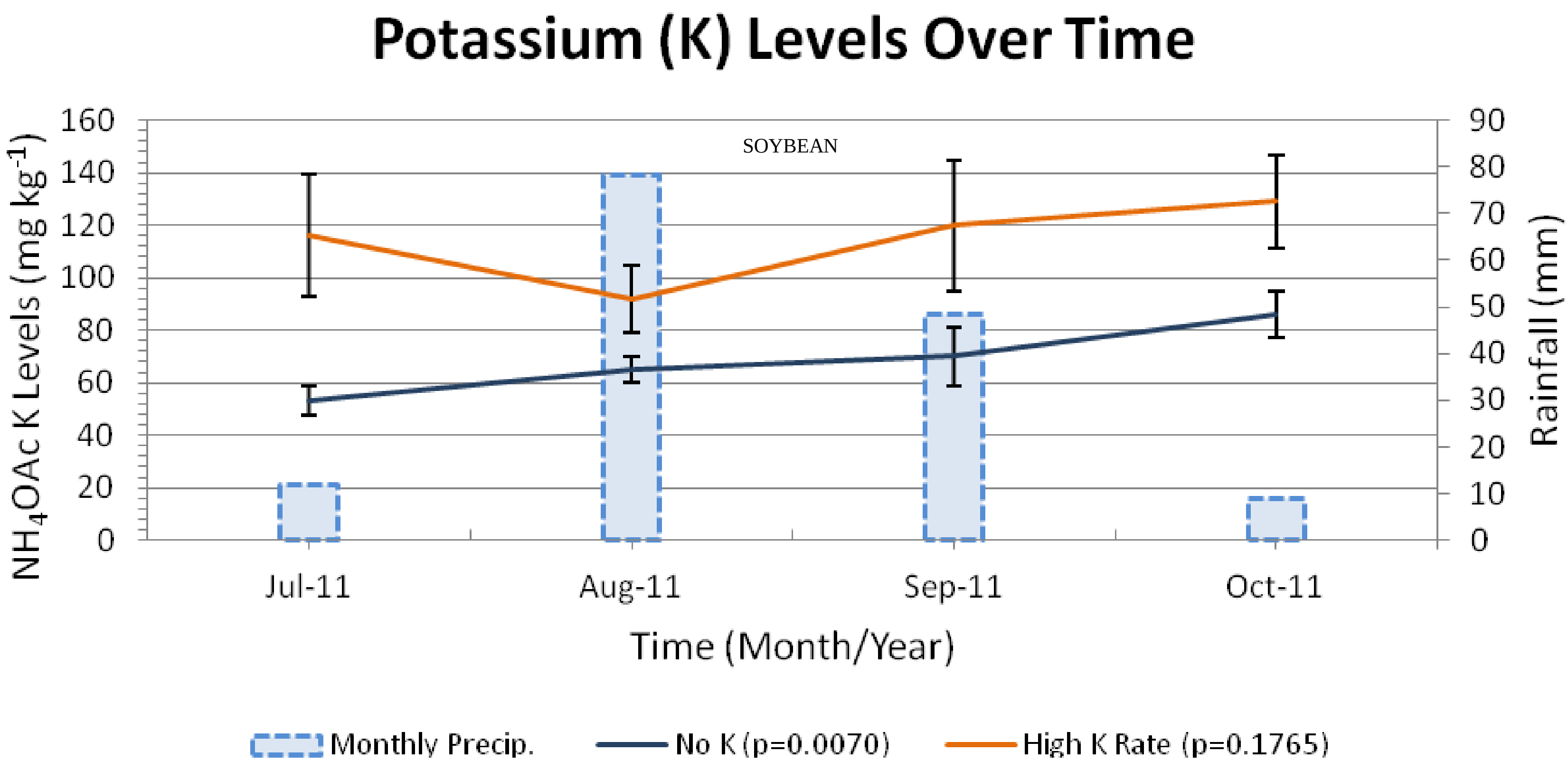

Figure 2.8 Average ammonium acetate (NH_4OAc) exchangeable K over time with standard error bars, monthly precipitation and crop for Pringles (2011), P-values are given for the effect of time on NH_4OAc exchangeable K levels

Conclusions

Soil test potassium (K) levels were found to be significantly affected by time of soil sampling during the three year period at multiple locations. During the study several noticeable trends were documented. Soil exchangeable K levels consistently increased with K fertilization, than decreased during a majority of the crop growing seasons from crop establishment to crop harvest. Crop K removal is assumed to be the main reason for the decline in soil test K (STK) levels during the growing seasons, however, K leaching could also be a factor in the decrease. The one exception where exchangeable K levels actually increased through the growing season was at the three locations that were established in 2011. At these locations soil test exchangeable K levels were quite low all season long and rain was limited. Research has shown that when dried, soils low in exchangeable K express increases in exchangeable K, while soils high in exchangeable K exhibited decreases (McLean and Watson, 1985). This could be the potential cause in the increase in exchangeable K throughout the growing season at these locations. The post-harvest exchangeable K levels at most locations increased until the next crop was well established and began absorbing exchangeable K from the soil. As the crop residue broke-down and decomposed, K leached from the residue potentially resulting in the rise in exchangeable K between crops. Some of the increase could also be due to the release of K from non-exchangeable sites.

Fluctuations in STK have also been linked to wetting and drying periods due to their influence on K release and/or fixation. Our research showed that during several wet months exchangeable K increased and during numerous dry months exchangeable K decreased. This relationship was mainly observed with the 2009-2011 and 2010-2011 sites. However, the relationship between STK and wetting and drying periods was very inconsistent throughout the three year study. There were months were an inverse relationship was recorded, wet months had K levels that decreased and dry months resulted in increased K levels. Crop K uptake could have influenced the decrease in K during many of the wet months, which could vastly skew the relationship over time. Additionally, when the K levels increased during several dry periods, fixed K could have been released if exchangeable K was depleted to a specific point. There appears to be various mechanism's involved, which makes the relationships so complex, so we can only speculate as to the exact cause of these changes during any specific time period.

Overall at most locations soil test exchangeable K levels decreased over the duration of the study. The reduction in STK with crop removal would be understood and expected, however, the levels generally decreased beyond the predicted amount based on standardized crop K removal rates and soil K buffering factors. Possible explanations for this behavior could be related to the probability that these soils possess a high K leaching potential, the capability for mineral K fixation and/or the soils have a lower than expected K buffering capacity. Changes in STK level with the addition of K fertilizer and/or removal of K is related to the K buffering capacity of the soil. Currently, Kansas State University assumes that Kansas soils have a K buffering capacity of 10 kg K_2O ha^{-1} per 1 mg kg^{-1} change in STK. The soils in southeast Kansas are highly weathered with low clay content, organic matter content and cation exchange capacity. As a result they could have much lower buffering capacities then the normalized value used. This could give rise to the extreme monthly and yearly fluctuations that are otherwise unexplainable. More evidence and further investigation is necessary to confirm these assumptions.

The majority of producers in southeast Kansas typically soil sample either in the fall or winter months. The 2009-2011 sites demonstrated that spring soil samples had significantly higher exchangeable K levels then in the fall as long as a crop was not established in the field prior to the spring soil sampling. The 2010-2011 sites displayed very inconsistent results, some exchangeable K levels increased while others decreased over the winter months. The results of this study suggest that changes in STK level between fall and spring sampling dates are not consistent from year to year, at a given location. Thus, soil sampling at the same time of year whenever possible is useful to reduce K variability over time. Equally important is for producers to keep good soil test records to plot trends in STK level over time to reduce yearly variability impacts on fertilizer recommendations.

A number of factors have been mentioned to explain the variation in STK observed within and across years. Many factors are uncontrollable, but some can be managed by crop advisers and producers when conducting their soil samples. Our best suggestion is for soil samples to be taken either in the fall, well after harvest to allow amble time for K to leach out of crop residues, or in the spring prior to crop establishment. Choose a time to soil sample that is convenient and sample the field(s) at the same time of year to help minimize any seasonal STK variability over time. Switching back and forth from fall to spring soil sampling can introduce significant changes from one sampling period to the next. Furthermore, it is recommended to soil sample after the same crop in the rotation to avoid any seasonal soil K inconsistencies due to release of K from crop residues. Use strict depth control when soil sampling and collect a sufficient number of soil cores per sample to insure you are collecting a representative soil sample. The use of proper soil sampling techniques can help stabilize some of the variation over time as well.

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Chapter 3 - Impact of Potassium Fertilizer Rates and Method of Placement on Soybeans in Southeast Kansas

Abstract

The majority of Kansas soils have historically been recognized for having high available potassium (K) levels and traditionally little attention has been focused on K as a nutrient needing supplemental fertilization. However, in the older and more highly weathered soils in southeast Kansas, an area bounded by the Flinthills on the west and the Kansas River on the north, it is not uncommon to encounter soybean (*Glycine max* L.) fields that are visually suffering from inadequate K nutrition. This has raised a number of questions and concerns over the proper K management practices that need to be implemented to optimize soybean production. The objective of this study was to evaluate the response of soybeans to K fertilizer and determine if surface band applications increase K availability to crops compared to broadcast applications.

This study was conducted at eleven locations in southeast Kansas with soybeans during the 2009, 2010 and 2011 cropping seasons. Selected sites varied in soil test K levels, ranging from slightly above the current critical level of 130 mg kg^{-1} to well below the optimum level where responses to K fertilization would be expected, and K fertilizer recommended. Treatments consisted of K rates ranging from 0 to 202 kg K_2O ha^{-1} applied using either a broadcast or surface band method of application.

Plant samples were taken twice during the growing season to monitor treatment affects. The first set of tissue samples were collected at the R3 (pod-set) growth stage and the second set at the R4 (pod-fill) growth stage. Yield and grain K concentrations were measured at harvest to further disclose treatment effects. Sampling data showed some mixed results and some locations provided some interesting findings. Several locations showed that increased K fertilization rate either broadcasted or surface banded increased leaf K concentrations. At locations that had very low (< 90 mg kg^{-1}) soil test K levels, surface banding resulted in significantly higher leaf K levels as compared to broadcasting at the same rate. Grain K concentrations and soybean yield responses were only observed with the addition of K fertilizer on soils testing very low in soil test exchangeable K.

Introduction

Soybeans (*Glycine max* L.) are an economically important crop grown under conventional and conservation tillage in southeast Kansas. Over three hundred thousand hectares of soybeans were planted in southeast Kansas in 2010 (USDA, 2011). In the past, there has been a widespread opinion that soybeans are easy crops to grow that require minimal inputs, especially when compared to a crop such as corn. However, in recent years as soybean production has increased in southeast Kansas so has the occurrence of potassium (K) deficiency. Likely contributors are continuous cropping for over a century and inadequate K fertilization over time. Consequently, more soils in the area are testing lower than optimum (< 130 mg kg^{-1}) in soil test exchangeable K. This has caused many questions and concerns to surface involving the use of K fertilizer as a soybean crop input and the appropriate K management programs that should be practiced.

Potassium is one of the principle plant nutrients involved with crop yield production and quality determination. Potassium plays vital roles in plant-water relations, photosynthesis, assimilate transport and enzyme activation (Pettigrew, 2008). Additionally, K has been shown to improve soybean nodulation and nitrogen fixation, resulting in an increased potential supply of residual nitrogen for subsequent crops (Premaratne and Oertli, 1994). Therefore, relatively high levels of K are generally required to ensure a high yielding soybean crop. Hanway and Weber (1971) reported that the uptake of K is highest during rapid vegetative growth and slows as seed formation begins. Thus, in fields that suffer from soil K shortages, adverse effects to soybean growth, development and reproduction are likely to occur. Specifically, K deficient soybeans generally grow slower and regularly have poorly developed roots and weak stems.

Soybean K deficiency is generally observed with low soil test K levels, however, K deficiencies can be an issue in soils with apparent adequate exchangeable K. Many soil and weather related factors that stress or limit root growth can induce K deficiency symptoms. Soil K stratification, compacted soils, cool soil temperatures and dry loose soil can all limit plant K uptake. As growth continues during the season, K uptake may be increased or remain reduced depending on subsoil K supply and soil moisture content. The intensity and practices of K management become essential to overcome the effects of some of these issues.

To achieve maximal soybean yields supplemental K fertilization may be required. In numerous studies K fertilization often increased K uptake (Borges and Mallarino, 2003; Borges and Mallarino, 2000) and plant tissue K content (Ebelhar and Varsa, 2000; Hudak et al., 1989) in soybeans, even at sites that tested in the optimum to high (130 to 274 mg kg^{-1}) range in soil test K. Soybean yield responses have been observed with K fertilization when soybeans were grown under conventional tillage (Casanova, 2000; Heckman and Kamprath, 1995) and conservation tillage (Borges and Mallarino, 2000; Buah et al., 2000; Coale and Grove, 1990). However, it seems that the probability of a soybean response is highly dependent on soil test K levels. Relevant research has shown that soybeans demonstrate positive responses to added K on very low (< 90 mg kg^{-1}) K testing soils (Yin and Vyn, 2003; Yin and Vyn, 2002; Randall et al., 1997; Rehm, 1995). Rarely was a significant yield response observed in studies were soil test K levels were optimum to high (130 to 274 mg kg^{-1}) (Yin and Vyn, 2002; Borges and Mallarino, 2000; Buah et al., 2000).

The placement of K is a major management consideration and can have an effect on how rapidly K fertilizer will be available and utilized by plants. Practices such as broadcasting and deep-banding K fertilizers are both well documented methods of K application. Broadcast fertilization is a relatively low cost, convenient application method that allows producers to apply large quantities of nutrient quickly. However, this application method has a number of drawbacks, especially with the use of conservation tillage systems. Broadcast applications can lead to added accumulation of K in the upper soil layer making plant K uptake difficult. Furthermore, broadcast applications have a higher potential for K fixation which can reduce the immediate efficiency of K fertilizer (International Plant Nutrition Institute, 2006). When fertilizer is placed in a band it is concentrated which allows for less exposure to K fixing clay minerals and allows producers to place the fertilizer in close proximity to the growing crop. However, deep-band placement of K requires a significant power source to pull specialized application equipment. Producers, especially those in no-till systems, may find it unappealing to pull such equipment through their fields due to the disruption of residue cover and soil structure. This has led us to explore the potential of surface band applied K fertilizer.

Research conducted by Yin and Vyn (2002) and Ebelhar and Varsa (2000) concluded that there were no significant difference of soybean leaf K concentrations at early reproductive growth stages between broadcast and banded treatments. Other research (Hudak et al., 1989) also showed no K placement effect on yield of no-till soybean grown on silt loam soils in Ohio. However, Hairston (1990) and Yin and Vyn (2003) showed that deep-banded fertilizer had an advantage over surface broadcast placement at the same rates in terms of leaf K and yield on low to medium testing K soils. Work done by Eckert and Johnson (1985) and Yibirin et al. (1993) also showed that shallow sub-surface banding can significantly increase P and K fertilizer use efficiency compared with broadcast fertilizer applications for no-till soybeans. Research in Iowa (Borges and Mallarino, 2000) reported that both deep-band and starter K fertilizer in no-till systems produced slightly higher soybean yields than surface broadcast applications on optimum to very high testing soils. These results agree with long known effects of banding in minimizing retention of K by soil constituents resulting in increased fertilizer use efficiency by crops.

Several challenges exist in recommending the use of K fertilizer on the highly weathered soils of southeast Kansas. Among these challenges is determining under what conditions plant growth response to K fertilizer would be expected and assessing the appropriate K fertilizer rate, and placement method needed to optimize soybean yield.

The objectives of this study were to:

1. Determine if soybean K deficiency under conventional and conservation tillage in southeast Kansas is impacting soybean yields.
2. Test the response of soybeans to K fertilizer being applied broadcast or surface banded at different K fertilizer rates.

Materials and Methods

Research was conducted on-farm in cooperation with local producers. Field experiments were established at four locations in 2009, four locations in 2010 and three locations in 2011, to evaluate the response of soybeans (*Glycine max* L.) to varying potassium (K) fertilization rates and surface banded or broadcast K placements. Field site locations, year study was established and geographical coordinates are presented in Table 3.1. Sites in 2009 and 2010 were selected based on soil test results provided by the cooperating farmers, from samples collected in the fall of 2007. In 2011 sites were selected based on the K tests of soil samples sent to the Kansas State University (KSU) Soil Testing Lab by producers in the spring. Initial indications were that all sites had soil test K levels substantially below optimum (130 mg kg^{-1}). However, samples collected in the spring immediately before planting, showed that not to be the case, particularly for the sites established in 2009 and 2010. Selected sites varied in soil test K levels, ranging from slightly above optimum to well below where responses to K fertilization would be expected, and K fertilizer recommended. Field site soil descriptions and average soil test levels for each site are given in Table 3.2. All eleven locations were rain-fed and no supplemental irrigation was used. Cumulative in-season precipitation, average daily temperature and 30 year normals, were based on the nearest local weather station data for each area (National Climatic Data Center, 2011). For the Hallowell, Columbus and Buffalo sites, weather data was taken from the Oswego, Columbus and Yates Center weather stations, respectively.

At each location plots were arranged in a randomized complete block design with four replications. Soybeans were all planted with a row spacing of 76.2 cm. Plots were 15.2 meters long and 6.2 meters (or 8 rows) wide at all locations from 2009 to 2011 except at Pringles in 2011, where plots measured 15.2 meters long and 4.6 meters (or 6 rows) wide. Ten different combinations of K rates and fertilizer application methods were applied to the soybeans in 2009 to 2011 (Table 3.3) except at North Leeper. At the North Leeper field site only eight different combinations of K rates and fertilizer application methods were applied to the soybeans because of field space restrictions (Table 3.4). The treatments involved rates of K application applied in both annual and biannual applications. All treatments were applied to soybeans and only the annual treatments were applied to the rotational corn (*Zea mays* L.) the following year. One treatment was based on the KSU soybean K sufficiency recommendation, and the equation used to calculate K rates can be found in the KSU Soil Test Interpretations and Fertilizer Recommendations publication (Leikam et al., 2003). Surface band applications were placed in a 10 cm wide band along the side of the soybean rows. The bands were applied slightly off-set from the row to minimize the potential for salt injury to the seedling soybeans. Granular potassium chloride (0-0-62) was used as the K fertilization source.

Table 3.1 Locations, year study was established and geographical coordinates

Location	*Area*	*County*	*Study Year*	*Geographical Coordinates*
SW Jennings	Hallowell, KS	Cherokee	2009	37^o 8’ 8” N, 94^o 59’ 36” W
SE Brown	Hallowell, KS	Cherokee	2009	37^o 10’ 47” N, 95^o 0’ 27” W
SW Brown	Hallowell, KS	Cherokee	2009	37^o 10’ 47” N, 95^o 0’ 42” W
Delmont	Hallowell, KS	Cherokee	2009	37^o 11’ 54” N, 95^o 0’ 53” W
NW of Dads	Hallowell, KS	Cherokee	2010	37^o 11’ 41” N, 95^o 2’ 54” W
East Marks	Hallowell, KS	Cherokee	2010	37^o 11’ 35” N, 95^o 1’ 25” W
Krantz	Hallowell, KS	Cherokee	2010	37^o 11’ 54” N, 95^o 1’ 51” W
Spieth	Hallowell, KS	Cherokee	2010	37^o 11’ 14” N, 95^o 1’ 50” W
North Leeper	Columbus, KS	Cherokee	2011	37^o 15’ 9” N, 94^o 54’ 7” W
South Leeper	Columbus, KS	Cherokee	2011	37^o 15’ 5” N, 94^o 54’ 14” W
Pringle	Buffalo, KS	Wilson	2011	37^o 43’ 36” N, 95^o 45’ 8” W

Table 3.2 Locations, description of soils present and average soil test values at soybean study initiation

Location	*Soil Series*	*Soil pH*	*Mehlich-3 P*	*NH_4OAc Exchangeable K*	*Organic Matter*	*Zinc*	*Manganese*	*CEC*
			mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	cmol kg^{-1}
SW Jennings	Cherokee silt loam	6.4	22	147	16	4.8	23	6.0
SE Brown	Cherokee silt loam	7.1	50	154	16	4.8	18	6.2
SW Brown	Cherokee silt loam	6.6	36	149	16	9.6	30	5.1
Delmont	Cherokee silt loam	6.2	23	139	16	5.0	29	3.5
NW of Dads	Cherokee silt loam	5.8	24	114	18	3.4	40	7.6
East Marks	Cherokee silt loam	5.7	24	108	17	2.2	24	5.9
Krantz	Cherokee silt loam	6.3	35	110	14	2.8	18	8.3
Spieth	Cherokee silt loam	6.1	27	122	15	1.1	9	8.3
North Leeper	Dennis silt loam	6.0	7	57	16	3.9	47	8.6
South Leeper	Dennis silt loam	6.1	6	55	18	8.0	31	9.2
Pringle	Lanton silt loam	6.1	4	82	7	2.0	25	13.5

Table 3.3 Potassium fertilizer rate and placement method

Treatment No.	*Treatment Abv.*	*Treatment Description*
1	CK	Unfertilized check
2	BC Rec (A)	Annual broadcast K rate based on sufficiency rec.
3	BC 34 (A)	Annual broadcast 34 kg K_2O ha^{-1}
4	BC 67 (A)	Annual broadcast 67 kg K_2O ha^{-1}
5	BC 67 (BA)	Biannual broadcast 67 kg K_2O ha^{-1}
6	BC 134 (BA)	Biannual broadcast 134 kg K_2O ha^{-1}
7	BC 202 (BA)	Biannual broadcast 202 kg K_2O ha^{-1}
8	SB 67 (BA)	Biannual surface band 67 kg K_2O ha^{-1}
9	SB 134 (BA)	Biannual surface band 134 kg K_2O ha^{-1}
10	SB 202 (BA)	Biannual surface band 202 kg K_2O ha^{-1}

Table 3.4 Potassium placement and application method for the study at North Leeper

Treatment No.	*Treatment Abv.*	*Treatment Description*
1	CK	Unfertilized check
4	BC 67 (A)	Annual broadcast 67 kg K_2O ha^{-1}
5	BC 67 (BA)	Biannual broadcast 67 kg K_2O ha^{-1}
6	BC 134 (BA)	Biannual broadcast 134 kg K_2O ha^{-1}
7	BC 202 (BA)	Biannual broadcast 202 kg K_2O ha^{-1}
8	SB 67 (BA)	Biannual surface band 67 kg K_2O ha^{-1}
9	SB 134 (BA)	Biannual surface band 134 kg K_2O ha^{-1}
10	SB 202 (BA)	Biannual surface band 202 kg K_2O ha^{-1}

Cultural Practices

In 2009 the study was conducted at four locations near Hallowell, Kansas. Each site had double crop soybeans no-till planted into wheat (*Triticum aestivum* L.) stubble. Soil test K results from fall 2007 and a yield goal of 2690 kg ha^{-1} were used in the KSU soybean K sufficiency recommendation equation to determine appropriate K rates for treatment 2 (Table 3.5). All treatments were applied at the V-1 soybean growth stage in 2009. Additionally, all plots received 45 kg P_2O_5 ha^{-1} using mono-ammonium phosphate (11-52-0) as the fertilizer source. All other soil fertility needs were sufficient.

In 2010 the study was expanded to four new locations also near Hallowell, KS. The sites were double crop soybeans no-till planted into wheat stubble except for the study at NW of Dads, it was conventionally tilled and full season soybeans were planted following corn. Soil test K results just prior to planting in 2010 and a yield goal of 2690 kg ha^{-1} were used in the KSU soybean K sufficiency recommendation equation to determine appropriate K rates for treatment 2 (Table 3.5). All treatments were applied at the V-4 soybean growth stage. Additionally, all plots received 45 kg P_2O_5 ha^{-1} using mono-ammonium phosphate (11-52-0) as the fertilizer source. Soil pH levels at NW of Dads and East Marks were slightly below the recommended range for soybean growth, but no lime was applied to address the issue.

In 2011 two additional locations near Columbus, KS and one location near Buffalo, KS were added. The sites were all full season soybeans following corn. The location at Pringles, near Buffalo, was no-tilled while the other two locations had been conventionally tilled. Soil test K results just prior to planting in 2011 and a yield goal of 2690 kg ha^{-1} were used in the KSU soybean K sufficiency recommendation equation to determine appropriate K rates for treatment 2 (Table 3.5). All treatments were applied directly after soybean planting. Additionally, all plots received 67 kg P_2O_5 ha^{-1} using di-ammonium phosphate (18-46-0) as the fertilizer source. All other soil fertility needs were sufficient.

Across all field sites varieties planted were adapted to the region and planted by the cooperating producers. Key cultural practices are summarized in Table 3.6. Weed control was also performed by the producers with the use of glyphosate (Round-up). A post application of glyphosate was applied at 2.3 liters ha^{-1}.

Table 3.5 Initial soil test potassium level and the sufficiency recommendation rate by location

Location	*Soil Test K Level* mg kg^{-1}	*Sufficiency K Rate* kg K_2O ha^{-1}
SW Jennings	87	32
SE Brown	88	31
SW Brown	106	18
Delmont	99	23
NW of Dads	114	12
East Marks	108	17
Krantz	110	15
Spieth	122	6
North Leeper	57	No Treatment
South Leeper	55	49
Pringles	82	36

Table 3.6 Key cultural practices used in conducting soybean experiments

Loaction	*Variety*	*Relative Maturity*	*Seeding Rate (seeds ha^{-1})*	*Planting Date*	*Fertilizer App. Date*	*R3 Leaf Sampling*	*R4 Leaf Sampling*	*Harvest Date*
SW Jennings	Pioneer 95Y40	5.4	271 816	28-Jun	30-Jun	17-Sep	13-Oct	28-Nov
SE Brown	Asgrow 5605	5.6	271 816	25-Jun	1-Jul	17-Sep	13-Oct	28-Nov
SW Brown	Asgrow 5605	5.6	271 816	25-Jun	1-Jul	17-Sep	13-Oct	1-Dec
Delmont	Asgrow 5605	5.6	271 816	25-Jun	1-Jul	17-Sep	13-Oct	27-Nov
NW of Dads	Asgrow 5605	5.6	283 925	4-Jun	24-Jun	19-Aug	17-Sep	6-Nov
East Marks	Asgrow 5605	5.6	283 925	21-Jun	19-Jul	2-Sep	28-Sep	28-Oct
Krantz	Asgrow 5605	5.6	283 925	22-Jun	19-Jul	2-Sep	28-Sep	6-Nov
Spieth	Asgrow 5605	5.6	283 925	23-Jun	19-Jul	2-Sep	28-Sep	28-Oct
North Leeper	Asgrow 5405	5.4	321 238	7-Jun	7-Jun	9-Aug	1-Sep	27-Oct
South Leeper	Asgrow 5405	5.4	321 238	7-Jun	7-Jun	9-Aug	1-Sep	27-Oct
Pringles	Pioneer 94Y70	4.7	259 461	31-May	3-Jun	9-Aug	1-Sep	11-Oct

Soil Sampling and Analysis

Soil samples consisted of 0-15 cm depth cores collected at random from each replication at all of the soybean sites just prior to applying treatments. Soil samples were taken using a manual soil probe and samples consisted of 10 to 12 individual cores mixed together to form a single composite sample. After collection, soil samples were oven dried at $60^{o}C$ and ground to pass through a 2-mm sieve by a Dyna-Crush 5 flail grinder (Custom Laboratory Equipment Inc., Orange City, FL). The samples were analyzed to determine soil pH, available phosphorus (P), exchangeable potassium (K), soil organic matter (SOM), zinc, manganese and cation exchange capacity (CEC) of the soils. Values reported in Table 3.2 are the mean values calculated from the four replication samples at each location. Soil analysis was conducted by the KSU Soil Sampling Lab using procedures described in Recommended Chemical Soil Testing Procedures for the North Central NCRR Publication no. 221 (1998).

Leaf Sampling and Analysis

Soybean trifoliate leaf samples were taken twice during the growing season. The first set of leaf samples were collected at the R-3 (pod-set) growth stage and the second set were collected at the R-4 (pod-fill) growth stage. Thirty trifoliate leaves, not including the petiole, were collected at random from the non-harvest rows of each plot. The composite samples were oven dried at $60^{o}C$ for two days and ground to pass a 0.5-mm stainless steel sieve using a Wiley rotary blade grinder (Arthur H. Thomas Co., Philadelphia, PA). Samples were digested using a sulfuric acid-hydrogen peroxide digest and analyzed for nitrogen, phosphorus and potassium concentrations by the KSU Soil Testing Lab. The analysis for nitrogen was done using an Alpkem RFA colormetric instrument and RFA Methodology A303-S072. Phosphorus analysis was done by an Inductively Coupled Plasma (ICP) Spectrometer, Model 720-ES ICP Optical Emission Spectrometer. Potassium analysis was conducted using a Bechman Model 200 Atomic Absorption Spectrometer.

Grain Yield and Analysis

After physiological maturity the two center soybean rows of each plot were mechanically harvested using a Wintersteiger classic plot combine (Wintersteiger Ag, Ried, Austria). Grain weight was recorded using a calibrated scale and a sub-sample was collected in a plastic jar to be analyzed for moisture content and test weight using a Dickey-John GAC 2100 (Dickey-John Corp., Auburn, IL). Soybean yields from all locations were adjusted to 130 g kg^{-1} moisture content. Grain sub-samples were oven dried at 60^{o}C for a minimum of four days and then ground to a powder for analysis. Samples were analyzed for nitrogen, phosphorus and potassium concentrations using the sulfuric acid-hydrogen peroxide wet digestion method. Grain analysis was done by the KSU Soil Testing Lab using the same methods described in analyzing the leaf samples.

Statistical Analysis

Soybean leaf tissue K concentrations, grain K concentrations and yield data were analyzed by location using the PROC MIXED procedure at alpha level 0.05, with blocks as a random affect, in SAS version 9.2 (SAS Institute, 2008). Data was also analyzed by study year for an overall analysis and run in the same PROC MIXED procedure, with blocks and locations as random affects. Significance of difference between treatment means by location and by study year were determined by pair-wise comparisons. Treatments 3 and 4 will not be discussed in this chapter, but will be covered in chapter 4.

Results and Discussion

The initial soil test potassium (K) levels at each location were presented in Table 3.2. The 2009 sites tested in the optimum (130 – 170 mg kg^{-1}) category according to Iowa State University soil test K interpretations (Sawyer et al., 2011), the 2010 sites tested low (90 – 130 mg kg^{-1}) and the 2011 sites tested very low (< 90 mg kg^{-1}). Previous research indicates that the probability of a yield response within each category is 80% for very low, 65% for low and 25% for optimum (Sawyer et al., 2011). A soybean K sufficiency rate was calculated and applied for treatment 2 based on soil test samples collected when sites were selected. In general these values were lower than those found when the plots were actually established later in the spring (Table 3.5).

Cumulative in-season (June1st – November 1st) precipitation and average daily temperatures for the different areas in 2009, 2010 and 2011, and the 30-year normal averages for each are illustrated in Table 3.7. In 2009 and 2010, environmental conditions presented favorable weather for crop growth and development. In-season precipitation in the area exceeded the 30-year average both years and the rainfall patterns correlated well with critical times of soybean development, blooming and pod-fill (Table 3.7). Average daily temperatures were below normal in 2009, but above normal in 2010. Although average daily temperatures were approximately one degree higher than normal in 2010, temperatures did not peak until after the first of August. The high temperatures only remained for about ten days before subsiding to below 35^{o}C, creating tolerable conditions for soybeans during flowering stages. In 2011, growing conditions were less than ideal. In-season precipitation was greatly limited and noticeably lower than the 30-year average for both areas. Daily temperatures ran at least one degree higher than normal with numerous days from early July until mid-September that surpassed 38^{o}C. Soybeans generally can tolerate high temperatures for short periods of time with adequate rainfall, but 2011 did not provide such conditions and yields were impacted. August precipitation at both areas provided some drought relief that averted our soybean crop from complete devastation.

Table 3.7 In-season cumulative precipitation and average daily temperature (June 1st – November 1st)

		Temperature		*Precipitation*	
Area	Study Year	30 Year (1981-2010) Average Daily Mean (c^{o})	Mean (c^{o})	30 Year (1981-2010) Average Total (mm)	Total (mm)
Hallowell	2009	22.6	20.7	541	808
Hallowell	2010	22.6	23.7	541	627
Columbus	2011	22.6	24.1	545	262
Buffalo	2011	21.5	22.6	593	204

Visual K deficiency symptoms were documented at two of the eleven sites. In 2011, at the Pringle and North Leeper field sites visual symptoms were observed (Figures 3.1 and 3.2). At Pringles, K deficiency symptoms were present early in the growing season (V6 – V7 growth stage), however, as the soybean crop progressed toward reproductive growth stages the symptoms dissipated from the plant tissue. At North Leeper, K deficiency symptoms were verified at around the R1 growth stage and observed the remainder of the growing season. Soil exchangeable K levels at both sites were very low (< 90 mg kg^{-1}), causing the occurrence of soybean K deficiency. Several climatic conditions were also likely contributors, 2011 was hot and dry resulting in less than ideal conditions for soil nutrient movement via diffusion.

Figure 3.1 Pringle K deficient soybeans

Figure 3.2 North Leeper K deficient soybeans

R3 (pod-set) Leaf Nutrient Analysis

Leaf K content at the R3 (pod-set) growth stage of development is commonly used as an indicator of soybean K nutrition at early growth stages (Mills and Jones, 1996). The pod-set leaf K data in response to treatments for the 2009, 2010 and 2011 sites are summarized in Tables 3.8 – 3.10. During the three year study five out of eleven sites displayed positive responses to K fertilization in regard to pod-set leaf K concentration.

In 2009 leaf K concentrations ranged from 16.78 – 19.45 g kg^{-1}, indicating that the majority of the soybean leaf K concentrations were within the sufficiency range of 17.0 – 25.0 g kg^{-1} (Mills and Jones, 1996). Overall, only one of the four site-samplings expressed significant ($P<0.10$) responses to K fertilization and application method. At SW Jennings, the pod-set data exhibited a 6% increase ($P<0.05$) in leaf K content with K fertilization compared to the unfertilized K control. The site was not expected to be responsive since the soil test exchangeable K levels were greater than 130 mg kg^{-1}. Among K rates being broadcast applied, the high rate (202 kg K_2O ha^{-1}) provided the highest pod-set leaf K content, significantly ($P<0.10$) higher than the low rate (67 kg K_2O ha^{-1}), but not higher than the medium rate (134 kg K_2O ha^{-1}) broadcast treatments. Additionally, the low and medium rate broadcast treatments did not differ ($P>0.05$) in leaf K concentrations. There were no significant responses found between rates when the fertilizer was surface band applied at SW Jennings. In comparing application methods at the low rate, the surface band treatment increased ($P<0.10$) leaf K content by nearly 5% compared to the broadcast application. The medium and high rates provided similar results ($P>0.10$) between application methods.

Table 3.8 Average K concentrations in soybean leaf tissue at the R3 (pod-set) growth stage by treatment for the 2009 sites

		SW Jennings	*SE Brown*	*SW Brown*	*Delmont*
Trt #	Treatment	-------------------------------	$g\ kg^{-1}$	-------------------------------	
1	CK	16.78	17.51	17.88	17.54
2	BC Rec (A)	17.51	17.47	18.23	17.47
3	BC 34 (A)	17.45	17.84	18.47	17.81
4	BC 67 (A)	17.86	17.91	18.68	17.82
5	BC 67 (BA)	17.36	17.92	18.64	17.95
6	BC 134 (BA)	17.74	18.35	18.48	17.60
7	BC 202 (BA)	18.46	19.52	19.64	19.45
8	SB 67 (BA)	18.24	18.00	18.39	18.54
9	SB 134 (BA)	17.99	18.24	19.13	17.64
10	SB 202 (BA)	18.12	18.43	18.69	18.68
Treatment Pr > F		0.0519	0.6131	0.2529	0.1883
Contrast					
CK (1) vs. K (2-10)		(1.08)*	---	---	---
BC 67 (5) vs. SB 67 (8)		(0.88)**	---	---	---
BC 134 (6) vs. SB 134 (9)		(0.25)	---	---	---
BC 202 (7) vs. SB 202 (10)		0.34	---	---	---
BC 67 (5) vs. BC 202 (7)		(1.10)*	---	---	---
BC 67 (5) vs. BC 134 (6)		(0.38)	---	---	---
BC 134 (6) vs. BC 202 (7)		(0.72)	---	---	---
SB 67 (8) vs. SB 202 (10)		0.12	---	---	---
SB 67 (8) vs. SB 134 (9)		0.24	---	---	---
SB 134 (9) vs. SB 202 (10)		(0.13)	---	---	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

In 2010 the pod-set leaf data revealed a wide range in K concentrations from 11.0 – 19.64 g kg^{-1}. The Spieth site was the only location that had leaf K concentrations within the sufficiency range. The initial soil test exchangeable K level at the location was the highest at 122 mg kg^{-1}, just below the optimum level. The other locations had leaf K content levels that were well below the sufficiency range, but no visual K deficiencies were observed at any location in 2010. Overall, one of the four site-samplings (NW of Dads) expressed significant differences ($P<0.05$) between treatment leaf K contents. Among the broadcast applications, both the medium and high rate treatments increased leaf K content by over 9% ($P<0.05$) compared to the low rate. There was no significant ($P>0.10$) effect observed between the medium and high rates, indicating a leaf K response up to the medium rate, but no further response to added K. Lastly, there was no significant effect found between the surface band rates or between application methods at the same rate at the NW of Dads field site.

The NW of Dads field site was the earliest site planted and K treatments were applied a couple weeks before the other three locations. The significant K response could be related to wetter environmental conditions experienced between K fertilizer application and leaf sampling that was different than what the other three locations experienced. Additionally, the site had been tilled prior to soybean planting, later in the season this could have led to increased root growth and increased plant K uptake via diffusion.

Table 3.9 Average K concentrations in soybean leaf tissue at the R3 (pod-set) growth stage by treatment for the 2010 sites

		NW of Dads	*East Marks*	*Krantz*	*Spieth*
Trt #	Treatment	------------------------------	g kg^{-1}	------------------------------	
1	CK	11.10	12.31	15.23	17.81
2	BC Rec (A)	11.95	13.88	14.91	17.66
3	BC 34 (A)	12.34	13.02	15.11	17.41
4	BC 67 (A)	12.38	13.67	16.16	18.26
5	BC 67 (BA)	12.56	13.63	15.76	17.51
6	BC 134 (BA)	13.84	14.84	15.73	17.79
7	BC 202 (BA)	13.88	14.08	16.55	19.64
8	SB 67 (BA)	12.88	13.73	15.82	18.44
9	SB 134 (BA)	13.41	14.32	16.53	18.40
10	SB 202 (BA)	13.72	14.15	16.52	17.13
Treatment Pr > F		<0.0001	0.5328	0.2599	0.6118
Contrast					
CK (1) vs. K (2-10)		(1.90)*	---	---	---
BC 67 (5) vs. SB 67 (8)		(0.32)	---	---	---
BC 134 (6) vs. SB 134 (9)		0.43	---	---	---
BC 202 (7) vs. SB 202 (10)		0.15	---	---	---
BC 67 (5) vs. BC 202 (7)		(1.31)*	---	---	---
BC 67 (5) vs. BC 134 (6)		(1.28)*	---	---	---
BC 134 (6) vs. BC 202 (7)		(0.04)	---	---	---
SB 67 (8) vs. SB 202 (10)		(0.84)	---	---	---
SB 67 (8) vs. SB 134 (9)		(0.53)	---	---	---
SB 134 (9) vs. SB 202 (10)		(0.31)	---	---	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Across the three 2011 locations pod-set leaf K concentrations ranged from 7.30 – 17.60 g kg^{-1}, just at or well below the sufficiency range. At North Leeper, there was a nice response to K fertilizer when it was surface band applied. The high rate provided the greatest leaf K concentration across all treatments, over 23% higher ($P<0.05$) compared to the low rate treatment. Additionally, the medium rate increased ($P<0.05$) leaf K content by nearly 17% compared to the low rate. However, the surface band medium and high rates were not significantly different ($P>0.10$). The broadcast treatments showed a nice response to K fertilization as well. The high rate treatment significantly ($P<0.05$) increased leaf K content by 20% compared to the low rate, but this was the only significant ($P>0.10$) broadcast rate response. Between application methods, when the medium and high rates were surface band applied leaf K increased ($P<0.05$) by approximately 19 and 15%, respectively, compared to the broadcast applications. Thus, the surface band applications presented an advantage in optimizing K availability at North Leepers.

At South Leeper, the surface band high rate provided the highest leaf K concentration, 18 and 14% higher ($P<0.05$) than the low and medium rates, respectively. The medium rate also increased leaf K by 0.58 g kg^{-1} over the low rate, but the difference was not significant. Among the broadcast treatments the medium rate provided the highest leaf K content, considerably ($P<0.05$) higher than the low rate. When analyzing the difference between application methods, the high rate surface band treatment provided a 17% increase ($P<0.05$) in leaf K content compared to the broadcast treatment. The low and medium rates provided comparable ($P>0.10$) leaf K values between application methods.

At Pringles, the soil test K level and leaf K contents were the highest among the 2011 sites. The broadcast high rate treatment was the only treatment above the sufficiency range. The high rate broadcast and surface band treatments increased ($P<0.05$) leaf K concentration 15 and 17%, respectively, compared to the low rate treatments. The broadcast medium rate increased leaf K by nearly 12% ($P<0.05$) compared to the low rate, but the difference between the high rate was not significant ($P>0.10$). Furthermore, there was no significant ($P>0.05$) advantage confirmed between placement methods when applied at the same rate at Pringles.

The sporadic increases in pod-set leaf K in 2009 and 2010 is likely due to adequate soil K and sufficient rainfall that resulted in high moisture levels that may have greatly increased K availability in soil, thus enhanced plant uptake even in the unfertilized control. In 2011 soil test

K levels at all sites were very low and rainfall was limited. These two factors greatly increased leaf K responses to K fertilization.

Table 3.10 Average K concentrations in soybean leaf tissue at the R3 (pod-set) growth stage by treatment for the 2011 sites

		North Leeper	*South Leeper*	*Pringles*
Trt #	Treatment	----------------------	g kg^{-1}	----------------------
1	CK	7.30	9.92	12.64
2	BC Rec (A)	-	10.98	13.75
3	BC 34 (A)	-	10.85	13.40
4	BC 67 (A)	9.58	11.70	13.93
5	BC 67 (BA)	8.84	11.46	14.68
6	BC 134 (BA)	9.80	12.69	16.62
7	BC 202 (BA)	11.08	12.17	17.60
8	SB 67 (BA)	10.00	12.01	14.45
9	SB 134 (BA)	12.17	12.59	15.53
10	SB 202 (BA)	13.03	14.71	16.93
Treatment Pr > F		<0.0001	<0.0001	<0.0001
Contrast				
CK (1) vs. K (2-10)		(3.35)*	(2.21)*	(2.57)*
BC 67 (5) vs. SB 67 (8)		(1.16)	(0.56)	0.23
BC 134 (6) vs. SB 134 (9)		(2.37)*	0.10	1.09
BC 202 (7) vs. SB 202 (10)		(1.95)*	(2.54)*	0.67
BC 67 (5) vs. BC 202 (7)		(2.24)*	(0.71)	(2.92)*
BC 67 (5) vs. BC 134 (6)		(0.96)	(1.23)*	(1.94)*
BC 134 (6) vs. BC 202 (7)		(1.29)	0.52	(0.98)
SB 67 (8) vs. SB 202 (10)		(3.04)*	(2.70)*	(2.48)*
SB 67 (8) vs. SB 134 (9)		(2.17)*	(0.58)	(1.08)
SB 134 (9) vs. SB 202 (10)		(0.86)	(2.12)*	(1.40)**

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

R4 (pod-fill) Leaf Nutrient Analysis

Once the pod and seed begin to develop, K is translocated from the leaf to the developing seed. This creates a stress on leaf K content and creates conditions which would be a good indicator of K stress. The effects of treatments on leaf K at the R4 (pod-fill) growth stage for the 2009, 2010 and 2011 sites are summarized in Tables 3.11 – 3.13. During the three year study eight out of the eleven sites displayed positive responses to K fertilization in regard to pod-fill leaf K concentration. All eleven sites had pod-fill leaf K contents that were drastically lower than the pod-set data by treatment. This is to be expected since soybean plants intensify the translocation of K from the plant tissue to the developing grain between the two growth stages.

In 2009 the range of leaf K content among the locations was between 9.48 – 12.05 g kg^{-1}. Overall, two of the four site-samplings showed significant ($P<0.05$) differences between treatment means. With the addition of K fertilizer, the pod-fill leaf K content increased by approximately 10 and 12% ($P<0.05$) compared to the unfertilized K control at Delmont and SW Jennings, respectively. At SW Jennings the low rate (67 kg K_2O ha^{-1}) provided considerably higher ($P<0.05$) leaf K concentrations when the equivalent rate was surface band applied compared to broadcast applied. Furthermore, the high rate (202 kg K_2O ha^{-1}) surface band application presented a 0.85 g kg^{-1} increase ($P<0.10$) in leaf K content than the same rate broadcast applied. In general, it appeared that the surface band placement method was more effective in increasing leaf K at the R4 growth stage for the SW Jennings field site. Among the surface band treatments the low rate application displayed the highest leaf K content, significantly ($P<0.05$) higher than the medium rate (134 kg K_2O ha^{-1}), which was not expected. There were no significant responses found between rates when the fertilizer was broadcast applied.

At the Delmont location the high rate broadcast application generated the highest pod-fill leaf K concentration, roughly 1.11 g kg^{-1} higher ($P<0.05$) than the broadcast low rate application. Among the surface band treatments, the medium rate performed the best by increasing leaf K content 0.96 g kg^{-1} ($P<0.05$) and 0.23 g kg^{-1} over the low and high rate treatments, respectively. There were no significant effects found between placement methods at the same rate at Delmont.

Table 3.11 Average K concentrations in soybean leaf tissue at the R4 (pod-fill) growth stage by treatment for the 2009 sites

		SW Jennings	*SE Brown*	*SW Brown*	*Delmont*
Trt #	Treatment	------------------------------	g kg^{-1}	------------------------------	
1	CK	9.88	9.92	10.29	10.02
2	BC Rec (A)	10.84	9.48	11.09	10.17
3	BC 34 (A)	10.53	9.84	11.01	10.94
4	BC 67 (A)	11.01	10.20	10.86	10.85
5	BC 67 (BA)	11.04	10.03	10.97	10.94
6	BC 134 (BA)	11.36	10.29	11.53	11.58
7	BC 202 (BA)	11.10	10.27	12.00	12.05
8	SB 67 (BA)	12.03	9.77	10.93	10.71
9	SB 134 (BA)	11.06	10.04	11.39	11.67
10	SB 202 (BA)	11.95	10.58	11.50	11.45
Treatment Pr > F		0.0043	0.3643	0.1502	0.0019
Contrast					
CK (1) vs. K (2-10)		(1.33)*	---	---	(1.13)*
BC 67 (5) vs. SB 67 (8)		(0.99)*	---	---	0.23
BC 134 (6) vs. SB 134 (9)		0.30	---	---	(0.10)
BC 202 (7) vs. SB 202 (10)		(0.85)**	---	---	0.61
BC 67 (5) vs. BC 202 (7)		(0.05)	---	---	(1.11)*
BC 67 (5) vs. BC 134 (6)		(0.32)	---	---	(0.64)
BC 134 (6) vs. BC 202 (7)		0.27	---	---	(0.48)
SB 67 (8) vs. SB 202 (10)		0.08	---	---	(0.74)
SB 67 (8) vs. SB 134 (9)		0.97*	---	---	(0.96)*
SB 134 (9) vs. SB 202 (10)		(0.88)	---	---	0.23

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

In 2010, the leaf K content among the locations was between 6.89 – 12.97 g kg^{-1}. Overall, three of four site-samplings showed significant ($P<0.05$) effect of treatments on pod-fill leaf K content. At NW of Dads, the broadcast medium and high rates both increased ($P<0.05$) leaf K content by approximately 16 and 20%, respectively, compared to the low rate. The high broadcast rate presented the maximum leaf K content, however, it was not significantly ($P>0.10$) higher than the medium broadcast rate. The surface band medium rate increased ($P<0.10$) leaf K content 10% compared to the low rate surface band treatment. In general, the medium rate, either broadcast or surface band applied, appeared to optimize pod-fill leaf K content at NW of Dads. Lastly, when the high rate was broadcast applied it significantly ($P<0.05$) increased leaf K content by approximately 10% compared to the surface band treatment.

At East Marks, the addition of K fertilizer significantly ($P<0.05$) increased leaf K content by 8% yet there was no significant effect between placement rates or between placement methods at the same rate.

At Krantz, the addition of K fertilizer increased ($P<0.05$) leaf K content by about 8%. The broadcast high rate treatment provided the highest leaf K content at 12.93 g kg^{-1}, which was significantly higher compared to the low and medium rates. Among the surface band treatments the medium and high rates had nearly identical leaf K values and both significantly increased leaf K content by 8% compared to the low rate treatment. Additionally, there were no significant impacts detected between placement methods at the same rate.

Table 3.12 Average K concentrations in soybean leaf tissue at the R4 (pod-fill) growth stage by treatment for the 2010 sites

		NW of Dads	*East Marks*	*Krantz*	*Spieth*
Trt #	Treatment	------------------------------	g kg^{-1}	------------------------------	
1	CK	6.89	9.48	11.05	11.80
2	BC Rec (A)	7.83	9.73	10.71	12.57
3	BC 34 (A)	8.02	9.29	11.40	12.02
4	BC 67 (A)	7.85	9.68	11.48	12.62
5	BC 67 (BA)	7.86	10.66	11.77	12.26
6	BC 134 (BA)	9.40	10.66	12.17	12.15
7	BC 202 (BA)	9.79	11.31	12.93	12.85
8	SB 67 (BA)	8.07	10.40	11.72	12.26
9	SB 134 (BA)	9.00	10.43	12.75	12.77
10	SB 202 (BA)	8.77	10.91	12.77	12.97
Treatment Pr > F		<0.0001	0.0019	<0.0001	0.2071
Contrast					
CK (1) vs. K (2-10)		(1.62)*	(0.86)*	(0.92)*	---
BC 67 (5) vs. SB 67 (8)		(0.21)	0.26	0.05	---
BC 134 (6) vs. SB 134 (9)		0.40	0.23	(0.58)	---
BC 202 (7) vs. SB 202 (10)		1.02*	0.40	0.16	---
BC 67 (5) vs. BC 202 (7)		(1.93)*	(0.65)	(1.17)*	---
BC 67 (5) vs. BC 134 (6)		(1.54)*	0.00	(0.41)	---
BC 134 (6) vs. BC 202 (7)		(0.39)	(0.66)	(0.76)*	---
SB 67 (8) vs. SB 202 (10)		(0.70)	(0.51)	(1.06)*	---
SB 67 (8) vs. SB 134 (9)		(0.93)**	(0.03)	(1.04)*	---
SB 134 (9) vs. SB 202 (10)		0.23	(0.48)	(0.02)	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

In 2011 the range of leaf K content among the locations was between 5.76 – 13.41 g kg^{-1}. Overall, K fertilization significantly ($P<0.05$) increased leaf K content at every location in 2011. At North Leeper, the broadcast applied treatments displayed a nice response to K fertilizer rates. As fertilizer rate increased the leaf K content significantly ($P<0.05$) increased as well. The surface band treatments showed a similar response, however, leaf K content only significantly increased up to the medium rate. The increase in K content from the medium to high rate was not significant even though the high rate treatment provided the highest leaf K content at 11.25 g kg^{-1}. Both the low and medium rates significantly ($P<0.10$) increased leaf K content when the rates were surface band applied compared to broadcast applied.

At South Leeper, the surface band applied treatments presented the best response to K fertilizer. With increasing rates leaf K content significantly ($P<0.10$) increased, with the high rate producing the highest leaf K level at 13.41 g kg^{-1}. The broadcast treatments showed a comparable response, however, leaf K content only significantly ($P<0.05$) increased up to the medium rate. Additionally, surface banding only provided a significant ($P<0.05$) advantage over broadcast applications at the high rate, with a 12.5% increase in pod-fill leaf K.

At Pringles, very similar responses to K fertility were discovered once again. The high rate surface band treatment increased ($P<0.05$) leaf K content 25 and 15% compared to the surface band low and medium rates, respectively. However, the surface band low and medium rate leaf K values were not found to be significantly different ($P>0.10$). The broadcast treatments also showed a beneficial response from the low to the high rate, however, the 1.03 g kg^{-1} difference in leaf K from the medium to the high rate was not significant ($P>0.10$), signifying no additional K response to the high rate. There were no effects observed between placement methods when applied at the same rate at Pringles.

While no standard values for leaf K levels during active grain fill have been developed, the fact that a higher number of sites showed treatment effects and differences between methods of application indicates that this may be a more sensitive time to evaluate K nutritional stress.

Using leaf K values during grain fill as a means to differentiate K availability would suggest that surface banding is more effective at supplying K to soybeans than broadcasting under many environmental conditions. Since the application cost of surface banding would only be slightly higher in many situations, this practice is worthy of further evaluation.

Table 3.13 Average K concentrations in soybean leaf tissue at the R4 (pod-fill) growth stage by treatment for the 2011 sites

		North Leeper	*South Leeper*	*Pringles*
Trt #	Treatment	----------------------	g kg^{-1}	----------------------
1	CK	5.76	7.41	6.69
2	BC Rec (A)	-	9.41	8.50
3	BC 34 (A)	-	8.81	8.18
4	BC 67 (A)	8.29	9.58	9.21
5	BC 67 (BA)	7.40	9.60	8.75
6	BC 134 (BA)	9.15	11.01	10.44
7	BC 202 (BA)	10.46	11.74	11.47
8	SB 67 (BA)	8.62	10.24	8.66
9	SB 134 (BA)	10.57	11.30	9.74
10	SB 202 (BA)	11.25	13.41	11.49
Treatment Pr > F		<0.0001	<0.0001	<0.0001
Contrast				
CK (1) vs. K (2-10)		(3.63)*	(3.16)*	(2.92)*
BC 67 (5) vs. SB 67 (8)		(1.21)**	(0.65)	0.08
BC 134 (6) vs. SB 134 (9)		(1.41)*	(0.29)	0.71
BC 202 (7) vs. SB 202 (10)		(0.79)	(1.67)*	(0.01)
BC 67 (5) vs. BC 202 (7)		(3.06)*	(2.15)*	(2.73)*
BC 67 (5) vs. BC 134 (6)		(1.75)*	(1.41)*	(1.70)*
BC 134 (6) vs. BC 202 (7)		(1.31)*	(0.74)	(1.03)
SB 67 (8) vs. SB 202 (10)		(2.63)*	(3.17)*	(2.82)*
SB 67 (8) vs. SB 134 (9)		(1.95)*	(1.06)**	(1.07)
SB 134 (9) vs. SB 202 (10)		(0.68)	(2.11)*	(1.75)*

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Grain Nutrient Analysis

The effects of K fertility on soybean grain K content at the 2009, 2010 and 2011 sites are displayed in Tables 3.14 – 3.16. During the three year study only three out of the eleven sites revealed positive responses to K fertilization in regard to grain K content.

In 2009 the grain samples ranged from 19.02 – 21.94 g kg^{-1} in K concentration. In 2010 the samples were slightly lower in K content, ranging from 16.59 – 20.14 g kg^{-1}. During these two study years there was no response in grain K to the addition of K fertilizer, K rate or fertilizer application method at the same rate, therefore no comparisons were conducted.

Table 3.14 Average K concentrations in soybean grain by treatment for the 2009 sites

		SW Jennings	*SE Brown*	*SW Brown*	*Delmont*
Trt #	Treatment	-------------------------------	g kg^{-1}	-------------------------------	
1	CK	19.02	19.93	21.47	19.84
2	BC Rec (A)	19.64	19.95	20.39	19.36
3	BC 34 (A)	19.64	20.11	21.76	19.82
4	BC 67 (A)	19.63	20.72	21.50	19.49
5	BC 67 (BA)	19.91	20.08	21.83	19.90
6	BC 134 (BA)	19.92	19.88	21.94	19.36
7	BC 202 (BA)	19.89	20.26	21.81	19.04
8	SB 67 (BA)	19.93	20.21	21.48	20.11
9	SB 134 (BA)	19.95	20.14	21.46	19.67
10	SB 202 (BA)	20.01	19.18	20.51	19.29
	Treatment Pr > F	0.4254	0.4540	0.1898	0.5947

Table 3.15 Average K concentrations in soybean grain by treatment for the 2010 sites

		NW of Dads	*East Marks*	*Krantz*	*Spieth*
Trt #	Treatment	-------------------------------	$g\ kg^{-1}$	-------------------------------	
1	CK	19.02	18.22	16.64	17.47
2	BC Rec (A)	18.97	18.06	16.52	17.20
3	BC 34 (A)	18.98	18.41	16.77	17.70
4	BC 67 (A)	19.26	17.80	16.68	17.10
5	BC 67 (BA)	18.89	18.38	16.70	17.35
6	BC 134 (BA)	19.29	20.14	16.59	17.53
7	BC 202 (BA)	19.57	18.41	16.71	18.09
8	SB 67 (BA)	19.01	18.51	16.70	17.35
9	SB 134 (BA)	18.96	18.96	16.81	18.06
10	SB 202 (BA)	18.97	18.77	16.85	17.28
Treatment Pr > F		0.9612	0.1158	0.9499	0.6053

In 2011 the grain samples across the locations were even lower than the previous year, ranging from 13.08 – 17.64 $g\ kg^{-1}$ in K concentration. The North and South Leeper grain K data showed a significant ($P<0.05$) response to K fertilizer, however, the samples did not indicate any increased effect on grain K content as a result of K rate or fertilizer placement method at the same rate. At Pringles, the medium rate (134 kg $K_2O\ ha^{-1}$) surface band and broadcast treatments provided the highest grain K content (17.64 $g\ kg^{-1}$), significantly ($P<0.10$) higher than the low rate (67 kg $K_2O\ ha^{-1}$) treatments. The Pringle site did not present an effect to placement method at the same rate on grain K content.

Table 3.16 Average K concentrations in soybean grain by treatment for the 2011 sites

Trt #	Treatment	*North Leeper*	*South Leeper*	*Pringles*
		----------	g kg^{-1}	----------
1	CK	13.08	13.31	15.69
2	BC Rec (A)	-	14.31	16.75
3	BC 34 (A)	-	13.97	17.07
4	BC 67 (A)	14.12	14.64	17.04
5	BC 67 (BA)	14.67	14.59	16.52
6	BC 134 (BA)	14.73	14.70	17.64
7	BC 202 (BA)	15.32	14.97	17.30
8	SB 67 (BA)	14.70	15.38	16.81
9	SB 134 (BA)	15.13	14.73	17.64
10	SB 202 (BA)	15.45	15.11	17.43
	Treatment Pr > F	0.0007	0.0105	0.0083
	Contrast			
	CK (1) vs. K (2-10)	(1.80)*	(1.40)*	(1.45)*
	BC 67 (5) vs. SB 67 (8)	(0.04)	(0.80)	(0.30)
	BC 134 (6) vs. SB 134 (9)	(0.40)	(0.03)	0
	BC 202 (7) vs. SB 202 (10)	(0.13)	(0.15)	(0.13)
	BC 67 (5) vs. BC 202 (7)	(0.65)	(0.38)	(0.78)
	BC 67 (5) vs. BC 134 (6)	(0.06)	(0.11)	(1.13)*
	BC 134 (6) vs. BC 202 (7)	(0.59)	(0.27)	0.34
	SB 67 (8) vs. SB 202 (10)	(0.75)	0.27	(0.62)
	SB 67 (8) vs. SB 134 (9)	(0.42)	0.66	(0.83)**
	SB 134 (9) vs. SB 202 (10)	(0.32)	(0.39)	0.22

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Soybean Yield

The effects of K fertilization and fertilizer placement method on soybean yield for the 2009, 2010 and 2011 sites are displayed in Tables 3.17 – 3.19. During the three year study one out of the eleven sites revealed positive responses to K fertilization in regard to soybean yield.

The yields in 2009 were satisfactory with all four locations producing yields that were comparable to the southeast Kansas regional average yield of 2420 kg ha^{-1} (USDA, 2010) with few responses to added K, K rate or placement method. Only one of the four sites showed significant ($P<0.10$) differences between treatment soybean yields. At the SW Brown field site the addition of K fertilizer increased ($P<0.05$) soybean yield over the unfertilized K control by about 15%. The high rate (202 kg K_2O ha^{-1}) treatment supplied a 360 kg ha^{-1} increase ($P<0.10$) in soybean yield over the low rate (67 kg K_2O ha^{-1}) when the treatments were surface band applied. However, when the same rates were broadcast applied the low rate significantly ($P<0.05$) increased yields by nearly 390 kg ha^{-1} over the highest rate. At the lower rate a greater ($P<0.10$) yield was produced when the fertilizer was broadcast applied versus surface banded. However, at the high rate, the surface band application produced a soybean yield that was about 17% higher ($P<0.05$) than the broadcast treatment, or 400 kg ha^{-1} more. Due to the inconsistent results between placement methods at the same rates, no distinct advantage could be verified between placement methods. At the SW Brown site the soybean plants had significantly lodged prior to harvest, making harvest very difficult. As a result the mixed results could be the result of harvest difficulties and not an actual response to K fertilization.

Table 3.17 Average soybean yield by treatment for the 2009 sites

Trt #	Treatment	*SW Jennings*	*SE Brown*	*SW Brown*	*Delmont*
		-------------------------------	kg ha^{-1}	-------------------------------	
1	CK	2610	2440	1940	2530
2	BC Rec (A)	2510	2150	2440	2570
3	BC 34 (A)	2630	2460	2250	2500
4	BC 67 (A)	2650	2110	2340	2430
5	BC 67 (BA)	2720	2600	2410	2320
6	BC 134 (BA)	2540	2130	2300	2420
7	BC 202 (BA)	2750	2250	2020	2550
8	SB 67 (BA)	2630	2430	2060	2570
9	SB 134 (BA)	2690	2230	2270	2600
10	SB 202 (BA)	2580	2050	2420	2300
Treatment Pr > F		0.9680	0.4088	0.0883	0.4551
Contrast					
CK (1) vs. K (2-10)		---	---	(340)*	---
BC 67 (5) vs. SB 67 (8)		---	---	350**	---
BC 134 (6) vs. SB 134 (9)		---	---	30	---
BC 202 (7) vs. SB 202 (10)		---	---	(400)*	---
BC 67 (5) vs. BC 202 (7)		---	---	390*	---
BC 67 (5) vs. BC 134 (6)		---	---	110	---
BC 134 (6) vs. BC 202 (7)		---	---	280	---
SB 67 (8) vs. SB 202 (10)		---	---	(360)**	---
SB 67 (8) vs. SB 134 (9)		---	---	(210)	---
SB 134 (9) vs. SB 202 (10)		---	---	(150)	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

In 2010 the soybean yields ranged from 2590 – 3960 kg ha^{-1}. Overall, the soybean yields were excellent with all four locations producing yields much higher than the southeast Kansas regional average yield of 1880 kg ha^{-1} (USDA, 2011). However, the addition of K fertilizer, K rate or placement method had no significant influence on soybean yield response at any location in 2010, therefore no comparisons were conducted.

Table 3.18 Average soybean yield by treatment for the 2010 sites

		NW of Dads	*East Marks*	*Krantz*	*Spieth*
Trt #	Treatment	kg ha^{-1}			
1	CK	2590	3460	3720	3080
2	BC Rec (A)	2680	3480	3930	2720
3	BC 34 (A)	2770	3190	3940	3060
4	BC 67 (A)	2650	3420	3820	3130
5	BC 67 (BA)	2770	3500	3860	2950
6	BC 134 (BA)	2660	3090	3960	3320
7	BC 202 (BA)	2680	3310	3870	2840
8	SB 67 (BA)	2710	3170	3810	3320
9	SB 134 (BA)	2780	3470	3740	3160
10	SB 202 (BA)	2720	3270	3870	3300
	Treatment Pr > F	0.8746	0.4201	0.2626	0.1165

In 2011 the soybean yields ranged from 1270 – 2580 kg ha^{-1}. Overall, soybean yields were poor to decent, with all three locations producing yields higher than the southeast Kansas 2011 regional average yield of 1075 kg ha^{-1} (USDA, 2011). At the North Leeper and Pringle field sites, the high rate surface band treatment provided the highest yields, 33 and 19%, respectively, greater compared to the unfertilized K control. However, the high rate broadcast treatment at South Leeper boosted yields the most, over 18% higher compared to the unfertilized K control. Even with the substantial increase in yields with K fertilization, the addition of K fertilizer, K rate or placement method had no significant influence on soybean yield response at any of the three locations.

The results in 2010 and 2011 were not expected for two main reasons. At each location soil test exchangeable K levels were below the critical K level (130 mg kg^{-1}) for soybeans reported in the KSU Soil Test Interpretations and Fertilizer Recommendations publication (Leikam et al., 2003). Secondly, other than the Spieth field site the R3 (pod-set) leaf K concentrations were not within the K sufficiency range in either year.

Table 3.19 Average soybean yield by treatment for the 2011 sites

		North Leeper	*South Leeper*	*Pringles*
Trt #	Treatment	----------------------	kg ha^{-1}	----------------------
1	CK	1270	1480	2100
2	BC Rec (A)	-	1460	2320
3	BC 34 (A)	-	1360	2270
4	BC 67 (A)	1590	1630	2010
5	BC 67 (BA)	1290	1590	2290
6	BC 134 (BA)	1820	1590	2340
7	BC 202 (BA)	1580	1750	2430
8	SB 67 (BA)	1610	1570	2340
9	SB 134 (BA)	1870	1760	2470
10	SB 202 (BA)	1890	1640	2580
	Treatment Pr > F	0.1359	0.6261	0.2273

Combined Study Year Analysis

Tables 3.20 – 3.22 summarize the combined K fertility effect on leaf K content at the R3 (pod-set) and R4 (pod-fill) growth stages, grain K concentration and soybean yield across the 2009, 2010 and 2011 sites. Small and Ohlrogge (1973) determined that the plant sufficiency range for K was 17.0 to 25.0 g kg^{-1}. In 2009 the pod-set leaf K contents were within this range, however, the 2010 and 2011 leaf K contents were well below 17 g kg^{-1}. Figure 3.3 shows the responses of soybeans to K fertilization in 2009, 2010 and 2011. In 2009 all sites tested in the optimum range (130 – 170 mg kg^{-1}). In 2010 the soils tested in the low range (90 – 130 mg kg^{-1}) and in 2011 the sites tested in the very low range (< 90 mg kg^{-1}). Overall, the pod-set leaf K data correlated very well with soil test K (Figure 3.3). The higher pod-set leaf K levels were observed on the optimum sites and the lowest were observed on the very low soil test K sites. However, soybean pod-set leaf K concentrations increased significantly with K fertilization regardless of soil test K. The observed response could be related to soybean K luxury consumption.

In 2009 and 2010 the broadcast high rate (202 kg K_2O ha^{-1}) treatment produced the highest pod-set leaf K contents, substantially ($P<0.05$) higher compared to the low (67 kg K_2O ha^{-1}) rate and in 2009 the medium (134 kg K_2O ha^{-1}) rate as well. In 2011 the surface band high rate produced the greatest pod-set leaf K content, almost 9% higher ($P<0.05$) compared to the equivalent rate broadcast applied. Furthermore, in 2011 the soybean pod-set leaf K concentrations displayed a nice response to the surface banded rates. As K rate increased from the low to the high rate, leaf K content significantly ($P<0.05$) increased by approximately 10% with each additional increment (67 kg K_2O ha^{-1}) in K fertilizer. The broadcast treatments also showed a nice response in respect to soybean leaf K concentrations, but only up to the medium rate. The results indicate that surface banding on very low soil test K sites is a more valid option versus broadcasting K fertilizer.

The pod-fill leaf K content data for each year expressed positive responses to K fertilization as well. In 2009 the broadcast and surface band treatments all had nearly equal values in leaf K concentrations, with the high rates being significantly ($P<0.10$) greater compared to the low rates. In 2010 the broadcast applications increased leaf K content 4% ($P<0.10$) from the low to medium rate and 5% ($P<0.05$) from the medium to the high rate. The 2011 site-year analysis displayed a similar broadcast rate response with leaf K content increasing

($P<0.05$) by 16 and 9% between rates. There were also sizable differences in leaf K content between the surface band rates in both years. In 2010 the surface band medium rate increased ($P<0.05$) leaf K content 6% over the low rate, but the high rate did not significantly ($P>0.10$) increase leaf K content over the medium rate. In 2011 with each additional increment in K from the low to high rate, leaf K content significantly ($P<0.05$) increased by approximately 13%. Additionally, at low and high rates surface banding increased ($P<0.05$) pod-fill leaf K concentrations 6 and 7%, respectively, compared to broadcast applications.

The grain K concentrations were not affected by the addition of K, K rate or placement methods in 2009 and 2010. In 2011, at very low soil test K, grain K concentrations were significantly ($P<0.05$) affected by the addition of K fertilizer. The surface band rate provided the highest grain K concentration, approximately 4% ($P<0.05$) higher in grain K content compared to the low rate. No other placement rate or placement method at the same rate presented significant effects on grain K content.

In 2009 and 2010 soybean yields were average to excellent with yields at or above 2340 kg ha^{-1}. These good yields are attributed to the favorable weather and growing conditions experienced during the two cropping seasons. Even though there were observed differences between leaf K contents, there were no significant differences found in soybean yield due to added K fertilizer or placement methods at the same rate in 2009 and 2010. In 2011 soybean yields averaged around 1860 kg ha^{-1}, much lower than the previous two years, but were higher than the 2011 regional dry land yield averages (USDA 2011). The low yields in 2011 can be attributed to the lack of precipitation, extensive exposure to higher than normal temperatures and very low soil test K levels. A response to K fertilization was observed, however, no responses to K rates or placement methods were documented in 2011.

The yield results are similar to those of Yin and Vyn (2003), who also observed significant yield increases on very low soil test K soils. However, their results showed a significant response to surface banded K and not for broadcast applied fertilizer. The results from this study did not suggest a significant yield advantage to surface banding. Buah et al. (2000) concluded that broadcast application was equally effective to starter band placement on optimum soil test K soils.

Table 3.20 Average soybean R3 (pod-set) leaf K, R4 (pod-fill) leaf K, grain K and yield by treatment across all 2009 (optimum soil K) study sites

		R3 Leaf K	*R4 Leaf K*	*Grain K*	*Yield*
Trt #	Treatment	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}
1	CK	17.43	10.03	20.07	2380
2	BC Rec (A)	17.67	10.39	19.84	2420
3	BC 34 (A)	17.89	10.58	20.33	2460
4	BC 67 (A)	18.07	10.73	20.33	2380
5	BC 67 (BA)	17.97	10.74	20.43	2510
6	BC 134 (BA)	18.04	11.19	20.27	2350
7	BC 202 (BA)	19.27	11.35	20.25	2390
8	SB 67 (BA)	18.29	10.86	20.43	2420
9	SB 134 (BA)	18.25	11.04	20.30	2450
10	SB 202 (BA)	18.48	11.37	19.75	2340
Treatment Pr > F		<0.0001	<0.0001	0.1285	0.8404
Contrast					
CK (1) vs. K (2-10)		(0.79)*	(0.89)*	---	---
BC 67 (5) vs. SB 67 (8)		(0.32)	(0.11)	---	---
BC 134 (6) vs. SB 134 (9)		(0.21)	0.15	---	---
BC 202 (7) vs. SB 202 (10)		0.79*	(0.02)	---	---
BC 67 (5) vs. BC 202 (7)		(1.30)*	(0.61)*	---	---
BC 67 (5) vs. BC 134 (6)		(0.07)	(0.44)	---	---
BC 134 (6) vs. BC 202 (7)		(1.23)*	(0.16)	---	---
SB 67 (8) vs. SB 202 (10)		(0.19)	(0.51)**	---	---
SB 67 (8) vs. SB 134 (9)		0.04	(0.18)	---	---
SB 134 (9) vs. SB 202 (10)		(0.23)	(0.33)	---	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Table 3.21 Average soybean R3 (pod-set) leaf K, R4 (pod-fill) leaf K, grain K and yield by treatment across all 2010 (low soil K) study sites

		R3 Leaf K	*R4 Leaf K*	*Grain K*	*Yield*
Trt #	Treatment	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}
1	CK	14.11	9.80	17.83	3210
2	BC Rec (A)	14.60	10.21	17.69	3200
3	BC 34 (A)	14.47	10.18	17.96	3240
4	BC 67 (A)	15.12	10.41	17.71	3260
5	BC 67 (BA)	14.86	10.64	17.83	3270
6	BC 134 (BA)	15.55	11.09	18.38	3260
7	BC 202 (BA)	16.04	11.72	18.19	3170
8	SB 67 (BA)	15.22	10.61	17.89	3250
9	SB 134 (BA)	15.67	11.24	18.20	3290
10	SB 202 (BA)	15.32	11.35	17.97	3290
Treatment Pr > F		0.0006	<0.0001	0.1371	0.9529
Contrast					
CK (1) vs. K (2-10)		(1.09)*	(1.03)*	---	---
BC 67 (5) vs. SB 67 (8)		(0.36)	0.03	---	---
BC 134 (6) vs. SB 134 (9)		(0.12)	(0.14)	---	---
BC 202 (7) vs. SB 202 (10)		0.72	0.37	---	---
BC 67 (5) vs. BC 202 (7)		(1.17)*	(1.08)*	---	---
BC 67 (5) vs. BC 134 (6)		(0.69)	(0.46)**	---	---
BC 134 (6) vs. BC 202 (7)		(0.49)	(0.63)*	---	---
SB 67 (8) vs. SB 202 (10)		(0.10)	(0.74)*	---	---
SB 67 (8) vs. SB 134 (9)		(0.45)	(0.63)*	---	---
SB 134 (9) vs. SB 202 (10)		0.35	(0.12)	---	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Table 3.22 Average soybean R3 (pod-set) leaf K, R4 (pod-fill) leaf K, grain K and yield by treatment across all 2011 (very low soil K) study sites

		R3 Leaf K	*R4 Leaf K*	*Grain K*	*Yield*
Trt #	Treatment	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}
1	CK	9.95	6.62	14.02	1620
2	BC Rec (A)	11.20	8.60	15.14	1770
3	BC 34 (A)	10.97	8.14	15.12	1700
4	BC 67 (A)	11.74	9.03	15.26	1750
5	BC 67 (BA)	11.66	8.58	15.26	1720
6	BC 134 (BA)	13.03	10.20	15.69	1920
7	BC 202 (BA)	13.61	11.23	15.86	1920
8	SB 67 (BA)	12.15	9.17	15.63	1840
9	SB 134 (BA)	13.43	10.53	15.83	2040
10	SB 202 (BA)	14.89	12.05	15.99	2040
Treatment Pr > F		<0.0001	<0.0001	<0.0001	0.0537
Contrast					
CK (1) vs. K (2-10)		(2.57)*	(3.11)*	(1.51)*	(240)*
BC 67 (5) vs. SB 67 (8)		(0.50)	(0.59)**	(0.38)	(120)
BC 134 (6) vs. SB 134 (9)		(0.40)	(0.33)	(0.14)	(120)
BC 202 (7) vs. SB 202 (10)		(1.28)*	(0.82)*	(0.13)	(120)
BC 67 (5) vs. BC 202 (7)		(1.96)*	(2.64)*	(0.60)*	(200)
BC 67 (5) vs. BC 134 (6)		(1.38)*	(1.62)*	(0.43)	(200)
BC 134 (6) vs. BC 202 (7)		(0.58)	(1.03)*	(0.17)	(0)
SB 67 (8) vs. SB 202 (10)		(2.74)*	(2.87)*	(0.36)	(200)
SB 67 (8) vs. SB 134 (9)		(1.28)*	(1.36)*	(0.20)	(200)
SB 134 (9) vs. SB 202 (10)		(1.46)*	(1.51)*	(0.16)	(0)

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

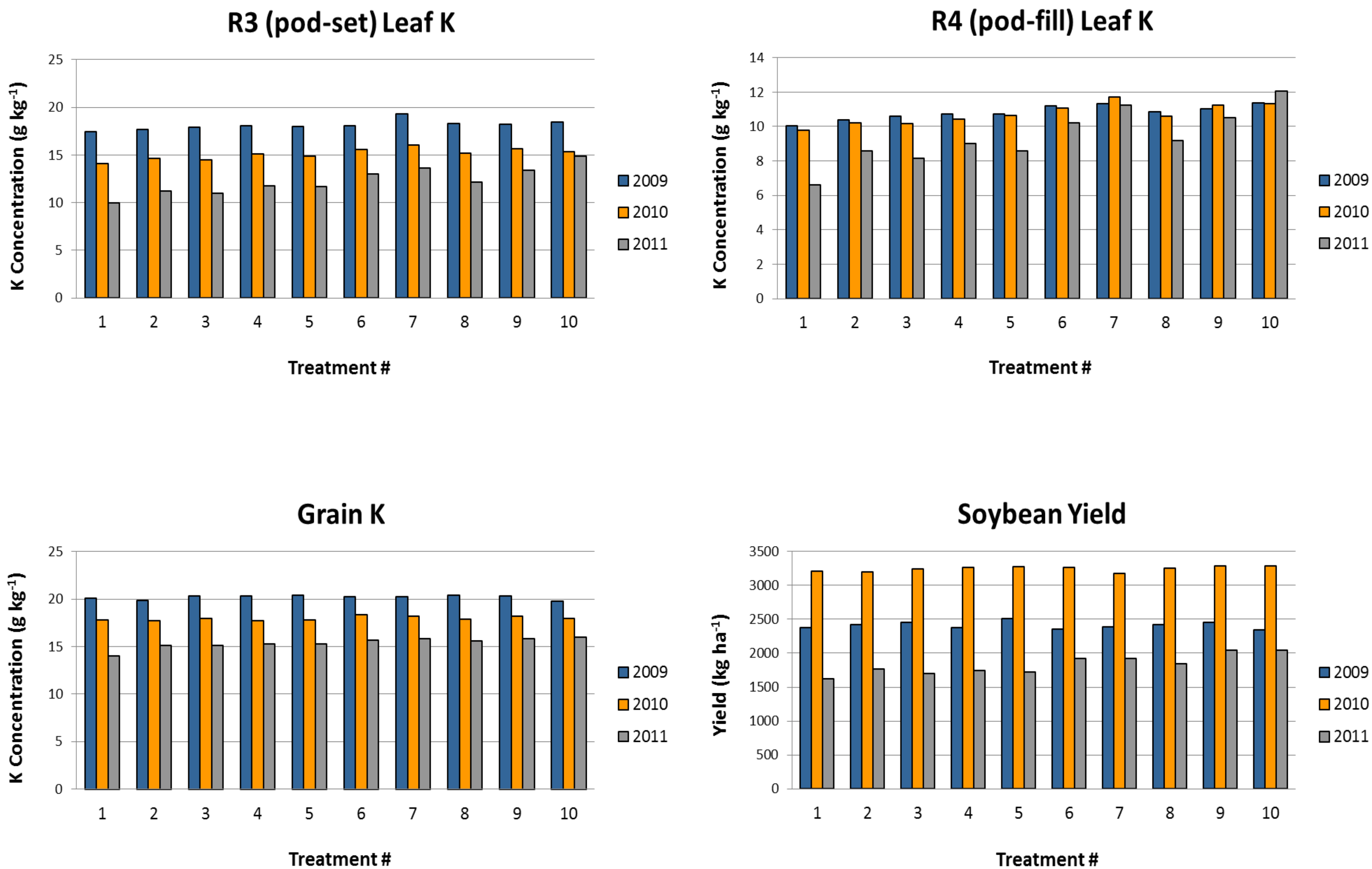

Figure 3.3 Response of soybean to K fertilization in 2009, 2010 and 2011 (statistics presented in Tables 3.20 – 3.22)

Conclusions

The results of this three year study indicated that potassium (K) fertilization had little to no influence on soybean yield and grain K content in 2009 and 2010 when soils tested in the low to optimum range (90 - 170 mg kg^{-1}) in soil test exchangeable K. However, in 2011 with soils testing very low (< 90 mg kg^{-1}) in soil test K with reported hot, dry weather conditions, deficiency symptoms were observable. At these sites K fertilization slightly increased soybean yields and grain K concentrations, but there was no large or significant difference in soybean yield between application methods. Leaf K parameters were regularly influenced by K fertilization regardless of soil test K level. At a majority of the sites, K fertilization significantly increased the pod-set and pod-fill leaf K contents and a response was frequently observed up to the highest K rate. At several low to optimum soil test K sites, soybeans responded to broadcast applications as well or better than surface band applications. Thus, there is no advantage in surface banding K fertilizer when soil test K levels are in the 90 – 170 mg kg^{-1} range. However, there was evidence in the leaf K data that surface banded fertilizer presented a distinct advantage over broadcasting on very low soil test K sites, especially when high K rates were applied. In the study, the KSU sufficiency soil test-based K recommendation was able to predict the need for K fertilization in regard to soybean yield. However, the treatment leaf K data often produced leaf K values that were the same or just slightly above the unfertilized control, causing concern over the sustainability of this fertilizer recommendation approach in the long-term. Additional research is needed to evaluate the reproducibility of these results and verifying the accuracy of the K fertilizer recommendation for soybeans.

Overall, the research suggests that the probability of observing soybean potassium deficiencies as well as a response to K fertilization is greater at fields that test very low in soil test K. Additionally, the use of surface banding would be a more efficient system compared to broadcasting the K fertilizer on the same soils mentioned, but on low to optimum K soils, broadcasting would be a more appropriate practice.

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Chapter 4 - Impact of Direct and Residual Potassium Fertilizer Rates and Method of Placement on Corn in Southeast Kansas

Abstract

The increase in potassium (K) deficient corn (*Zea mays* L.) along with volatile prices of K fertilizers over the past few years has created significant interest in further analyzing corn responses to K fertilizer. The majority of Kansas soils have historically been recognized for having high K levels and traditionally K has not been deemed as a nutrient needing supplemental fertilization. However, in the older and more highly weathered soils in southeast Kansas it is not uncommon to discover corn fields that are visually suffering from inadequate K nutrition. This has raised a lot of questions and concerns over proper K management decisions that need to be implemented to optimize corn production. The objective of this study was to evaluate the response of corn to both direct K fertilization as well as residual K fertilization at equivalent bi-yearly rates.

This study was conducted at six locations in southeast Kansas with corn during the 2010 and 2011 cropping seasons. All locations were established in the year prior to evaluate soybean (*Glycine max* L.) responses and were continued for a second year to assess rotational corn K responses. Selected sites varied in soil test K levels, ranging from slightly above the current critical level of 130 mg kg^{-1} to slightly below the optimum level were K response would be expected, and K fertilizer recommended. Treatments consisted of both annual and biannual K application rates ranging from 0 to 202 kg K_2O ha^{-1} that were applied using either a broadcast or surface band method of application to soybeans in the prior year. No additional K fertilizer was applied to the multi-year surface band and broadcast treatments to corn. However, additional K fertilization was broadcast applied to the annual treatments at 0 to 67 kg K_2O ha^{-1}.

Plant samples were taken at the R1 (silking) growth stage to monitor treatment effects on tissue K levels. Yield and grain K concentrations were collected at harvest to further document treatment responses. At several locations, increased direct and residual K fertilization rate both increased K tissue concentrations. The direct and residual rates were equally as effective with no residual placement method providing an advantage. The grain K data did not reveal any evidence of treatment responses and no corn yield response was observed even at low (90 – 130 mg kg^{-1}) soil K testing sites.

Introduction

Corn (*Zea mays* L.) is one of the main crops grown in southeast Kansas. Nearly two hundred thousand hectares were harvested in 2010 and average corn yields approached 6710 kg ha^{-1} (USDA, 2011). As cropping systems have intensified with the use of higher yielding corn varieties in combination with increased soybean production, soil potassium (K) levels have become increasingly limiting in southeast Kansas. As a result, K fertilization is a necessity in many fields in order to produce optimum corn grain yields. However, corn K deficiency symptoms have been observed even when soil-test based sufficiency fertilizer rates are applied. Therefore, improvements in the management of soil and fertilizer K are essential in order to increase K fertilizer-use efficiency, resulting in higher producer profit margins and increasing the long-term agricultural viability of the area.

Potassium is one of three primary nutrients, along with nitrogen (N) and phosphorus (P), required for proper corn growth and development. Potassium is taken up in large quantities by corn and plays essential roles in a number of metabolic functions. Over 60 enzymes require K for catalytic activity, some of which play a role in protein synthesis and sugar degradation (Suelter, 1985). Water-relations of plant cells rely on the rapid movement of K ions in order to maintain and regulate turgidity (Mengel and Arneke, 1982) and stomatal control can be affected if K is deficient (Graham and Ulrich, 1972). Potassium fertilization has been shown to decrease the impact of several diseases including Stewart's wilt (Spencer and McNew, 1938) and Stalk rot (Ellett, 1973; Hooker 1966) of corn. Improved structural integrity and increased resistance to stalk diseases may also contribute to the well-known role of K nutrition in lodging resistance (Walker and Parks, 1969). Additionally, K fertilization can lead to earlier silking, uniform maturity, improved grain fill and higher corn grain test weights (Welch and Flannery, 1985).

In numerous studies direct K fertilization often increased K uptake and/or plant tissue K content in corn, even at sites that tested in the optimum to high (130 to 274 mg kg^{-1}) range in soil test K (Ebelhar and Varsa, 2000; Borges and Mallarino, 1998). However, corn yield responses at optimum to high K fertility are frequently not observed (Rehm et al., 1988; Rehm and Lamb, 2004). Mozaffari et al. (2007) found that on low to optimum soil test K sites direct K fertilization did not provide significant increases in corn grain yields. Mozaffari and Slaton (2011) concluded from their research that soils having low soil test K levels, K fertilization increased K leaf concentration and uptake by corn. Additionally, K fertilization also increased corn grain yields at three out of four sites having very low to optimum soil test K levels. Gelderman et al. (2002) also found corn yield responses on relatively low testing soils with the addition of K in South Dakota.

Throughout the Midwest many producers consider corn to be more responsive to K fertilizer in the year of application than soybeans (*Glycine max* L.). As a result, biannual application of K fertilizer before corn has become a common management practice. The idea is to apply high enough rates to satisfy the K requirements of the corn and the subsequent soybean crop. Occasionally the sequence is reversed and the corn crop relies on residual K fertilizer, but the majority of producers use the previously described procedure. Although biannual applications have the potential to reduce input costs, questions exist as to how adequate the system is in supplying the needed K fertilizer to the following crop. The concern is magnified in areas where soils have either high K fixing or high K leaching potentials where applied K could be unavailable to the crop in the following year.

Most of the published research has been devoted to the effects of direct K fertilizer applications to soybeans and fewer reports are available concerning the residual effects on corn. Relevant research by deMooy et al. (1973) showed that corn was significantly more responsive to direct rather than residual fertilization on low (< 90 mg kg^{-1}) K testing soils. However, on optimum (> 130 mg kg^{-1}) soil K sites corn showed very little yield difference between direct and residual fertilization (deMooy et al., 1973). In the same study no measured effects between direct and residual fertilization on soybeans was observed even at the low soil test K sites. Further research by Buah et al. (2000) and Rehm and Lamb (2004) also found that residual and direct fertilization resulted in similar soybean yields. Research in Ontario, Canada (Yin and Vyn, 2002a) concluded that subsequent no-till soybeans responded more to residual K fertilizer rate than to application timing, tillage and K fertilizer placement in preceding corn. However, in further research by Yin and Vyn (2002b) found that no-till soybean response to residual K fertilizer management varied depending on the tillage system utilized in corn. Research in Minnesota (Rehm, 1995) on a high testing K soil with K stratification after six years of ridge-till, showed that residual K from a high rate of deep-banded K fertilizer to previous corn significantly increased soybean yield.

Several challenges exist in recommending the use of K fertilizer on the highly weathered soils of southeast Kansas. Among these challenges is determining under what conditions plant growth response to K fertilizer would be expected and assessing the appropriate K fertilizer rate, placement method and frequency of K applications needed to optimize corn yield.

The objectives of this study were to:

1. Evaluate the effect of direct broadcast applied K fertilizer rate on corn yield in southeast Kansas.
2. Test the response of corn to residual K fertilization rate being broadcast or surface band applied.

Materials and Methods

Research was conducted on-farm in cooperation with local producers. Field experiments were established at four locations in 2010 and two locations in 2011, to evaluate the response of corn (*Zea mays* L.) to direct and residual potassium (K) fertilization. Four sites were initially established for 2011, however, two sites where dropped due to a custom applicator accidentally applying a flat rate of K fertilizer across the study areas. Field site locations, year study was established and geographical coordinates are presented in Table 4.1. Selected sites used in this study were used a year prior to evaluate soybean (*Glycine max* L.) response to K fertilization. Location soil descriptions and average soil test levels for each site are given in Table 4.3. All six locations were rain-fed and no supplemental irrigation was used. Cumulative in-season precipitation, average daily temperature and 30 year normals, were based on the Oswego weather station data for all six field sites (National Climatic Data Center, 2011).

At each location plots were arranged in a randomized complete block design with four replications. Corn was planted using a 76.2 cm row spacing. Plots were 15.2 meters long and 6.2 meters (or 8 rows) wide at all locations in 2010 and 2011. Ten different combinations of K rates and fertilizer application methods were applied to soybeans in the year prior to the corn studies (Table 4.2). The treatments involved annual and biannual applications, so the rotational corn studies only received the three annual (direct) broadcast K rate treatments. The other six treatments were used to assess corn responses to residual K fertilization. With this treatment design, the total amounts of K applied to the corn crop were equal between the direct and residual applications over a two year period. One of the direct K rate treatments was based on the Kansas State University (KSU) corn K sufficiency recommendation, and the equation used to calculate K rates can be found in the KSU Soil Test Interpretations and Fertilizer Recommendations publication (Leikam et al., 2003). Granular potassium chloride (0-0-62) was used as the K fertilization source.

Table 4.1 Field site locations, year study was established and geographical coordinates

Location	*Area*	*County*	*Study Year*	*Geographical Coordinates*
SW Jennings	Hallowell, KS	Cherokee	2010	37° 8' 8" N, 94° 59' 36" W
SE Brown	Hallowell, KS	Cherokee	2010	37° 10' 47" N, 95° 0' 27" W
SW Brown	Hallowell, KS	Cherokee	2010	37° 10' 47" N, 95° 0' 42" W
Delmont	Hallowell, KS	Cherokee	2010	37° 11' 54" N, 95° 0' 53" W
NW of Dads	Hallowell, KS	Cherokee	2011	37° 11' 41" N, 95° 2' 54" W
East Marks	Hallowell, KS	Cherokee	2011	37° 11' 35" N, 95° 1' 25" W

Table 4.2 Direct and residual potassium fertilizer rate and placement method

Treatment No.	*Treatment Abv.*	*Treatment Description*
1	CK	Unfertilized check
2	BC Rec (A)	Annual broadcast K rate based on sufficiency rec.
3	BC 34 (A)	Annual broadcast 34 kg K_2O ha^{-1}
4	BC 67 (A)	Annual broadcast 67 kg K_2O ha^{-1}
5	BC 67 (BA)	Biannual broadcast 67 kg K_2O ha^{-1}
6	BC 134 (BA)	Biannual broadcast 134 kg K_2O ha^{-1}
7	BC 202 (BA)	Biannual broadcast 202 kg K_2O ha^{-1}
8	SB 67 (BA)	Biannual surface band 67 kg K_2O ha^{-1}
9	SB 134 (BA)	Biannual surface band 134 kg K_2O ha^{-1}
10	SB 202 (BA)	Biannual surface band 202 kg K_2O ha^{-1}

Table 4.3 Locations, description of soils present and average soil test values at corn study initiation

Location	*Soil Series*	*Soil pH*	*Mehlich-3 P*	*NH_4OAc Exchangeable K*	*Organic Matter*	*Nitrate Nitrogen*
			mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}
SW Jennings	Cherokee silt loam	6.1	25	134	14	10.3
SE Brown	Cherokee silt loam	7.0	63	155	15	8.4
SW Brown	Cherokee silt loam	6.3	36	143	13	6.6
Delmont	Cherokee silt loam	6.0	22	121	12	4.1
NW of Dads	Cherokee silt loam	6.5	25	104	20	n/a
East Marks	Cherokee silt loam	6.2	19	107	17	n/a

Cultural Practices

In 2010 and 2011 the study was conducted at six locations near Hallowell, Kansas. All sites were corn following soybeans and had been conventionally tilled prior to corn planting. Spring soil test K results from 2010 and 2011, and a yield goal of 9420 kg ha^{-1} were used in the KSU corn K sufficiency recommendation equation to determine appropriate K rates for treatment 2 (Table 4.4). Treatments were applied at the V-2 growth stage. Additionally, all plots received 45 kg P_2O_5 ha^{-1} using mono-ammonium phosphate (11-52-0) and 160 kg N ha^{-1} using anhydrous ammonia (82-0-0). All other soil fertility needs were sufficient.

Varieties planted were adapted to the region and selected by the cooperating producer. Key cultural practices are summarized in Table 4.5. Weed control was also performed by the producer with the use of glyphosate (Round-up) and atrazine (AAtrex) herbicides. A pre-emergent application of atrazine was applied at a rate of 4.6 liters ha^{-1} and a post application of glyphosate was applied at 2.3 liters ha^{-1}.

Table 4.4 Initial soil test potassium level and the sufficiency recommendation rate by location

Location	*Soil Test K Level* mg kg^{-1}	*Sufficiency K Rate* kg K_2O ha^{-1}
SW Jennings	134	0
SE Brown	155	0
SW Brown	143	0
Delmont	121	8
NW of Dads	104	23
East Marks	107	20

Table 4.5 Key cultural practices used in conducting corn experiments

Location	*Variety*	*Relative Maturity*	*Seeding Rate (seeds ha^{-1})*	*Planting Date*	*Fertilizer App. Date*	*Ear-leaf Sampling*	*Harvest Date*
SW Jennings	Pioneer 35F37	105	60 294	9-Apr	16-May	28-Jun	19-Aug
SE Brown	Pioneer 35F37	105	60 294	11-Apr	16-May	28-Jun	19-Aug
SW Brown	Pioneer 35F37	105	60 294	11-Apr	16-May	28-Jun	19-Aug
Delmont	Dekalb 52-59	102	60 294	13-Apr	16-May	28-Jun	19-Aug
NW of Dads	Pioneer 0541HR	105	69 931	10-Apr	10-May	18-Jul	25-Aug
East Marks	Pioneer 0541HR	105	69 931	3-Apr	10-May	6-Jul	25-Aug

Soil Sampling and Analysis

Soil samples were taken at 0-15 cm and 15-60 cm soil sampling depths. The 15-60 cm samples were only taken at the 2010 sites, in 2011 the producer applied nitrogen fertilizer before we could sample the areas. The cores were collected at random from each replication at all of the corn sites just prior to applying treatments. Separate samples were taken from the unfertilized K plots from each replication to get an assessment of soil K. Soil samples were taken using a manual soil probe and samples consisted of 10 to 12 individual cores mixed together to form a single composite sample. After collection, soil samples were oven dried at $60^{o}C$ and ground to pass through a 2-mm sieve by a Dyna-Crush 5 flail grinder (Custom Laboratory Equipment Inc., Orange City, FL). Soil samples at the 0-15 cm depths were analyzed to determine soil pH, available phosphorus (P), exchangeable potassium (K), soil organic matter (SOM) and surface nitrate-nitrogen (NO_3-N). The 15-60 cm depth samples were analyzed to determine sub-surface NO_3-N values and were added to the surface values to calculate the total profile NO_3-N values. Values reported in Table 4.2 are the mean values calculated from the four replication samples at each location. Soil analysis was conducted by the KSU Soil Sampling Lab using procedures described in Recommended Chemical Soil Testing Procedures for the North Central NCRR Publication no. 221 (1998).

Leaf Sampling and Analysis

Corn ear-leaf samples were collected at the R-1 (silking) growth stage. Fifteen ear-leaves were collected at random from the non-harvest rows of each plot. The composite samples were oven dried at $60^{o}C$ for two days and ground to pass a 0.5-mm stainless steel sieve using a Wiley rotary grinder (Arthur H. Thomas Co., Philadelphia, PA). Samples were digested using a sulfuric acid-hydrogen peroxide digest and analyzed for nitrogen, phosphorus and potassium concentrations by the KSU Soil Testing Lab. The analysis for nitrogen was done using an Alpkem RFA colormetric instrument and RFA Methodology A303-S072. Phosphorus analysis was done by an Inductively Coupled Plasma (ICP) Spectrometer, Model 720-ES ICP Optical Emission Spectrometer. Potassium analysis was conducted using a Bechman Model 200 Atomic Absorption Spectrometer.

Grain Yield and Analysis

After physiological maturity plots were hand harvested by marking 5.3 meters of plot in the center two rows and manually collecting all the ears in both rows of the marked area. Corn was then shelled using an Almaco mechanical thresher (Almaco, Nevada, IA) and the shelled corn was collected in a container. Grain weight was recorded using a calibrated scale and a sub-sample was collected in a plastic jar to be analyzed for moisture content and test weight using a Dickey-John GAC 2100 (Dickey-John Corp., Auburn, IL). Corn yields from all locations were adjusted to 155 g kg^{-1} moisture content. Grain sub-samples were oven dried at 60^{o}C for a minimum of four days and then ground to a powder for analysis. Samples were analyzed for nitrogen, phosphorus and potassium concentrations using the sulfuric acid-hydrogen peroxide wet digestion method. Grain analysis was done by the KSU Soil Testing Lab using the same methods described in analyzing the leaf samples.

Statistical Analysis

Corn ear-leaf tissue K concentrations, grain K concentrations and yield data were analyzed by location using the PROC MIXED procedure at alpha level 0.05, with blocks as a random affect, in SAS version 9.2 (SAS Institute, 2008). Data was also analyzed by study year for an overall analysis and run in the same PROC MIXED procedure, with blocks and locations as random affects. Significance of difference between treatment means by location and by study year were determined by pair-wise comparisons. Treatments 7 and 10 will be mentioned in this chapter, but no statistical comparisons were conducted due to the lack of an equivalent split annual rate.

Results and Discussion

The initial soil test potassium (K) levels at each location were presented in Table 4.2. Three of the 2010 sites tested in the optimum (130 – 170 mg kg^{-1}) category according to Iowa State University soil test K interpretations (Sawyer et al., 2011), the Delmont site in 2010 and both the 2011 sites tested in the low (90 – 130 mg kg^{-1}) category. Previous research indicates that the probability of a yield response within each category is 65% for low and 25% for optimum (Sawyer et al., 2011). A corn K sufficiency rate was calculated and applied for treatment 2 based on spring soil test samples collected prior to corn planting (Table 3.5).

Cumulative in-season (April 1st – September 1st) precipitation and average daily temperatures for the Hallowell area in 2010 and 2011, and the 30-year normal averages are illustrated in Table 4.6. In 2010, environmental conditions presented favorable weather for crop growth and development. In-season precipitation in the area exceeded the 30-year average and the rainfall pattern correlated well with critical times of corn development, pollen shed and silking (Table 4.6). Average daily temperatures were above normal in 2010, but temperatures did not peak until close to the R5 growth stage around the first of August. In 2011, growing conditions were less than ideal. In-season precipitation was greatly limited especially during the summer months. However, April rainfall amounts (217 mm) were in excess and at the NW of Dads field site the corn had to be replanted due to poor stand establishment. Daily temperatures ran at least one degree higher than normal with numerous days from early July until mid-September that surpassed 38^{o}C. The corn plants begin pollinating around the first of July when temperatures beginning climbing. Temperatures in excess of 35^{o}C can desiccate exposed silks and reduce pollen viability (Nielson, 1996). The combined effect of drought and heat stress severely impacted corn yields in 2011.

Table 4.6 In-season cumulative precipitation and average daily temperature (April 1st – September 1st)

		Temperature		*Precipitation*	
Area	Study Year	30 Year (1981-2010) Average Daily Mean (c^{o})	Mean (c^{o})	30 Year (1981-2010) Average Total (mm)	Total (mm)
Hallowell	2010	21.9	23.2	584	653
Hallowell	2011	21.9	23.4	584	528

Visual K deficiency symptoms were documented at one of the six sites. In 2011 at NW of Dads visual symptoms were observed (Figure 4.1). The symptoms were present at the R1 growth stage. The corn was very drought stressed, so the symptoms could be mistaken for premature leaf death from heat and drought stress. However, the leaf samples taken at this growth stage were not above the sufficient 17 g kg^{-1} critical value.

Figure 4.1 NW of Dads K deficient corn

R1 (silking) Ear-leaf Nutrient Analysis

Leaf K content at the R1 (silking) growth stage of development is commonly used as an indicator of corn K nutrition at early growth stages (Mills and Jones, 1996). The silking leaf K data in response to treatments for the 2010 and 2011 sites are summarized in Tables 4.7 and 4.8. During the two year study five out of the six sites displayed positive responses to K fertilization in regard to ear-leaf K concentration.

In 2010 leaf K concentrations ranged from 16.48 – 23.19 g kg^{-1}, indicating that the majority of the corn leaf K concentrations were within the sufficiency range of 17.0 – 30.0 g kg^{-1} (Mills and Jones, 1996). Overall, three of the four site-samplings expressed significant ($P<0.05$) responses to K fertilization. At SW Jennings, the residual (biannual) surface band high rate (202 kg K_2O ha^{-1}) provided the highest ear-leaf K content of 22.68 g kg^{-1}. When compared to the unfertilized control, both the use of direct (annual) and residual K fertilization decreased K ear-leaf concentrations by 0.35 and 0.22 g kg^{-1}, respectively. Ear-leaf K concentrations consistently increased from the low to medium K rates regardless of frequency of application (two direct vs. one residual). However, no significant treatment differences between annual and biannual K rates, frequency of K application or biannual placement methods at the same rate were observed.

At SE Brown, direct K fertilization increased ($P<0.05$) leaf K content 10% compared to the unfertilized control. The direct application of 67 kg K_2O ha^{-1} provided the highest leaf K concentration, 12 and 8% higher ($P<0.05$) compared to the residual broadcast and surface band applications of 134 kg K_2O ha^{-1}, respectively. The direct low rate (34 kg K_2O ha^{-1}) increased ($P<0.05$) leaf K content 2 g kg^{-1} compared to the residual surface band low rate (67 kg K_2O ha^{-1}). Overall, the use of two K applications were more effective in increasing leaf K content compared to biannual applications at the SE Brown field site. Leaf K content showed noticeable increases from the low to medium K rates with direct broadcast and residual surface band applications, however, no treatment effects between annual and biannual K rates or biannual placement methods at the same rate were observed.

At Delmont, both direct and residual fertilization increased leaf K content 14 and 10%, respectively, compared to the unfertilized control. The direct application of 67 kg K_2O ha^{-1} provided the highest leaf K content, 7% higher ($P>0.10$) than the direct low rate (34 kg K_2O ha^{-1}). There was an overall nice response to increased fertilization for both the direct and residual rates, however, no significant effects were found between annual and biannual K rates, frequency of K application or biannual placement methods at the same rate.

Table 4.7 Average K concentrations in corn ear-leaf tissue at the R1 (silking) growth stage by treatment for the 2010 sites

Trt #	Treatment	*SW Jennings*	*SE Brown*	*SW Brown*	*Delmont*
		-------------	------------- g kg^{-1}	-------------	-------------
1	CK	20.03	20.40	20.68	17.79
2	BC Rec (A)	16.48	22.31	20.42	18.04
3	BC 34 (A)	19.37	22.13	20.62	19.92
4	BC 67 (A)	19.99	23.19	21.04	21.38
5	BC 67 (BA)	19.04	21.35	21.31	19.14
6	BC 134 (BA)	20.91	20.31	19.59	20.51
7	BC 202 (BA)	20.78	22.61	22.84	21.08
8	SB 67 (BA)	19.41	20.13	20.60	19.69
9	SB 134 (BA)	19.90	21.33	19.18	20.07
10	SB 202 (BA)	22.68	20.85	20.96	20.22
Treatment Pr > F		0.0114	0.0062	0.2969	0.0189
Contrast					
CK (1) vs. Dir. K (3-4)		0.35	(2.27)*	---	(2.85)*
CK (1) vs. Res. K (5,6,8,9)		0.22	(0.39)	---	(2.07)*
BC 34 (3) vs. BC 67 (4)		(0.62)	(1.06)	---	(1.46)
BC 67 (5) vs. BC 134 (6)		(1.87)	1.03	---	(1.37)
SB 67 (8) vs. SB 134 (9)		(0.49)	(1.20)	---	(0.38)
BC 67 (5) vs. SB 67 (8)		(0.38)	1.22	---	(0.55)
BC 134 (6) vs. SB 134 (9)		1.01	(1.02)	---	0.45
BC 34 (3) vs. BC 67 (5)		0.34	0.79	---	0.78
BC 34 (3) vs. SB 67 (8)		(0.04)	2.00*	---	0.23
BC 67 (4) vs. BC 134 (6)		(0.92)	2.88*	---	0.87
BC 67 (4) vs. SB 134 (9)		0.09	1.86*	---	1.31

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

In 2011 leaf K concentrations ranged from 9.32 – 14.91 and 16.32 – 21.20 g kg^{-1} for NW of Dads and East Marks, respectively. The majority of treatment leaf K contents at east Marks were within the sufficiency range of 17.0 – 30.0 g kg^{-1} (Mills and Jones, 1996), however, at NW of Dads the values were all well below the critical range indicating limited K availability. Overall, the plants at both sites expressed significant ($P<0.05$) responses to K fertilization. At NW of Dads, both direct and residual fertilization increased leaf K content 25 and 23%, respectively, compared to the unfertilized control. The residual broadcast high rate (202 kg K_2O ha^{-1}) provided the highest leaf K content of 14.91 g kg^{-1}. The residual broadcast medium rate (134 kg K_2O ha^{-1}) increased ($P<0.05$) leaf K content 21% compared to the residual low rate (67 kg K_2O ha^{-1}). A positive response to increased fertilization for the direct and residual surface band rates was also observed. Overall, no significant treatment differences between annual rates, biannual surface band rates, frequency of K application or biannual placement methods at the same rate were observed.

At East Marks, residual fertilization increased ($P<0.05$) leaf K content 2.89 g kg^{-1} compared to the unfertilized control. The residual surface band high rate (202 kg K_2O ha^{-1}) provided the highest leaf K content of 14.91 g kg^{-1}. A clear increase in leaf K content with the biannual high rates was seen. The residual broadcast medium rate (134 kg K_2O ha^{-1}) increased ($P<0.05$) leaf K content 11% compared to the residual low rate (67 kg K_2O ha^{-1}). A positive response to increased fertilization for the direct and residual surface band rates was also observed. The residual broadcast medium rate (134 kg K_2O ha^{-1}) increased ($P<0.10$) leaf K content 2.24 g kg^{-1} compared to the direct medium rate (67 kg K_2O ha^{-1}). Overall, no significant treatment differences between annual added K, biannual surface band rates, or biannual placement methods at the same rate were observed.

Table 4.8 Average K concentrations in corn ear-leaf tissue at the R1 (silking) growth stage by treatment for the 2011 sites

Trt #	Treatment	*NW of Dads*	*East Marks*
		------------------- g kg^{-1}	-------------------
1	CK	9.32	16.32
2	BC Rec (A)	11.50	16.78
3	BC 34 (A)	11.83	17.17
4	BC 67 (A)	13.16	18.59
5	BC 67 (BA)	10.75	18.52
6	BC 134 (BA)	13.61	20.83
7	BC 202 (BA)	14.91	20.89
8	SB 67 (BA)	11.65	18.13
9	SB 134 (BA)	12.64	19.36
10	SB 202 (BA)	13.70	21.20
Treatment Pr > F		0.0002	0.0004
Contrast			
CK (1) vs. Dir. K (3-4)		(3.17)*	(1.56)
CK (1) vs. Res. K (5,6,8,9)		(2.84)*	(2.89)*
BC 34 (3) vs. BC 67 (4)		(1.33)	(1.42)
BC 67 (5) vs. BC 134 (6)		(2.87)*	(2.31)*
SB 67 (8) vs. SB 134 (9)		(0.99)	(1.23)
BC 67 (5) vs. SB 67 (8)		(0.90)	0.40
BC 134 (6) vs. SB 134 (9)		0.98	1.47
BC 34 (3) vs. BC 67 (5)		1.09	(1.35)
BC 34 (3) vs. SB 67 (8)		0.19	(0.96)
BC 67 (4) vs. BC 134 (6)		(0.45)	(2.24)**
BC 67 (4) vs. SB 134 (9)		0.53	(0.77)

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Grain Nutrient Analysis

The effects of K fertility on corn grain K content at the 2010 and 2011 sites are displayed in Tables 4.9 and 4.10. During the two year study only one of the six sites revealed positive responses to K fertilization in regard to grain K content.

In 2010 the grain samples ranged from 3.84 – 3.98 g kg^{-1} in K concentration. The grain samples did not indicate any effect to the addition of annual K, biannual K rate, frequency of K application or biannual placement method at the same rate, therefore no comparisons were conducted.

In 2011 the grain samples ranged from 3.56 – 4.09 g kg^{-1} in K concentration. The residual surface band low rate (67 kg K_2O ha^{-1}) increased ($P<0.05$) grain K by 0.27 g kg^{-1} compared to the residual surface band medium rate (134 kg K_2O ha^{-1}), which was no expected. The residual broadcast medium rate (134 kg K_2O ha^{-1}) increased grain K content by 0.29 g kg^{-1} compared to the same biannual rate surface band applied. There were no observed differences as a result of added annual K, biannual broadcast K rate or frequency of K application.

Table 4.9 Average K concentrations in corn grain by treatment for the 2010 sites

		SW Jennings	*SE Brown*	*SW Brown*	*Delmont*
Trt #	Treatment	------------------------------- g kg^{-1} -------------------------------			
1	CK	3.63	3.85	3.29	3.79
2	BC Rec (A)	3.58	3.66	3.22	3.74
3	BC 34 (A)	3.63	3.60	3.37	3.82
4	BC 67 (A)	3.57	3.82	3.30	3.90
5	BC 67 (BA)	3.66	3.73	3.19	3.80
6	BC 134 (BA)	3.72	3.58	3.33	3.80
7	BC 202 (BA)	3.69	3.72	3.33	3.92
8	SB 67 (BA)	3.84	3.74	3.34	3.71
9	SB 134 (BA)	3.60	3.78	3.33	3.85
10	SB 202 (BA)	3.70	3.81	3.22	3.98
Treatment Pr > F		0.5870	0.6269	0.8812	0.5814

Table 4.10 Average K concentrations in corn grain by treatment for the 2011 sites

Trt #	Treatment	*NW of Dads*	*East Marks*
		------------------- g kg^{-1}	-------------------
1	CK	3.91	3.72
2	BC Rec (A)	3.56	3.79
3	BC 34 (A)	3.85	3.78
4	BC 67 (A)	3.93	3.78
5	BC 67 (BA)	3.95	3.84
6	BC 134 (BA)	4.09	3.73
7	BC 202 (BA)	3.80	3.85
8	SB 67 (BA)	4.07	3.73
9	SB 134 (BA)	3.80	3.69
10	SB 202 (BA)	3.83	3.77
Treatment Pr > F		0.0203	0.9341
Contrast			
CK (1) vs. Dir. K (3-4)		0.02	---
CK (1) vs. Res. K (5,6,8,9)		(0.07)	---
BC 34 (3) vs. BC 67 (4)		(0.08)	---
BC 67 (5) vs. BC 134 (6)		(0.14)	---
SB 67 (8) vs. SB 134 (9)		0.27*	---
BC 67 (5) vs. SB 67 (8)		(0.13)	---
BC 134 (6) vs. SB 134 (9)		0.29*	---
BC 34 (3) vs. BC 67 (5)		(0.10)	---
BC 34 (3) vs. SB 67 (8)		(0.22)	---
BC 67 (4) vs. BC 134 (6)		(0.16)	---
BC 67 (4) vs. SB 134 (9)		0.13	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Corn Yield

The effects of the K fertilization treatments on corn yield for the 2010 and 2011 sites are presented in Tables 4.11 and 4.12. During the two year study none of the sites revealed responses to K fertilization in regard to corn yield.

The yields in 2010 ranged from 8450 – 10560 kg ha^{-1}. Overall, the corn yields were good with all four locations producing yields much higher than the southeast Kansas regional average yield of 6710 kg ha^{-1} (USDA, 2011). In 2011 the corn yields were much lower, ranging from 1090 – 2540 kg ha^{-1}. The yields were comparable to the southeast Kansas regional yield of 1940 kg ha^{-1} (USDA, 2011). The enduring heat and drought stress the corn suffered through during reproductive stages considerably reduced yields in 2011. Both years offered drastically different environmental conditions that would likely affect the response to K fertilization. However, no effect in either year to the addition of annual K, biannual K rate, frequency of K application, or biannual placement method at the same rate were observed, therefore no comparisons were conducted.

Table 4.11 Average corn yield by treatment for the 2010 sites

		SW Jennings	*SE Brown*	*SW Brown*	*Delmont*
Trt #	Treatment	------------------------------	kg ha^{-1}		------------------------------
1	CK	9520	9050	10430	9310
2	BC Rec (A)	9850	9860	10560	9000
3	BC 34 (A)	9770	9610	9540	10390
4	BC 67 (A)	9790	8450	10300	9290
5	BC 67 (BA)	9760	9000	10280	8920
6	BC 134 (BA)	9910	9480	9980	9090
7	BC 202 (BA)	9440	9500	10080	9400
8	SB 67 (BA)	9610	9030	9740	9080
9	SB 134 (BA)	9460	9390	10290	9130
10	SB 202 (BA)	9480	8930	10280	9090
	Treatment Pr > F	0.9966	0.1497	0.2682	0.4581

Table 4.12 Average corn yield by treatment for the 2011 sites

		NW of Dads	*East Marks*
Trt #	Treatment	------------------- kg ha^{-1}	-------------------
1	CK	1150	2080
2	BC Rec (A)	1090	2350
3	BC 34 (A)	1290	1850
4	BC 67 (A)	1490	2090
5	BC 67 (BA)	1280	2540
6	BC 134 (BA)	1470	1940
7	BC 202 (BA)	1480	2130
8	SB 67 (BA)	1230	2280
9	SB 134 (BA)	1120	2050
10	SB 202 (BA)	1500	2130
	Treatment Pr > F	0.7308	0.9370

Combined Study Year Analysis

Tables 4.13 and 4.14 summarize the combined K fertility effect on ear-leaf K content at the R1 (silking) growth stage, grain K concentration and corn yield across the 2010 and 2011 sites. Mills and Jones (1996) reported that the corn plant sufficiency range for K was 17.0 to 30.0 g kg^{-1}. In 2010 the silking ear-leaf K contents were within this range, however, in 2011 a majority of the ear-leaf K contents were below 17 g kg^{-1}. The residual broadcast application of 134 kg K_2O ha^{-1} and both the residual placement applications of 202 kg K_2O ha^{-1} were the only treatments to have K contents within the sufficiency range. In 2010 three of the four sites soil tested in the optimum range (130 – 170 mg kg^{-1}) and one soil tested in the low range (90 – 130 mg kg^{-1}) along with the two 2011 sites. Overall, the silking ear-leaf K data correlated well with soil test K. The higher silking leaf K levels were observed on the optimum soil test K sites and the lowest values were observed on the low soil test K sites. The hot and dry weather in 2011 could have also contributed to the lower leaf K concentrations due to the reduced soil movement of K via diffusion. An increase in ear-leaf K with K fertilization was evident in both years regardless of soil test K levels.

In 2010 the residual broadcast application of 202 kg K_2O ha^{-1} produced the largest silking ear-leaf K content. Direct (annual) K fertilization increased ($P<0.05$) leaf K content 6% over the unfertilized control. The direct application of 67 kg K_2O ha^{-1} increased ($P<0.10$) leaf K 6% over the residual (biannual) surface band application of 134 kg K_2O ha^{-1}. Furthermore, in 2010 the ear-leaf K concentrations displayed a nice response to increased K rates, however, no significant effects were found between K rates or residual placement method at the same rate.

In 2011 the residual broadcast application of 202 kg K_2O ha^{-1} produced the largest silking ear-leaf K content of 17.90 g kg^{-1}. The direct and residual fertilization rates increased leaf K content 16 and 18%, respectively, compared to the unfertilized control. There was a large response ($P<0.10$) to added direct K fertilizer from the low (34 kg K_2O ha^{-1}) to the high rate (67 kg K_2O ha^{-1}). Also a significant increase in leaf K content was found between the broadcast residual rates, the medium rate (134 kg K_2O ha^{-1}) increased leaf K 15% compared to the low rate (67 kg K_2O ha^{-1}). The residual medium rate (134 kg K_2O ha^{-1}) produced a higher ($P<0.10$) leaf K content when broadcast applied compared to surface banded. Additionally, the residual application of 134 kg K_2O ha^{-1} also increased ($P<0.10$) leaf K content 8% compared to the direct application of 67 kg K_2O ha^{-1}.

The grain K concentrations were not affected by the addition of K, residual K (rate and placement) or frequency of K application in 2010 and 2011.

In 2010 the corn yields were excellent with yields at or above 9370 kg ha^{-1}. The good yields are attributed to optimum soil test K levels and favorable weather conditions experienced during the year. In 2011 the corn yields were poor with yields at or above 1579 kg ha^{-1}. The low yields can be accredited to the lack of precipitation and extensive exposure to higher than normal temperatures. Low soil test K levels could of also contributed to the low yields and likely enhanced the effects of drought stress. There were no significant differences in corn yield found due to added K fertilizer, residual K (rate and placement) or frequency of K application in 2010 and 2011.

The yield results do not agree with deMooy et al. (1973), who observed a significant yield increase with direct fertilization over residual fertilization on low to optimum soil test K soils. However, the results do agree with Mozaffari and Slaton (2011) who observed no direct K fertilization yield response at one low soil test K site. The site had relatively low yields suggesting that other factors besides K availability were more yield-limiting.

Table 4.13 Average corn R1 (silking) ear-leaf K, grain K and yield by treatment across all 2010 study sites

		R1 Leaf K	*Grain K*	*Yield*
Trt #	Treatment	g kg^{-1}	g kg^{-1}	kg ha^{-1}
1	CK	19.72	3.64	9580
2	BC Rec (A)	19.31	3.55	9820
3	BC 34 (A)	20.51	3.61	9830
4	BC 67 (A)	21.40	3.65	9460
5	BC 67 (BA)	20.21	3.59	9490
6	BC 134 (BA)	20.33	3.61	9620
7	BC 202 (BA)	21.83	3.66	9610
8	SB 67 (BA)	19.96	3.66	9370
9	SB 134 (BA)	20.12	3.64	9570
10	SB 202 (BA)	21.18	3.68	9450
Treatment Pr > F		0.0054	0.7041	0.7686
Contrast				
CK (1) vs. Dir. K (3-4)		(1.23)*	---	---
CK (1) vs. Res. K (5,6,8,9)		(0.43)	---	---
BC 34 (3) vs. BC 67 (4)		(0.89)	---	---
BC 67 (5) vs. BC 134 (6)		(0.12)	---	---
SB 67 (8) vs. SB 134 (9)		(0.16)	---	---
BC 67 (5) vs. SB 67 (8)		0.25	---	---
BC 134 (6) vs. SB 134 (9)		0.21	---	---
BC 34 (3) vs. BC 67 (5)		0.30	---	---
BC 34 (3) vs. SB 67 (8)		0.55	---	---
BC 67 (4) vs. BC 134 (6)		1.07	---	---
BC 67 (4) vs. SB 134 (9)		1.28**	---	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Table 4.14 Average corn R1 (silking) ear-leaf K, grain K and yield by treatment across all 2011 study sites

		R1 Leaf K	*Grain K*	*Yield*
Trt #	Treatment	g kg^{-1}	g kg^{-1}	kg ha^{-1}
1	CK	12.82	3.81	1610
2	BC Rec (A)	14.14	3.67	1720
3	BC 34 (A)	14.50	3.82	1570
4	BC 67 (A)	15.89	3.86	1790
5	BC 67 (BA)	14.63	3.89	1910
6	BC 134 (BA)	17.22	3.91	1700
7	BC 202 (BA)	17.90	3.82	1800
8	SB 67 (BA)	14.89	3.90	1750
9	SB 134 (BA)	16.00	3.74	1580
10	SB 202 (BA)	17.45	3.80	1810
Treatment Pr > F		<0.0001	0.3053	0.9530
Contrast				
CK (1) vs. Dir. K (3-4)		(2.37)*	---	---
CK (1) vs. Res. K (5,6,8,9)		(2.86)*	---	---
BC 34 (3) vs. BC 67 (4)		(1.38)**	---	---
BC 67 (5) vs. BC 134 (6)		(2.59)*	---	---
SB 67 (8) vs. SB 134 (9)		(1.11)	---	---
BC 67 (5) vs. SB 67 (8)		(0.25)	---	---
BC 134 (6) vs. SB 134 (9)		1.22**	---	---
BC 34 (3) vs. BC 67 (5)		(0.13)	---	---
BC 34 (3) vs. SB 67 (8)		(0.39)	---	---
BC 67 (4) vs. BC 134 (6)		(1.35)**	---	---
BC 67 (4) vs. SB 134 (9)		(0.12)	---	---

--- No contrast performed, ANOVA Pr > F non-significant

* Indicates significance < 0.05, ** Indicates significance < 0.10

Conclusions

The results of this two year study indicated that direct and residual K fertilization had little to no influence on corn yield and grain K concentration on soils that tested in the low to optimum range (90 – 170 mg kg^{-1}) in soil test exchangeable K. However, at a majority of the sites direct and residual K fertilization both increased ear-leaf K concentrations. The sites that soil tested low (90 – 130 mg kg^{-1}) in exchangeable K seemed to be the most responsive to K fertilization. Overall, when comparing two direct applications versus one residual application in a two year period, neither provided prominently higher leaf K contents. As a result, both split annual and biannual equivalent rates work equally as well on these soils. Furthermore, no residual placement method seemed to provide a distinct response advantage in the measured corn parameters. The similar corn responses to surface band placement compared to broadcast placement method suggest that producers should not be concerned about which placement method they select for the preceding crop in the rotation. In this study, the KSU sufficiency soil test-based recommendation was able to predict the need of K fertilization in regard to corn yield. However, additional research is needed to further evaluate the correlation between K fertilization and corn response parameters.

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Chapter 5 - Research Summary

Notable Conclusions

The increase in reports of yearly soil test potassium (K) variability and increase in K deficient crops in southeast Kansas over the last decade has raised many questions and concerns on how to manage soil K in order to optimize crop production. The main objective of these studies was to provide local research data to help producers manage these issues.

Evaluation of soil test K over a 3-year period on the highly weathered clay-pan soils of southeast Kansas indicated that K variability exists throughout the growing season. The extent of K variability can be quite extreme and is to a degree dependent on weather related conditions. Months with higher precipitation often had a higher exchangeable K level and drier months had a lower exchangeable K level. However, the relationship was very inconsistent making it difficult to confirm any correlation. During several of the growing seasons exchangeable K decreased from crop establishment to harvest, a large portion of the decrease likely due to crop K uptake over time. Additionally, from fall to spring soil test K levels generally increased, which could be explained by the return of K from decaying crop residue to the soil. Additional soil related mechanisms are apparent in generating some of the K variability observed.

Soybean (*Glycine max* L.) responses over the 3-year period suggested that the effects of K fertilization on soybean yield and grain K content were significant only at very low (< 90 mg kg^{-1}) soil test K levels based on spring soil sampling. Even when soybean yields or grain K were affected by K fertilizer treatments, the effects were generally small. Soybean yields and grain K concentrations were not negatively or positively affected when K fertilizers were surface band applied versus surface broadcast. Leaf K concentrations were more often affected by K fertility treatments than any other measured soybean parameter. Regardless of initial soil test K, K fertilization increased leaf K content at most sites. At several low to optimum (90 – 170 mg kg^{-1}) soil test K sites, soybean leaf K indicated a positive response to broadcast applications that were equal to or better than surface band applications. However, there was evidence that surface banded fertilizer presented a distinct advantage over broadcasting on very low (< 90 mg kg^{-1}) soil test K sites, especially when high K rates were applied.

In an associated 2-year field experiment, corn (*Zea mays* L.) yield and grain K responses to direct and residual K fertilization were not significant at low to optimum (90 – 170 mg kg^{-1}) soil-test K levels based on spring soil sampling. Potassium fertilization regularly increased ear-leaf K and the corn plants on the soils that tested in the low (90 – 130 mg kg^{-1}) range in soil test K seemed to be more responsive. Furthermore, corn responses to the residual effects of surface band versus broadcast K fertilizer to prior soybeans were small and not found to be significantly different.

Implications

Results of this research will assist farmers in several ways. First, variability in soil test potassium (K) is a definite concern for southeast Kansas farmers. The variability can be experienced on a monthly and yearly basis. However, the data collected in these studies verified that when soil test K levels were above 90 mg kg^{-1} in the spring, no adverse effects to corn and soybean yields were observed. Though we did not observe a yield response above this level, our leaf K data, as well as the unpredictable nature of soil test K, would suggest that building and maintaining K levels above the current optimum level (130 mg kg^{-1}) is highly recommended. The use of a build and maintain philosophy will minimize the likelihood that K will limit crop yield. At very low soil test K sites the use of surface band K applications improved fertilizer use efficiency and resulted in higher soybean leaf K concentrations compared to broadcast applications. The use of a single application of fertilizer at high enough rates to meet the needs of both crops every two years appeared to be an acceptable practice and works equally as well as two split direct applications at equivalent rates. The small corn response to surface banded K compared to broadcast placement suggests that growers should not be concerned about which placement method (surface band vs. broadcast) they select for the preceding crop in the rotation in soils similar to those of this study. Additionally, the use of proper soil test sampling procedures in conjunction with the use of a spring soil sampling date following the same crop in the rotation could help minimize the magnitude of K variability and provide the best depiction of soil K availability to crops.

Future Research

Future research should be focused on further evaluating and determining soil related mechanisms that are driving potassium (K) variability in southeast Kansas. An intense investigation into the clay mineralogy and K fixation potential of the soils as well as an in-depth examination of the soil K buffering capacities and/or K leaching potential of the soils is needed to better manage soil K. Additional research is also needed to validate corn and soybean responses to K fertilization. Continued work at analyzing crop responses to direct and residual K rates and placement will only enhance K management strategies and reduce potential crop K deficiencies. Work in these areas is needed to improve the accuracy of the KSU sufficiency soil test based K fertilizer recommendation for both corn and soybeans.

Appendix A - Changes in Potassium Soil Test Levels over Time – Raw Data

Table A.1 Ammonium acetate exchangeable K levels, SW Jennings (2009-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2009	July	Control	1	0	132
2009	July	Control	2	0	122
2009	July	Control	3	0	129
2009	July	Control	4	0	175
2009	August	Control	1	0	136
2009	August	Control	2	0	129
2009	August	Control	3	0	121
2009	August	Control	4	0	159
2009	October	Control	1	0	119
2009	October	Control	2	0	100
2009	October	Control	3	0	76
2009	October	Control	4	0	120
2010	March	Control	1	0	171
2010	March	Control	2	0	119
2010	March	Control	3	0	114
2010	March	Control	4	0	130
2010	April	Control	1	0	95
2010	April	Control	2	0	107
2010	April	Control	3	0	88
2010	April	Control	4	0	127
2010	May	Control	1	0	126
2010	May	Control	2	0	123
2010	May	Control	3	0	114
2010	May	Control	4	0	127
2010	June	Control	1	0	104
2010	June	Control	2	0	79
2010	June	Control	3	0	80
2010	June	Control	4	0	90
2010	July	Control	1	0	87
2010	July	Control	2	0	76
2010	July	Control	3	0	103
2010	July	Control	4	0	101

Table A.1 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	August	Control	1	0	104
2010	August	Control	2	0	77
2010	August	Control	3	0	79
2010	August	Control	4	0	98
2010	September	Control	1	0	108
2010	September	Control	2	0	73
2010	September	Control	3	0	82
2010	September	Control	4	0	91
2010	October	Control	1	0	133
2010	October	Control	2	0	125
2010	October	Control	3	0	137
2010	October	Control	4	0	160
2010	December	Control	1	0	117
2010	December	Control	2	0	108
2010	December	Control	3	0	113
2010	December	Control	4	0	122
2011	April	Control	1	0	75
2011	April	Control	2	0	68
2011	April	Control	3	0	61
2011	April	Control	4	0	93
2011	May	Control	1	0	74
2011	May	Control	2	0	74
2011	May	Control	3	0	82
2011	May	Control	4	0	105
2011	June	Control	1	0	77
2011	June	Control	2	0	77
2011	June	Control	3	0	69
2011	June	Control	4	0	94
2011	July	Control	1	0	107
2011	July	Control	2	0	91
2011	July	Control	3	0	92
2011	July	Control	4	0	119
2011	August	Control	1	0	95

Table A.1 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	August	Control	2	0	100
2011	August	Control	3	0	98
2011	August	Control	4	0	110
2011	September	Control	1	0	125
2011	September	Control	2	0	111
2011	September	Control	3	0	107
2011	September	Control	4	0	108
2011	October	Control	1	0	113
2011	October	Control	2	0	113
2011	October	Control	3	0	105
2011	October	Control	4	0	133
2009	July	High K Rate	1	202	268
2009	July	High K Rate	2	202	244
2009	July	High K Rate	3	202	204
2009	July	High K Rate	4	202	188
2009	August	High K Rate	1	202	237
2009	August	High K Rate	2	202	224
2009	August	High K Rate	3	202	187
2009	August	High K Rate	4	202	359
2009	October	High K Rate	1	202	107
2009	October	High K Rate	2	202	83
2009	October	High K Rate	3	202	116
2009	October	High K Rate	4	202	159
2010	March	High K Rate	1	202	150
2010	March	High K Rate	2	202	169
2010	March	High K Rate	3	202	143
2010	March	High K Rate	4	202	156
2010	April	High K Rate	1	202	159
2010	April	High K Rate	2	202	167
2010	April	High K Rate	3	202	149
2010	April	High K Rate	4	202	189
2010	May	High K Rate	1	202	155

Table A.1 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	May	High K Rate	2	202	164
2010	May	High K Rate	3	202	163
2010	May	High K Rate	4	202	186
2010	June	High K Rate	1	202	145
2010	June	High K Rate	2	202	115
2010	June	High K Rate	3	202	114
2010	June	High K Rate	4	202	141
2010	July	High K Rate	1	202	122
2010	July	High K Rate	2	202	121
2010	July	High K Rate	3	202	92
2010	July	High K Rate	4	202	118
2010	August	High K Rate	1	202	126
2010	August	High K Rate	2	202	121
2010	August	High K Rate	3	202	94
2010	August	High K Rate	4	202	100
2010	September	High K Rate	1	202	144
2010	September	High K Rate	2	202	137
2010	September	High K Rate	3	202	104
2010	September	High K Rate	4	202	115
2010	October	High K Rate	1	202	151
2010	October	High K Rate	2	202	152
2010	October	High K Rate	3	202	150
2010	October	High K Rate	4	202	160
2010	December	High K Rate	1	202	171
2010	December	High K Rate	2	202	139
2010	December	High K Rate	3	202	126
2010	December	High K Rate	4	202	147
2011	April	High K Rate	1	202	111
2011	April	High K Rate	2	202	91
2011	April	High K Rate	3	202	95
2011	April	High K Rate	4	202	143
2011	May	High K Rate	1	202	132
2011	May	High K Rate	2	202	95

Table A.1 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	May	High K Rate	3	202	99
2011	May	High K Rate	4	202	113
2011	June	High K Rate	1	202	107
2011	June	High K Rate	2	202	102
2011	June	High K Rate	3	202	113
2011	June	High K Rate	4	202	120
2011	July	High K Rate	1	202	138
2011	July	High K Rate	2	202	133
2011	July	High K Rate	3	202	125
2011	July	High K Rate	4	202	167
2011	August	High K Rate	1	202	113
2011	August	High K Rate	2	202	117
2011	August	High K Rate	3	202	104
2011	August	High K Rate	4	202	152
2011	September	High K Rate	1	202	172
2011	September	High K Rate	2	202	120
2011	September	High K Rate	3	202	130
2011	September	High K Rate	4	202	169
2011	October	High K Rate	1	202	137
2011	October	High K Rate	2	202	127
2011	October	High K Rate	3	202	134
2011	October	High K Rate	4	202	171

Table A.2 Ammonium acetate exchangeable K levels, SE Brown (2009-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2009	July	Control	1	0	157
2009	July	Control	2	0	152
2009	July	Control	3	0	156
2009	July	Control	4	0	154
2009	August	Control	1	0	163
2009	August	Control	2	0	142
2009	August	Control	3	0	161
2009	August	Control	4	0	183
2009	October	Control	1	0	129
2009	October	Control	2	0	87
2009	October	Control	3	0	99
2009	October	Control	4	0	121
2010	March	Control	1	0	163
2010	March	Control	2	0	144
2010	March	Control	3	0	157
2010	March	Control	4	0	155
2010	April	Control	1	0	138
2010	April	Control	2	0	124
2010	April	Control	3	0	159
2010	April	Control	4	0	137
2010	May	Control	1	0	161
2010	May	Control	2	0	146
2010	May	Control	3	0	151
2010	May	Control	4	0	152
2010	June	Control	1	0	112
2010	June	Control	2	0	122
2010	June	Control	3	0	118
2010	June	Control	4	0	112
2010	July	Control	1	0	114
2010	July	Control	2	0	95
2010	July	Control	3	0	109
2010	July	Control	4	0	115

Table A.2 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	August	Control	1	0	100
2010	August	Control	2	0	87
2010	August	Control	3	0	108
2010	August	Control	4	0	111
2010	September	Control	1	0	99
2010	September	Control	2	0	113
2010	September	Control	3	0	132
2010	September	Control	4	0	114
2010	October	Control	1	0	123
2010	October	Control	2	0	106
2010	October	Control	3	0	129
2010	October	Control	4	0	104
2010	December	Control	1	0	132
2010	December	Control	2	0	131
2010	December	Control	3	0	140
2010	December	Control	4	0	142
2011	April	Control	1	0	100
2011	April	Control	2	0	85
2011	April	Control	3	0	96
2011	April	Control	4	0	86
2011	May	Control	1	0	97
2011	May	Control	2	0	93
2011	May	Control	3	0	97
2011	May	Control	4	0	87
2011	June	Control	1	0	118
2011	June	Control	2	0	104
2011	June	Control	3	0	109
2011	June	Control	4	0	106
2011	July	Control	1	0	132
2011	July	Control	2	0	124
2011	July	Control	3	0	127
2011	July	Control	4	0	118
2011	August	Control	1	0	129

Table A.2 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	August	Control	2	0	101
2011	August	Control	3	0	125
2011	August	Control	4	0	110
2011	September	Control	1	0	142
2011	September	Control	2	0	117
2011	September	Control	3	0	144
2011	September	Control	4	0	152
2011	October	Control	1	0	150
2011	October	Control	2	0	117
2011	October	Control	3	0	152
2011	October	Control	4	0	142
2009	July	High K Rate	1	202	340
2009	July	High K Rate	2	202	169
2009	July	High K Rate	3	202	227
2009	July	High K Rate	4	202	253
2009	August	High K Rate	1	202	295
2009	August	High K Rate	2	202	212
2009	August	High K Rate	3	202	237
2009	August	High K Rate	4	202	338
2009	October	High K Rate	1	202	113
2009	October	High K Rate	2	202	132
2009	October	High K Rate	3	202	113
2009	October	High K Rate	4	202	126
2010	March	High K Rate	1	202	182
2010	March	High K Rate	2	202	181
2010	March	High K Rate	3	202	175
2010	March	High K Rate	4	202	170
2010	April	High K Rate	1	202	203
2010	April	High K Rate	2	202	170
2010	April	High K Rate	3	202	175
2010	April	High K Rate	4	202	148
2010	May	High K Rate	1	202	227
2010	May	High K Rate	2	202	188

Table A.2 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	May	High K Rate	3	202	195
2010	May	High K Rate	4	202	169
2010	June	High K Rate	1	202	155
2010	June	High K Rate	2	202	132
2010	June	High K Rate	3	202	156
2010	June	High K Rate	4	202	166
2010	July	High K Rate	1	202	147
2010	July	High K Rate	2	202	132
2010	July	High K Rate	3	202	137
2010	July	High K Rate	4	202	130
2010	August	High K Rate	1	202	129
2010	August	High K Rate	2	202	138
2010	August	High K Rate	3	202	150
2010	August	High K Rate	4	202	125
2010	September	High K Rate	1	202	123
2010	September	High K Rate	2	202	132
2010	September	High K Rate	3	202	153
2010	September	High K Rate	4	202	122
2010	October	High K Rate	1	202	166
2010	October	High K Rate	2	202	141
2010	October	High K Rate	3	202	158
2010	October	High K Rate	4	202	136
2010	December	High K Rate	1	202	157
2010	December	High K Rate	2	202	144
2010	December	High K Rate	3	202	140
2010	December	High K Rate	4	202	147
2011	April	High K Rate	1	202	110
2011	April	High K Rate	2	202	97
2011	April	High K Rate	3	202	94
2011	April	High K Rate	4	202	103
2011	May	High K Rate	1	202	105
2011	May	High K Rate	2	202	100
2011	May	High K Rate	3	202	103

Table A.2 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	May	High K Rate	4	202	107
2011	June	High K Rate	1	202	120
2011	June	High K Rate	2	202	114
2011	June	High K Rate	3	202	111
2011	June	High K Rate	4	202	115
2011	July	High K Rate	1	202	135
2011	July	High K Rate	2	202	142
2011	July	High K Rate	3	202	143
2011	July	High K Rate	4	202	131
2011	August	High K Rate	1	202	136
2011	August	High K Rate	2	202	135
2011	August	High K Rate	3	202	138
2011	August	High K Rate	4	202	140
2011	September	High K Rate	1	202	157
2011	September	High K Rate	2	202	158
2011	September	High K Rate	3	202	133
2011	September	High K Rate	4	202	152
2011	October	High K Rate	1	202	151
2011	October	High K Rate	2	202	153
2011	October	High K Rate	3	202	146
2011	October	High K Rate	4	202	145

Table A.3 Ammonium acetate exchangeable K levels, SW Brown (2009-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2009	July	Control	1	0	132
2009	July	Control	2	0	135
2009	July	Control	3	0	159
2009	July	Control	4	0	194
2009	August	Control	1	0	160
2009	August	Control	2	0	150
2009	August	Control	3	0	182
2009	August	Control	4	0	166
2009	October	Control	1	0	111
2009	October	Control	2	0	100
2009	October	Control	3	0	126
2009	October	Control	4	0	110
2010	March	Control	1	0	155
2010	March	Control	2	0	141
2010	March	Control	3	0	133
2010	March	Control	4	0	143
2010	April	Control	1	0	122
2010	April	Control	2	0	109
2010	April	Control	3	0	126
2010	April	Control	4	0	115
2010	May	Control	1	0	132
2010	May	Control	2	0	124
2010	May	Control	3	0	149
2010	May	Control	4	0	131
2010	June	Control	1	0	114
2010	June	Control	2	0	93
2010	June	Control	3	0	123
2010	June	Control	4	0	110
2010	July	Control	1	0	87
2010	July	Control	2	0	77
2010	July	Control	3	0	103
2010	July	Control	4	0	115

Table A.3 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	August	Control	1	0	88
2010	August	Control	2	0	72
2010	August	Control	3	0	91
2010	August	Control	4	0	102
2010	September	Control	1	0	113
2010	September	Control	2	0	74
2010	September	Control	3	0	100
2010	September	Control	4	0	102
2010	October	Control	1	0	96
2010	October	Control	2	0	94
2010	October	Control	3	0	101
2010	October	Control	4	0	114
2010	December	Control	1	0	107
2010	December	Control	2	0	117
2010	December	Control	3	0	125
2010	December	Control	4	0	123
2011	April	Control	1	0	86
2011	April	Control	2	0	75
2011	April	Control	3	0	81
2011	April	Control	4	0	104
2011	May	Control	1	0	75
2011	May	Control	2	0	79
2011	May	Control	3	0	81
2011	May	Control	4	0	90
2011	June	Control	1	0	81
2011	June	Control	2	0	94
2011	June	Control	3	0	113
2011	June	Control	4	0	113
2011	July	Control	1	0	76
2011	July	Control	2	0	82
2011	July	Control	3	0	102
2011	July	Control	4	0	107
2011	August	Control	1	0	98

Table A.3 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	August	Control	2	0	90
2011	August	Control	3	0	113
2011	August	Control	4	0	121
2011	September	Control	1	0	108
2011	September	Control	2	0	105
2011	September	Control	3	0	106
2011	September	Control	4	0	101
2011	October	Control	1	0	120
2011	October	Control	2	0	99
2011	October	Control	3	0	135
2011	October	Control	4	0	136
2009	July	High K Rate	1	202	245
2009	July	High K Rate	2	202	303
2009	July	High K Rate	3	202	268
2009	July	High K Rate	4	202	311
2009	August	High K Rate	1	202	287
2009	August	High K Rate	2	202	217
2009	August	High K Rate	3	202	251
2009	August	High K Rate	4	202	284
2009	October	High K Rate	1	202	115
2009	October	High K Rate	2	202	188
2009	October	High K Rate	3	202	94
2009	October	High K Rate	4	202	159
2010	March	High K Rate	1	202	170
2010	March	High K Rate	2	202	181
2010	March	High K Rate	3	202	190
2010	March	High K Rate	4	202	156
2010	April	High K Rate	1	202	165
2010	April	High K Rate	2	202	174
2010	April	High K Rate	3	202	176
2010	April	High K Rate	4	202	153
2010	May	High K Rate	1	202	218
2010	May	High K Rate	2	202	239

Table A.3 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	May	High K Rate	3	202	236
2010	May	High K Rate	4	202	189
2010	June	High K Rate	1	202	181
2010	June	High K Rate	2	202	147
2010	June	High K Rate	3	202	138
2010	June	High K Rate	4	202	116
2010	July	High K Rate	1	202	167
2010	July	High K Rate	2	202	146
2010	July	High K Rate	3	202	152
2010	July	High K Rate	4	202	131
2010	August	High K Rate	1	202	144
2010	August	High K Rate	2	202	128
2010	August	High K Rate	3	202	155
2010	August	High K Rate	4	202	135
2010	September	High K Rate	1	202	147
2010	September	High K Rate	2	202	134
2010	September	High K Rate	3	202	161
2010	September	High K Rate	4	202	113
2010	October	High K Rate	1	202	153
2010	October	High K Rate	2	202	153
2010	October	High K Rate	3	202	152
2010	October	High K Rate	4	202	142
2010	December	High K Rate	1	202	146
2010	December	High K Rate	2	202	165
2010	December	High K Rate	3	202	165
2010	December	High K Rate	4	202	145
2011	April	High K Rate	1	202	122
2011	April	High K Rate	2	202	112
2011	April	High K Rate	3	202	142
2011	April	High K Rate	4	202	100
2011	May	High K Rate	1	202	118
2011	May	High K Rate	2	202	119
2011	May	High K Rate	3	202	130

Table A.3 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	May	High K Rate	4	202	100
2011	June	High K Rate	1	202	124
2011	June	High K Rate	2	202	123
2011	June	High K Rate	3	202	140
2011	June	High K Rate	4	202	117
2011	July	High K Rate	1	202	129
2011	July	High K Rate	2	202	123
2011	July	High K Rate	3	202	136
2011	July	High K Rate	4	202	147
2011	August	High K Rate	1	202	140
2011	August	High K Rate	2	202	148
2011	August	High K Rate	3	202	168
2011	August	High K Rate	4	202	146
2011	September	High K Rate	1	202	145
2011	September	High K Rate	2	202	146
2011	September	High K Rate	3	202	165
2011	September	High K Rate	4	202	151
2011	October	High K Rate	1	202	141
2011	October	High K Rate	2	202	155
2011	October	High K Rate	3	202	168
2011	October	High K Rate	4	202	143

Table A.4 Ammonium acetate exchangeable K levels, Delmont (2009-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2009	July	Control	1	0	161
2009	July	Control	2	0	156
2009	July	Control	3	0	143
2009	July	Control	4	0	169
2009	August	Control	1	0	171
2009	August	Control	2	0	141
2009	August	Control	3	0	146
2009	August	Control	4	0	116
2009	October	Control	1	0	91
2009	October	Control	2	0	106
2009	October	Control	3	0	94
2009	October	Control	4	0	94
2010	March	Control	1	0	133
2010	March	Control	2	0	106
2010	March	Control	3	0	125
2010	March	Control	4	0	120
2010	April	Control	1	0	84
2010	April	Control	2	0	106
2010	April	Control	3	0	101
2010	April	Control	4	0	94
2010	May	Control	1	0	117
2010	May	Control	2	0	109
2010	May	Control	3	0	121
2010	May	Control	4	0	109
2010	June	Control	1	0	74
2010	June	Control	2	0	79
2010	June	Control	3	0	83
2010	June	Control	4	0	81
2010	July	Control	1	0	82
2010	July	Control	2	0	85
2010	July	Control	3	0	83
2010	July	Control	4	0	81

Table A.4 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	August	Control	1	0	87
2010	August	Control	2	0	80
2010	August	Control	3	0	82
2010	August	Control	4	0	84
2010	September	Control	1	0	142
2010	September	Control	2	0	95
2010	September	Control	3	0	99
2010	September	Control	4	0	90
2010	October	Control	1	0	91
2010	October	Control	2	0	83
2010	October	Control	3	0	98
2010	October	Control	4	0	87
2010	December	Control	1	0	107
2010	December	Control	2	0	120
2010	December	Control	3	0	109
2010	December	Control	4	0	96
2011	April	Control	1	0	73
2011	April	Control	2	0	95
2011	April	Control	3	0	91
2011	April	Control	4	0	75
2011	May	Control	1	0	64
2011	May	Control	2	0	75
2011	May	Control	3	0	71
2011	May	Control	4	0	70
2011	June	Control	1	0	79
2011	June	Control	2	0	96
2011	June	Control	3	0	81
2011	June	Control	4	0	75
2011	July	Control	1	0	89
2011	July	Control	2	0	98
2011	July	Control	3	0	99
2011	July	Control	4	0	98
2011	August	Control	1	0	91

Table A.4 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	August	Control	2	0	99
2011	August	Control	3	0	88
2011	August	Control	4	0	85
2011	September	Control	1	0	94
2011	September	Control	2	0	105
2011	September	Control	3	0	102
2011	September	Control	4	0	81
2011	October	Control	1	0	98
2011	October	Control	2	0	98
2011	October	Control	3	0	98
2011	October	Control	4	0	85
2009	July	High K Rate	1	202	224
2009	July	High K Rate	2	202	187
2009	July	High K Rate	3	202	260
2009	July	High K Rate	4	202	302
2009	August	High K Rate	1	202	221
2009	August	High K Rate	2	202	169
2009	August	High K Rate	3	202	219
2009	August	High K Rate	4	202	261
2009	October	High K Rate	1	202	128
2009	October	High K Rate	2	202	110
2009	October	High K Rate	3	202	119
2009	October	High K Rate	4	202	112
2010	March	High K Rate	1	202	167
2010	March	High K Rate	2	202	149
2010	March	High K Rate	3	202	151
2010	March	High K Rate	4	202	155
2010	April	High K Rate	1	202	161
2010	April	High K Rate	2	202	143
2010	April	High K Rate	3	202	145
2010	April	High K Rate	4	202	144
2010	May	High K Rate	1	202	194
2010	May	High K Rate	2	202	170

Table A.4 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	May	High K Rate	3	202	181
2010	May	High K Rate	4	202	191
2010	June	High K Rate	1	202	125
2010	June	High K Rate	2	202	108
2010	June	High K Rate	3	202	131
2010	June	High K Rate	4	202	114
2010	July	High K Rate	1	202	124
2010	July	High K Rate	2	202	116
2010	July	High K Rate	3	202	107
2010	July	High K Rate	4	202	137
2010	August	High K Rate	1	202	112
2010	August	High K Rate	2	202	98
2010	August	High K Rate	3	202	109
2010	August	High K Rate	4	202	132
2010	September	High K Rate	1	202	162
2010	September	High K Rate	2	202	92
2010	September	High K Rate	3	202	106
2010	September	High K Rate	4	202	139
2010	October	High K Rate	1	202	131
2010	October	High K Rate	2	202	112
2010	October	High K Rate	3	202	110
2010	October	High K Rate	4	202	132
2010	December	High K Rate	1	202	135
2010	December	High K Rate	2	202	140
2010	December	High K Rate	3	202	133
2010	December	High K Rate	4	202	136
2011	April	High K Rate	1	202	120
2011	April	High K Rate	2	202	105
2011	April	High K Rate	3	202	105
2011	April	High K Rate	4	202	123
2011	May	High K Rate	1	202	106
2011	May	High K Rate	2	202	90
2011	May	High K Rate	3	202	87

Table A.4 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	May	High K Rate	4	202	102
2011	June	High K Rate	1	202	120
2011	June	High K Rate	2	202	90
2011	June	High K Rate	3	202	82
2011	June	High K Rate	4	202	100
2011	July	High K Rate	1	202	133
2011	July	High K Rate	2	202	121
2011	July	High K Rate	3	202	119
2011	July	High K Rate	4	202	120
2011	August	High K Rate	1	202	123
2011	August	High K Rate	2	202	121
2011	August	High K Rate	3	202	108
2011	August	High K Rate	4	202	116
2011	September	High K Rate	1	202	124
2011	September	High K Rate	2	202	106
2011	September	High K Rate	3	202	127
2011	September	High K Rate	4	202	91
2011	October	High K Rate	1	202	133
2011	October	High K Rate	2	202	116
2011	October	High K Rate	3	202	122
2011	October	High K Rate	4	202	114

Table A.5 Ammonium acetate exchangeable K levels, NW of Dad (2010-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	July	Control	1	0	80
2010	July	Control	2	0	106
2010	July	Control	3	0	95
2010	July	Control	4	0	93
2010	August	Control	1	0	86
2010	August	Control	2	0	98
2010	August	Control	3	0	92
2010	August	Control	4	0	102
2010	September	Control	1	0	90
2010	September	Control	2	0	92
2010	September	Control	3	0	90
2010	September	Control	4	0	96
2010	October	Control	1	0	77
2010	October	Control	2	0	82
2010	October	Control	3	0	75
2010	October	Control	4	0	71
2010	December	Control	1	0	124
2010	December	Control	2	0	60
2010	December	Control	3	0	59
2010	December	Control	4	0	104
2011	April	Control	1	0	109
2011	April	Control	2	0	99
2011	April	Control	3	0	102
2011	April	Control	4	0	105
2011	May	Control	1	0	110
2011	May	Control	2	0	113
2011	May	Control	3	0	103
2011	May	Control	4	0	112
2011	June	Control	1	0	94
2011	June	Control	2	0	103
2011	June	Control	3	0	93
2011	June	Control	4	0	102

Table A.5 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	July	Control	1	0	84
2011	July	Control	2	0	88
2011	July	Control	3	0	84
2011	July	Control	4	0	91
2011	August	Control	1	0	77
2011	August	Control	2	0	97
2011	August	Control	3	0	88
2011	August	Control	4	0	85
2011	September	Control	1	0	78
2011	September	Control	2	0	87
2011	September	Control	3	0	90
2011	September	Control	4	0	90
2010	July	High K Rate	1	202	158
2010	July	High K Rate	2	202	170
2010	July	High K Rate	3	202	140
2010	July	High K Rate	4	202	144
2010	August	High K Rate	1	202	165
2010	August	High K Rate	2	202	193
2010	August	High K Rate	3	202	154
2010	August	High K Rate	4	202	146
2010	September	High K Rate	1	202	123
2010	September	High K Rate	2	202	137
2010	September	High K Rate	3	202	157
2010	September	High K Rate	4	202	151
2010	October	High K Rate	1	202	134
2010	October	High K Rate	2	202	164
2010	October	High K Rate	3	202	131
2010	October	High K Rate	4	202	144
2010	December	High K Rate	1	202	138
2010	December	High K Rate	2	202	150
2010	December	High K Rate	3	202	166
2010	December	High K Rate	4	202	157
2011	April	High K Rate	1	202	121

Table A.5 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	April	High K Rate	2	202	134
2011	April	High K Rate	3	202	138
2011	April	High K Rate	4	202	144
2011	May	High K Rate	1	202	139
2011	May	High K Rate	2	202	141
2011	May	High K Rate	3	202	145
2011	May	High K Rate	4	202	149
2011	June	High K Rate	1	202	142
2011	June	High K Rate	2	202	148
2011	June	High K Rate	3	202	147
2011	June	High K Rate	4	202	162
2011	July	High K Rate	1	202	122
2011	July	High K Rate	2	202	153
2011	July	High K Rate	3	202	123
2011	July	High K Rate	4	202	149
2011	August	High K Rate	1	202	105
2011	August	High K Rate	2	202	143
2011	August	High K Rate	3	202	105
2011	August	High K Rate	4	202	121
2011	September	High K Rate	1	202	121
2011	September	High K Rate	2	202	139
2011	September	High K Rate	3	202	127
2011	September	High K Rate	4	202	157

Table A.6 Ammonium acetate exchangeable K levels, East Mark (2010-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	July	Control	1	0	132
2010	July	Control	2	0	116
2010	July	Control	3	0	154
2010	July	Control	4	0	141
2010	August	Control	1	0	106
2010	August	Control	2	0	105
2010	August	Control	3	0	111
2010	August	Control	4	0	110
2010	September	Control	1	0	109
2010	September	Control	2	0	112
2010	September	Control	3	0	129
2010	September	Control	4	0	103
2010	October	Control	1	0	90
2010	October	Control	2	0	99
2010	October	Control	3	0	96
2010	October	Control	4	0	85
2010	December	Control	1	0	104
2010	December	Control	2	0	110
2010	December	Control	3	0	135
2010	December	Control	4	0	113
2011	April	Control	1	0	107
2011	April	Control	2	0	98
2011	April	Control	3	0	113
2011	April	Control	4	0	109
2011	May	Control	1	0	103
2011	May	Control	2	0	89
2011	May	Control	3	0	128
2011	May	Control	4	0	123
2011	June	Control	1	0	98
2011	June	Control	2	0	99
2011	June	Control	3	0	124
2011	June	Control	4	0	116

Table A.6 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	July	Control	1	0	93
2011	July	Control	2	0	86
2011	July	Control	3	0	94
2011	July	Control	4	0	93
2011	August	Control	1	0	89
2011	August	Control	2	0	89
2011	August	Control	3	0	103
2011	August	Control	4	0	83
2011	September	Control	1	0	63
2011	September	Control	2	0	62
2011	September	Control	3	0	76
2011	September	Control	4	0	71
2010	July	High K Rate	1	202	128
2010	July	High K Rate	2	202	139
2010	July	High K Rate	3	202	131
2010	July	High K Rate	4	202	142
2010	August	High K Rate	1	202	164
2010	August	High K Rate	2	202	170
2010	August	High K Rate	3	202	153
2010	August	High K Rate	4	202	161
2010	September	High K Rate	1	202	111
2010	September	High K Rate	2	202	180
2010	September	High K Rate	3	202	250
2010	September	High K Rate	4	202	143
2010	October	High K Rate	1	202	150
2010	October	High K Rate	2	202	177
2010	October	High K Rate	3	202	141
2010	October	High K Rate	4	202	132
2010	December	High K Rate	1	202	133
2010	December	High K Rate	2	202	190
2010	December	High K Rate	3	202	177
2010	December	High K Rate	4	202	146
2011	April	High K Rate	1	202	138

Table A.6 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	April	High K Rate	2	202	162
2011	April	High K Rate	3	202	119
2011	April	High K Rate	4	202	122
2011	May	High K Rate	1	202	148
2011	May	High K Rate	2	202	145
2011	May	High K Rate	3	202	167
2011	May	High K Rate	4	202	125
2011	June	High K Rate	1	202	143
2011	June	High K Rate	2	202	158
2011	June	High K Rate	3	202	141
2011	June	High K Rate	4	202	139
2011	July	High K Rate	1	202	164
2011	July	High K Rate	2	202	146
2011	July	High K Rate	3	202	121
2011	July	High K Rate	4	202	121
2011	August	High K Rate	1	202	122
2011	August	High K Rate	2	202	141
2011	August	High K Rate	3	202	128
2011	August	High K Rate	4	202	100
2011	September	High K Rate	1	202	101
2011	September	High K Rate	2	202	143
2011	September	High K Rate	3	202	106
2011	September	High K Rate	4	202	87

Table A.7 Ammonium acetate exchangeable K levels, Krantz (2010-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	July	Control	1	0	143
2010	July	Control	2	0	139
2010	July	Control	3	0	130
2010	July	Control	4	0	146
2010	August	Control	1	0	128
2010	August	Control	2	0	122
2010	August	Control	3	0	103
2010	August	Control	4	0	125
2010	September	Control	1	0	102
2010	September	Control	2	0	102
2010	September	Control	3	0	90
2010	September	Control	4	0	110
2010	October	Control	1	0	77
2010	October	Control	2	0	79
2010	October	Control	3	0	75
2010	October	Control	4	0	107
2010	December	Control	1	0	118
2010	December	Control	2	0	102
2010	December	Control	3	0	102
2010	December	Control	4	0	118
2011	April	Control	1	0	105
2011	April	Control	2	0	105
2011	April	Control	3	0	92
2011	April	Control	4	0	104
2011	May	Control	1	0	132
2011	May	Control	2	0	131
2011	May	Control	3	0	129
2011	May	Control	4	0	145
2010	July	High K Rate	1	202	155
2010	July	High K Rate	2	202	132
2010	July	High K Rate	3	202	150
2010	July	High K Rate	4	202	125

Table A.7 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	August	High K Rate	1	202	169
2010	August	High K Rate	2	202	217
2010	August	High K Rate	3	202	194
2010	August	High K Rate	4	202	149
2010	September	High K Rate	1	202	160
2010	September	High K Rate	2	202	201
2010	September	High K Rate	3	202	187
2010	September	High K Rate	4	202	153
2010	October	High K Rate	1	202	147
2010	October	High K Rate	2	202	150
2010	October	High K Rate	3	202	161
2010	October	High K Rate	4	202	143
2010	December	High K Rate	1	202	172
2010	December	High K Rate	2	202	157
2010	December	High K Rate	3	202	176
2010	December	High K Rate	4	202	155
2011	April	High K Rate	1	202	148
2011	April	High K Rate	2	202	134
2011	April	High K Rate	3	202	175
2011	April	High K Rate	4	202	187
2011	May	High K Rate	1	202	193
2011	May	High K Rate	2	202	183
2011	May	High K Rate	3	202	205
2011	May	High K Rate	4	202	192

Table A.8 Ammonium acetate exchangeable K levels, Spieth (2010-2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	July	Control	1	0	176
2010	July	Control	2	0	128
2010	July	Control	3	0	147
2010	July	Control	4	0	119
2010	August	Control	1	0	160
2010	August	Control	2	0	125
2010	August	Control	3	0	135
2010	August	Control	4	0	117
2010	September	Control	1	0	156
2010	September	Control	2	0	124
2010	September	Control	3	0	142
2010	September	Control	4	0	112
2010	October	Control	1	0	188
2010	October	Control	2	0	129
2010	October	Control	3	0	143
2010	October	Control	4	0	132
2010	December	Control	1	0	147
2010	December	Control	2	0	114
2010	December	Control	3	0	127
2010	December	Control	4	0	105
2011	April	Control	1	0	156
2011	April	Control	2	0	99
2011	April	Control	3	0	111
2011	April	Control	4	0	104
2011	May	Control	1	0	163
2011	May	Control	2	0	134
2011	May	Control	3	0	147
2011	May	Control	4	0	106
2010	July	High K Rate	1	202	167
2010	July	High K Rate	2	202	154
2010	July	High K Rate	3	202	122
2010	July	High K Rate	4	202	128

Table A.8 continued

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2010	August	High K Rate	1	202	206
2010	August	High K Rate	2	202	200
2010	August	High K Rate	3	202	160
2010	August	High K Rate	4	202	199
2010	September	High K Rate	1	202	187
2010	September	High K Rate	2	202	209
2010	September	High K Rate	3	202	247
2010	September	High K Rate	4	202	185
2010	October	High K Rate	1	202	205
2010	October	High K Rate	2	202	175
2010	October	High K Rate	3	202	188
2010	October	High K Rate	4	202	174
2010	December	High K Rate	1	202	204
2010	December	High K Rate	2	202	173
2010	December	High K Rate	3	202	176
2010	December	High K Rate	4	202	205
2011	April	High K Rate	1	202	201
2011	April	High K Rate	2	202	164
2011	April	High K Rate	3	202	157
2011	April	High K Rate	4	202	183
2011	May	High K Rate	1	202	181
2011	May	High K Rate	2	202	188
2011	May	High K Rate	3	202	183
2011	May	High K Rate	4	202	201

Table A.9 Ammonium acetate exchangeable K levels, North Leeper (2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	July	Control	1	0	51
2011	July	Control	2	0	44
2011	July	Control	3	0	39
2011	July	Control	4	0	45
2011	August	Control	1	0	35
2011	August	Control	2	0	39
2011	August	Control	3	0	36
2011	August	Control	4	0	40
2011	September	Control	1	0	45
2011	September	Control	2	0	44
2011	September	Control	3	0	33
2011	September	Control	4	0	35
2011	October	Control	1	0	46
2011	October	Control	2	0	45
2011	October	Control	3	0	45
2011	October	Control	4	0	50
2011	July	High K Rate	1	202	93
2011	July	High K Rate	2	202	78
2011	July	High K Rate	3	202	103
2011	July	High K Rate	4	202	96
2011	August	High K Rate	1	202	102
2011	August	High K Rate	2	202	96
2011	August	High K Rate	3	202	109
2011	August	High K Rate	4	202	61
2011	September	High K Rate	1	202	129
2011	September	High K Rate	2	202	99
2011	September	High K Rate	3	202	83
2011	September	High K Rate	4	202	78
2011	October	High K Rate	1	202	101
2011	October	High K Rate	2	202	139
2011	October	High K Rate	3	202	123
2011	October	High K Rate	4	202	96

Table A.10 Ammonium acetate exchangeable K levels, South Leeper (2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	July	Control	1	0	50
2011	July	Control	2	0	48
2011	July	Control	3	0	36
2011	July	Control	4	0	49
2011	August	Control	1	0	43
2011	August	Control	2	0	50
2011	August	Control	3	0	32
2011	August	Control	4	0	43
2011	September	Control	1	0	42
2011	September	Control	2	0	33
2011	September	Control	3	0	33
2011	September	Control	4	0	36
2011	October	Control	1	0	45
2011	October	Control	2	0	44
2011	October	Control	3	0	37
2011	October	Control	4	0	59
2011	July	High K Rate	1	202	90
2011	July	High K Rate	2	202	72
2011	July	High K Rate	3	202	87
2011	July	High K Rate	4	202	125
2011	August	High K Rate	1	202	79
2011	August	High K Rate	2	202	77
2011	August	High K Rate	3	202	71
2011	August	High K Rate	4	202	87
2011	September	High K Rate	1	202	64
2011	September	High K Rate	2	202	54
2011	September	High K Rate	3	202	103
2011	September	High K Rate	4	202	82
2011	October	High K Rate	1	202	81
2011	October	High K Rate	2	202	92
2011	October	High K Rate	3	202	97
2011	October	High K Rate	4	202	129

Table A.11 Ammonium acetate exchangeable K levels, Pringle (2011)

Year	Month	Plot	Block	K_2O Rate kg ha^{-1}	K Level mg kg^{-1}
2011	July	Control	1	0	68
2011	July	Control	2	0	45
2011	July	Control	3	0	55
2011	July	Control	4	0	45
2011	August	Control	1	0	66
2011	August	Control	2	0	58
2011	August	Control	3	0	79
2011	August	Control	4	0	57
2011	September	Control	1	0	88
2011	September	Control	2	0	51
2011	September	Control	3	0	91
2011	September	Control	4	0	51
2011	October	Control	1	0	85
2011	October	Control	2	0	66
2011	October	Control	3	0	110
2011	October	Control	4	0	84
2011	July	High K Rate	1	202	149
2011	July	High K Rate	2	202	82
2011	July	High K Rate	3	202	70
2011	July	High K Rate	4	202	162
2011	August	High K Rate	1	202	113
2011	August	High K Rate	2	202	90
2011	August	High K Rate	3	202	56
2011	August	High K Rate	4	202	108
2011	September	High K Rate	1	202	179
2011	September	High K Rate	2	202	136
2011	September	High K Rate	3	202	61
2011	September	High K Rate	4	202	105
2011	October	High K Rate	1	202	172
2011	October	High K Rate	2	202	128
2011	October	High K Rate	3	202	86
2011	October	High K Rate	4	202	129

Appendix B - Impact of Potassium Fertilizer Rates and Method of Placement on Soybeans in Southeast Kansas – Raw Data

Table B.1 SW Jennings soybean study 2009

Plot	Treatment	R3 Leaf K $g\ kg^{-1}$	R4 Leaf K $g\ kg^{-1}$	Grain K $g\ kg^{-1}$	Moisture $g\ kg^{-1}$	Test Weight $kg\ hL^{-1}$	Yield $kg\ ha^{-1}$
101	9	17.55	11.62	19.92	111	72.2	2715
102	4	17.66	12.30	19.64	111	70.1	2354
103	7	17.60	11.38	20.36	112	71.4	2934
104	1	16.98	10.63	19.69	111	72.7	2757
105	5	17.74	11.29	20.02	113	72.1	2984
106	2	16.54	11.36	19.54	110	70.9	2782
107	6	16.92	12.76	19.84	111	70.8	3139
108	3	17.65	10.66	18.39	110	70.5	2633
109	8	18.66	11.72	20.63	108	70.7	2639
110	10	17.95	11.89	19.95	107	71.0	2642
201	5	16.87	11.16	20.11	113	71.6	2645
202	8	17.23	11.01	19.98	113	71.2	2307
203	2	18.17	9.48	19.81	113	71.9	2455
204	4	18.71	10.27	19.64	111	71.3	2609
205	3	17.17	9.80	19.46	112	71.4	2775
206	7	18.49	10.87	19.58	113	71.0	2709
207	10	16.84	11.82	19.86	112	71.4	3093
208	1	17.53	9.59	19.32	109	70.1	2721
209	6	17.44	10.71	20.04	109	71.6	2615
210	9	18.35	9.96	19.65	108	71.7	2639
301	1	15.99	9.30	19.52	113	70.9	2540
302	6	18.16	11.40	20.14	110	70.5	2527

Table B.1 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	16.83	10.81	20.17	111	70.7	2588
304	10	18.59	11.72	19.95	111	71.9	2821
305	7	18.44	11.86	20.76	111	71.2	2821
306	9	17.85	11.80	20.25	112	71.3	2712
307	5	17.31	10.48	19.73	112	70.5	2733
308	8	18.64	12.15	19.28	109	71.9	2955
309	2	16.63	10.40	19.23	108	71.4	2554
310	4	17.37	10.98	19.22	110	71.7	2612
401	2	18.70	12.10	19.99	113	70.7	2243
402	10	19.10	12.35	20.26	112	71.7	1780
403	5	17.51	11.24	19.79	113	71.2	2518
404	8	18.41	13.23	19.81	113	70.3	2624
405	1	16.62	10.00	17.55	109	71.0	2423
406	6	18.44	10.57	19.66	113	72.5	1862
407	4	17.69	10.50	20.02	111	71.8	3012
408	9	18.22	10.87	19.97	109	71.2	2700
409	3	18.15	10.83	20.52	110	72.2	2527
410	7	19.30	10.27	18.84	107	71.2	2514

Table B.2 SE Brown soybean study 2009

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	16.90	10.56	19.73	108	71.7	2554
102	4	17.13	10.57	20.89	108	70.0	1915
103	7	20.10	10.44	20.16	106	72.1	1962
104	1	16.34	9.64	19.50	107	71.0	2450
105	5	17.57	10.74	19.57	106	71.6	2389
106	2	17.83	10.60	20.53	105	70.0	2157
107	6	18.67	10.28	20.41	106	72.1	2176
108	3	17.71	9.49	20.45	112	70.7	2648
109	8	17.98	10.06	20.48	101	72.2	2788
110	10	17.36	10.72	20.12	103	72.2	1862
201	5	18.97	9.39	20.66	105	70.8	2627
202	8	17.65	10.49	20.47	103	68.5	2076
203	2	18.49	9.25	19.52	105	70.8	1772
204	4	17.91	9.60	21.26	106	72.1	2218
205	3	19.83	9.81	20.61	108	65.5	2235
206	7	21.04	10.47	20.60	106	72.3	2240
207	10	19.23	10.45	16.50	104	67.2	2052
208	1	16.23	9.06	20.43	107	71.7	2535
209	6	17.73	10.53	18.70	104	71.3	2726
210	9	19.76	10.25	20.59	104	72.5	1881
301	1	15.67	10.51	19.03	110	71.0	2527
302	6	19.19	10.43	20.32	109	71.3	1658

Table B.2 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	16.98	10.93	19.65	108	69.0	2107
304	10	17.10	10.56	20.24	117	70.0	2402
305	7	18.91	10.52	20.22	102	67.4	2378
306	9	18.32	10.09	19.86	106	71.6	1813
307	5	16.76	10.06	19.97	107	74.5	2770
308	8	17.89	9.23	20.55	105	71.9	2733
309	2	17.17	8.40	19.89	106	71.9	2944
310	4	18.34	9.94	20.35	104	72.6	1753
401	2	16.37	9.66	19.85	111	72.5	1718
402	10	20.03	10.60	19.85	108	71.9	1873
403	5	18.38	9.92	20.1	106	72.3	2595
404	8	18.47	9.29	19.32	108	67.3	2128
405	1	21.78	10.45	20.77	106	71.4	2240
406	6	17.81	9.91	20.07	106	70.8	1962
407	4	18.27	10.68	20.37	106	70.8	2538
408	9	17.97	9.24	20.36	106	72.7	2688
409	3	16.83	9.12	19.72	105	73.6	2840
410	7	18.04	9.63	20.07	103	71.9	2418

Table B.3 SW Brown soybean study 2009

Plot	Treatment	R3 Leaf K	R4 Leaf K	Grain K	Moisture	Test Weight	Yield
		g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	kg ha^{-1}
101	9	19.72	12.78	21.01	137	71.8	2739
102	4	18.68	10.84	21.49	134	72.7	2128
103	7	18.35	11.40	21.75	135	72.6	2208
104	1	17.94	9.94	21.01	134	72.6	1860
105	5	17.81	11.04	21.58	135	71.8	2311
106	2	17.53	11.24	21.42	135	72.3	2353
107	6	17.69	11.61	21.49	134	72.5	2417
108	3	17.15	10.76	21.58	132	72.7	2257
109	8	18.36	11.73	21.18	133	72.5	2193
110	10	17.97	12.65	20.80	131	72.8	2923
201	5	19.04	11.24	21.59	136	72.2	2453
202	8	18.86	10.78	21.28	132	72.5	2257
203	2	17.72	10.98	17.33	135	72.3	2353
204	4	18.07	10.78	21.15	133	72.6	2255
205	3	19.10	10.90	21.86	134	72.3	2046
206	7	19.30	12.65	21.56	137	72.6	2327
207	10	19.74	11.12	17.65	132	72.6	2071
208	1	18.00	9.72	21.53	131	73.0	1659
209	6	17.86	10.83	22.50	132	72.7	2340
210	9	18.62	10.13	21.35	133	72.7	2275
301	1	16.63	11.09	21.59	136	72.2	2020
302	6	18.74	11.32	22.08	133	71.9	2317

Table B.3 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	18.18	10.43	21.72	134	71.7	2335
304	10	18.75	11.39	22.06	134	72.6	2583
305	7	20.69	11.53	22.04	133	72.3	1696
306	9	19.54	12.50	22.01	134	73.0	2046
307	5	18.80	11.04	21.92	130	72.8	2283
308	8	18.79	11.27	21.73	130	73.0	1598
309	2	17.43	11.78	21.10	134	71.7	2727
310	4	17.94	11.31	21.27	133	73.2	2565
401	2	20.23	10.34	21.72	136	72.3	2309
402	10	18.30	10.85	21.54	133	72.7	2093
403	5	18.91	10.55	22.22	134	72.1	2583
404	8	17.55	9.92	21.71	134	72.8	2190
405	1	18.93	10.40	21.76	133	72.6	2213
406	6	19.62	12.36	21.67	135	72.7	2105
407	4	20.02	10.52	22.10	130	73.0	2408
408	9	18.63	10.16	21.48	130	73.4	2034
409	3	19.44	11.95	21.89	133	71.9	2358
410	7	20.23	12.40	21.88	134	72.3	1860

Table B.4 Delmont soybean study 2009

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	16.69	10.54	20.09	113	67.2	2582
102	4	18.02	9.59	19.88	106	71.9	2410
103	7	20.83	11.31	19.40	107	72.6	2514
104	1	18.20	9.55	20.36	109	73.0	2317
105	5	16.53	10.34	19.69	105	71.0	2584
106	2	15.92	9.91	19.46	103	70.4	2697
107	6	17.14	10.94	19.51	106	70.5	2069
108	3	17.72	11.46	20.06	103	71.7	2418
109	8	17.14	10.48	20.27	103	71.8	2611
110	10	18.58	11.03	20.11	103	71.7	2311
201	5	18.99	10.83	19.62	106	71.2	2176
202	8	18.80	9.42	20.06	107	71.9	2663
203	2	19.70	9.23	19.67	108	72.2	2511
204	4	17.32	9.90	19.64	104	70.4	2458
205	3	17.67	9.83	19.79	103	72.1	2804
206	7	19.75	11.50	17.50	102	71.2	2635
207	10	18.47	11.79	19.47	103	70.8	2162
208	1	17.59	9.84	19.23	103	70.1	2226
209	6	17.70	11.96	20.19	102	68.6	2314
210	9	19.11	12.03	19.60	103	70.0	2440
301	1	17.35	10.12	20.05	103	71.2	2718
302	6	16.93	11.18	17.28	102	71.9	2464

Table B.4 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	17.51	10.22	19.40	104	69.9	2715
304	10	20.02	10.95	17.65	106	72.3	2197
305	7	17.60	11.20	19.36	105	71.8	2712
306	9	16.87	11.41	19.61	104	72.5	2822
307	5	17.70	10.20	19.77	105	70.4	2306
308	8	19.22	11.22	19.61	102	69.0	2464
309	2	17.89	9.90	19.95	104	69.4	2501
310	4	19.02	10.71	19.21	103	68.1	2354
401	2	16.35	11.65	18.35	106	71.7	2560
402	10	17.65	12.02	19.93	108	72.6	2554
403	5	18.58	12.39	20.52	105	69.8	2199
404	8	18.98	11.72	20.48	105	70.1	2520
405	1	17.02	10.56	19.70	104	71.8	2865
406	6	18.62	12.23	20.44	106	69.9	2837
407	4	16.91	13.19	19.21	101	68.3	2488
408	9	17.90	12.71	19.39	102	70.9	2550
409	3	18.32	12.26	20.01	101	68.5	2081
410	7	19.62	14.20	19.90	104	71.2	2352

Table B.5 NW of Dad soybean study 2010

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	12.61	8.45	18.05	96	71.7	2739
102	4	12.48	7.10	19.64	95	71.9	2807
103	7	13.39	8.69	19.37	95	72.1	2699
104	1	10.60	6.10	19.31	92	67.4	2340
105	5	12.14	7.67	19.19	95	73.0	2764
106	2	12.77	8.03	20.28	94	71.8	2853
107	6	14.22	9.05	19.43	92	69.4	2296
108	3	10.80	8.00	19.58	93	69.4	2986
109	8	13.20	8.36	19.84	94	73.2	2659
110	10	13.57	8.37	18.80	92	70.5	2578
201	5	13.08	7.03	18.86	96	71.3	2976
202	8	12.64	7.82	18.70	95	72.6	2634
203	2	12.08	7.34	18.87	94	71.2	2702
204	4	12.19	7.95	18.29	95	68.5	2677
205	3	13.47	8.13	19.00	92	68.0	2881
206	7	15.71	10.64	20.35	97	71.9	2995
207	10	13.80	9.21	19.30	94	73.0	2745
208	1	11.56	7.11	19.29	93	72.1	2597
209	6	14.61	8.87	19.20	93	71.4	2705
210	9	13.44	8.98	18.57	92	73.2	2621
301	1	11.12	6.74	18.52	97	72.2	2758
302	6	12.86	8.56	18.91	96	72.6	2890

Table B.5 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	11.80	7.03	17.94	97	73.1	2693
304	10	14.29	8.69	18.33	92	66.5	2730
305	7	14.17	9.46	19.21	96	73.7	2524
306	9	14.03	9.00	19.36	96	71.4	2890
307	5	12.81	8.41	19.10	94	71.3	2745
308	8	13.15	8.01	20.31	94	71.8	2897
309	2	11.77	8.98	18.82	92	69.9	2448
310	4	12.35	8.18	20.10	93	72.5	2640
401	2	11.18	6.96	17.92	96	73.7	2718
402	10	13.23	8.80	19.46	94	68.0	2832
403	5	12.22	8.33	18.41	97	74.4	2607
404	8	12.54	8.10	17.17	95	73.2	2656
405	1	11.12	7.62	18.94	96	73.0	2675
406	6	13.67	11.12	19.60	95	72.8	2742
407	4	12.51	8.18	18.99	95	72.7	2483
408	9	13.57	9.57	19.85	96	73.2	2869
409	3	13.28	8.93	19.41	95	73.6	2505
410	7	12.23	10.36	19.34	94	73.4	2486

Table B.6 East Mark soybean study 2010

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	16.10	10.01	19.94	101	71.9	3925
102	4	13.29	10.43	18.49	101	73.1	3582
103	7	17.07	11.95	18.77	100	72.6	3436
104	1	12.86	9.28	17.97	101	72.3	3625
105	5	13.40	11.99	17.94	100	71.8	3221
106	2	14.58	10.36	18.16	102	72.2	3107
107	6	12.33	11.23	19.22	98	72.2	2475
108	3	10.99	9.68	18.47	100	71.8	2749
109	8	14.72	10.14	18.90	98	72.7	3034
110	10	14.26	10.42	18.46	97	72.3	3146
201	5	15.85	11.06	18.23	104	71.9	3912
202	8	14.59	11.10	17.78	100	73.1	3285
203	2	14.59	9.44	16.47	101	71.7	3496
204	4	15.10	9.05	17.41	102	72.7	3492
205	3	15.70	9.57	18.51	98	72.7	3121
206	7	13.67	11.97	18.71	99	73.1	3225
207	10	15.08	10.48	18.93	98	72.6	3056
208	1	11.48	9.42	18.12	98	71.8	3056
209	6	14.49	9.84	23.80	101	73.0	3518
210	9	12.69	10.36	18.30	98	72.3	3077
301	1	12.38	9.56	18.51	102	72.5	3728
302	6	16.17	11.23	18.82	102	73.0	3278

Table B.6 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	13.74	9.28	18.20	99	72.2	3569
304	10	13.38	10.72	18.15	101	72.8	3689
305	7	12.46	11.21	17.97	99	72.6	3289
306	9	13.91	11.21	19.09	98	72.7	3357
307	5	12.87	9.82	18.93	98	73.0	3379
308	8	13.20	9.99	18.46	99	72.1	3182
309	2	14.01	9.53	18.59	100	73.2	3500
310	4	11.98	9.20	18.20	100	72.8	3393
401	2	12.34	9.59	19.03	101	72.2	3797
402	10	13.89	12.00	19.55	100	72.6	3178
403	5	12.39	9.76	18.41	101	72.8	3475
404	8	12.42	10.36	18.88	102	72.5	3192
405	1	12.52	9.64	18.26	98	72.8	3422
406	6	16.38	10.32	18.73	99	73.0	3096
407	4	14.29	10.04	17.11	97	72.3	3210
408	9	14.59	10.13	18.52	99	73.1	3504
409	3	11.66	8.61	18.44	98	72.1	3314
410	7	13.13	10.11	18.20	98	72.6	3293

Table B.7 Krantz soybean study 2010

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	16.10	13.14	17.26	81	70.4	3399
102	4	15.79	11.33	16.29	97	71.4	3813
103	7	16.95	13.16	16.81	80	69.8	3819
104	1	14.77	10.55	17.50	80	70.0	3644
105	5	14.57	11.56	16.67	80	68.0	3885
106	2	14.27	10.30	16.87	82	70.5	4008
107	6	14.58	11.61	16.44	82	71.3	3921
108	3	15.41	11.38	16.92	81	70.4	3771
109	8	15.65	12.30	16.67	80	65.4	3973
110	10	17.07	13.16	17.17	81	71.2	4013
201	5	16.64	11.40	16.56	80	71.0	3841
202	8	15.65	10.92	16.32	82	70.9	3877
203	2	16.05	11.61	16.69	80	69.8	4039
204	4	15.53	11.35	17.09	81	72.3	3771
205	3	14.45	11.18	16.76	80	65.4	4083
206	7	15.42	12.52	16.44	80	69.6	4039
207	10	15.70	12.54	16.44	79	65.1	4065
208	1	15.11	11.12	16.42	80	71.0	3973
209	6	15.15	11.88	16.91	81	71.2	3991
210	9	13.85	12.09	17.03	80	71.8	3951
301	1	15.01	10.42	16.24	78	65.8	3608
302	6	14.80	12.38	16.28	81	71.8	3991

Table B.7 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	15.63	11.40	16.56	80	69.5	4017
304	10	15.43	12.38	16.87	80	71.8	3732
305	7	16.27	12.98	16.84	80	69.2	3907
306	9	17.84	12.31	16.17	80	69.9	4017
307	5	15.09	11.27	16.78	80	69.9	4061
308	8	15.83	11.85	16.99	80	70.1	3863
309	2	14.78	11.06	16.44	80	70.4	3973
310	4	17.28	11.47	16.87	79	70.4	3867
401	2	14.53	9.87	16.09	81	71.9	3684
402	10	16.81	13.01	16.91	81	72.2	3684
403	5	16.72	12.83	16.79	81	72.2	3662
404	8	16.16	11.79	16.83	80	72.1	3512
405	1	16.01	12.09	16.38	81	72.6	3640
406	6	18.38	12.82	16.71	79	65.4	3933
407	4	16.04	11.78	16.47	80	71.3	3841
408	9	18.31	13.47	16.76	80	70.7	3600
409	3	14.93	11.65	16.84	79	67.6	3867
410	7	17.56	13.06	16.75	80	69.4	3710

Table B.8 Spieth soybean study 2010

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	17.65	13.48	17.75	99	72.2	2773
102	4	20.25	13.40	17.85	101	72.8	2831
103	7	21.29	12.83	17.71	100	71.8	2749
104	1	19.04	12.52	17.19	97	72.7	2693
105	5	16.22	11.87	16.85	98	72.6	2475
106	2	16.70	12.70	18.23	97	71.8	2844
107	6	16.24	12.70	17.96	101	71.6	3389
108	3	16.15	12.44	18.00	102	72.5	3428
109	8	18.00	12.16	17.07	103	72.2	3424
110	10	18.04	13.16	15.93	103	71.3	3510
201	5	19.18	11.70	17.23	100	71.9	2792
202	8	18.58	13.56	17.34	104	71.6	3014
203	2	20.23	12.53	17.57	99	71.7	2902
204	4	21.15	12.93	17.75	98	73.1	2970
205	3	20.33	11.85	16.50	100	72.6	2491
206	7	19.60	12.70	17.92	97	72.6	2693
207	10	19.29	12.64	18.09	101	70.8	3389
208	1	18.00	11.44	17.95	99	71.8	3397
209	6	18.81	12.23	17.69	104	72.7	3378
210	9	17.91	13.10	17.64	107	71.0	3494
301	1	15.36	12.34	17.23	98	72.1	2798
302	6	18.12	11.82	16.07	105	71.7	3310

Table B.8 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	16.81	11.61	17.72	100	72.2	3071
304	10	15.38	13.32	17.91	98	73.6	2841
305	7	18.64	12.46	18.31	99	73.2	2924
306	9	20.49	13.03	17.91	101	72.1	3089
307	5	17.14	12.65	18.22	97	72.2	3232
308	8	16.94	10.86	17.23	98	72.6	3314
309	2	18.60	12.94	16.40	101	73.1	2960
310	4	15.24	12.50	15.54	100	72.2	3264
401	2	15.12	12.11	16.58	97	72.2	2176
402	10	15.82	12.76	17.20	100	71.9	3457
403	5	17.51	12.83	17.11	99	72.1	3289
404	8	20.25	12.45	17.77	101	72.5	3539
405	1	18.83	10.90	17.52	101	72.7	3410
406	6	17.99	11.85	18.38	98	72.1	3207
407	4	16.41	11.64	17.25	99	71.4	3440
408	9	17.56	11.46	18.95	100	72.5	3264
409	3	16.36	12.19	18.58	99	71.4	3268
410	7	19.04	13.42	18.40	99	72.6	2988

Table B.9 North Leeper soybean study 2011

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	12.57	10.72	15.19	96	72.5	1725
102	4	8.90	8.19	14.87	97	72.2	1670
103	7	12.29	11.17	14.87	97	71.4	1767
104	1	7.40	6.36	13.00	94	71.6	1513
105	5	10.32	7.68	15.30	96	72.8	1801
106	6	10.74	10.15	15.41	97	71.7	2316
107	8	10.66	8.72	14.78	99	72.7	2171
108	10	14.72	11.98	16.81	99	72.2	2848
201	5	9.66	7.75	14.12	106	69.6	1152
202	8	9.76	8.54	15.03	100	70.1	1535
203	4	9.14	8.11	13.65	99	70.7	1344
204	7	11.55	10.78	15.46	94	72.3	1654
205	10	14.10	11.33	14.71	96	69.4	2038
206	1	8.17	5.75	13.30	94	70.5	1773
207	6	10.32	9.63	14.89	95	71.6	2084
208	9	12.93	11.23	15.26	95	72.1	2267
301	1	7.47	5.52	12.42	106	68.0	768
302	6	8.07	7.54	14.51	93	71.2	1320
303	10	11.36	12.20	15.40	93	72.7	1504
304	7	8.29	8.54	16.65	93	72.3	1342
305	9	10.69	9.33	15.12	97	72.6	1670
306	5	9.43	7.96	14.23	95	72.5	1576

Table B.9 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
307	8	10.99	9.22	14.39	93	72.5	1774
308	4	10.38	8.97	14.60	93	71.4	1861
401	10	11.94	9.47	14.87	101	71.3	1169
402	5	5.94	6.22	15.01	94	70.9	616
403	8	8.57	7.98	14.61	94	71.2	973
404	1	6.14	5.40	13.55	93	71.6	1028
405	6	10.05	9.29	14.10	96	72.6	1542
406	4	9.90	7.87	13.34	96	72.5	1499
407	9	12.48	10.98	14.93	95	71.8	1814
408	7	12.19	11.35	14.29	96	71.8	1575

Table B.10 South Leeper soybean study 2011

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	12.10	10.96	14.22	128	72.1	1553
102	4	11.52	9.38	14.59	117	72.1	1501
103	7	11.66	12.75	15.18	122	70.1	1545
104	1	9.10	6.72	13.08	122	69.5	1060
105	5	11.51	9.72	13.79	123	70.0	1279
106	2	10.62	11.20	14.72	122	70.3	1420
107	6	12.35	11.85	14.86	121	70.5	1463
108	3	10.80	7.80	14.49	120	70.4	1309
109	8	12.19	10.22	13.92	122	69.9	1264
110	10	15.36	13.59	15.12	121	67.4	1500
201	5	10.58	10.22	15.12	121	71.4	1585
202	8	11.55	10.42	15.70	123	69.0	1240
203	2	11.35	9.45	14.66	123	68.9	1218
204	4	10.85	10.40	13.90	120	66.0	950
205	3	10.49	8.86	13.09	121	69.0	1167
206	7	11.39	11.54	14.57	125	71.7	1520
207	10	13.38	13.94	14.29	124	71.4	1648
208	1	10.18	7.44	13.91	121	72.8	1587
209	6	13.63	11.05	13.72	124	70.5	1468
210	9	12.55	11.73	13.61	122	71.3	1394
301	1	9.52	6.59	12.50	122	72.1	1295
302	6	11.50	10.83	15.29	124	72.1	1303

Table B.10 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	10.79	9.51	13.79	121	69.0	1283
304	10	14.55	11.52	15.57	123	73.1	1870
305	7	12.44	10.29	14.76	125	73.7	1933
306	9	12.23	11.34	15.23	121	73.4	1898
307	5	11.53	7.99	14.52	123	71.4	2010
308	8	11.72	10.37	15.94	122	72.6	2021
309	2	11.65	8.90	14.21	123	73.0	2018
310	4	11.97	9.48	15.66	123	72.3	2107
401	2	10.29	8.10	13.66	125	70.5	1175
402	10	15.54	14.58	15.46	125	70.7	1529
403	5	12.20	10.45	14.92	123	71.0	1499
404	8	12.59	9.95	15.97	123	72.1	1759
405	1	10.87	8.89	13.75	121	72.5	1980
406	6	13.27	10.30	14.92	125	71.8	2134
407	4	12.46	9.05	14.39	119	73.0	1963
408	9	13.49	11.17	15.84	121	72.7	2209
409	3	11.32	9.08	14.51	123	71.9	1698
410	7	13.17	12.39	15.35	129	72.5	1986

Table B.11 Pringle soybean study 2011

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	14.29	8.17	16.12	128	69.9	2459
102	4	13.02	9.20	15.89	117	70.5	1390
103	7	16.27	10.56	17.38	122	70.4	1969
104	1	12.46	7.50	15.87	122	70.3	2241
105	5	14.82	10.41	17.15	123	69.9	2605
106	2	13.98	8.72	16.92	122	68.2	2451
107	6	16.23	9.89	17.72	121	70.1	2118
108	3	12.44	8.20	16.57	120	70.3	2236
109	8	14.80	9.05	16.93	122	69.2	2221
110	10	16.14	12.19	17.49	121	69.1	2601
201	5	12.62	8.11	15.51	121	70.9	1730
202	8	14.95	7.36	16.35	123	69.1	2469
203	2	12.70	7.52	17.15	123	70.0	2270
204	4	15.08	9.91	17.47	120	69.5	1995
205	3	14.70	8.63	17.30	121	71.2	2192
206	7	18.48	12.61	17.19	125	68.5	2484
207	10	17.16	11.79	16.65	124	69.4	2445
208	1	13.30	7.08	15.46	121	70.1	1908
209	6	17.16	10.19	17.14	124	70.0	2362
210	9	14.94	10.63	19.18	122	68.5	2493
301	1	13.15	6.16	16.30	122	69.4	1938
302	6	16.34	10.17	18.51	124	70.7	2675

Table B.11 continued

Plot	Treatment	R3 Leaf K g kg^{-1}	R4 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	13.58	7.80	16.92	121	70.0	2181
304	10	19.12	10.25	18.31	123	68.9	2448
305	7	18.48	11.08	17.07	125	70.3	2850
306	9	14.98	10.55	17.38	121	67.6	2705
307	5	14.57	7.32	16.85	123	67.4	2134
308	8	14.30	9.73	17.23	122	69.1	2116
309	2	15.58	8.85	16.45	123	70.3	2239
310	4	14.30	9.42	17.30	123	68.1	2574
401	2	12.72	8.90	16.49	125	68.3	2317
402	10	15.30	11.71	17.25	125	70.1	2839
403	5	16.71	9.14	16.55	123	68.1	2689
404	8	13.75	8.51	16.73	123	69.6	2563
405	1	11.65	6.01	15.11	121	70.3	2296
406	6	16.74	11.51	17.19	125	68.1	2202
407	4	13.30	8.32	17.50	119	68.0	2081
408	9	17.90	9.59	17.88	121	69.9	2234
409	3	12.89	8.09	17.47	123	69.9	2459
410	7	17.16	11.64	17.55	129	69.4	2400

Appendix C - Impact of Direct and Residual Fertilizer Rates and Method of Placement on Corn in Southeast Kansas – Raw Data

Table C.1 SW Jennings corn study 2010

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	18.76	3.74	143	75.2	7904
102	4	19.44	3.70	141	75.7	8094
103	7	19.92	3.60	138	77.0	8980
104	1	17.59	3.65	140	76.4	8560
105	5	18.71	3.69	137	75.5	9563
106	2	15.07	3.58	140	76.8	10329
107	6	19.10	3.79	143	77.1	9838
108	3	16.65	3.60	146	77.1	9633
109	8	16.77	4.04	141	77.0	10203
110	10	18.80	3.80	144	76.1	10564
201	5	18.66	3.58	144	76.1	9145
202	8	17.68	3.83	140	76.6	10271
203	2	14.37	3.45	142	77.3	8995
204	4	19.36	3.47	146	75.9	10596
205	3	17.61	3.55	146	76.7	10483
206	7	17.95	4.03	140	76.4	10386
207	10	20.66	3.57	143	77.0	10520
208	1	22.71	3.50	142	75.9	10589
209	6	20.14	4.07	144	76.8	10337
210	9	19.32	3.52	143	76.6	10691
301	1	20.11	3.70	149	76.2	10333
302	6	21.45	3.57	150	76.6	9814

Table C.1 continued

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	19.64	3.50	146	76.7	9633
304	10	20.97	3.57	146	75.8	8386
305	7	22.92	3.59	144	75.8	9315
306	9	19.35	3.57	143	76.7	10349
307	5	18.22	3.77	148	75.8	9611
308	8	19.89	3.47	144	76.1	10224
309	2	18.40	3.61	149	76.1	10842
310	4	19.03	3.78	153	74.5	10734
401	2	18.09	3.66	157	75.5	9229
402	10	30.29	3.85	157	75.3	8446
403	5	20.55	3.59	146	75.2	10710
404	8	23.30	4.03	148	76.6	7745
405	1	19.71	3.65	165	75.4	8588
406	6	22.94	3.44	155	76.2	9644
407	4	22.14	3.31	157	76.6	9733
408	9	22.17	3.58	152	76.2	8890
409	3	23.58	3.85	148	76.1	9328
410	7	22.34	3.55	159	76.3	9096

Table C.2 SE Brown corn study 2010

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	20.99	4.01	151	76.1	8844
102	4	22.72	3.64	149	76.7	9656
103	7	22.15	3.56	152	75.9	10353
104	1	21.17	4.09	152	77.0	9059
105	5	20.44	3.49	152	76.3	9509
106	2	21.63	3.73	152	75.5	10578
107	6	19.66	3.69	150	76.6	9250
108	3	22.33	3.90	154	76.2	9150
109	8	19.89	3.48	151	76.8	9351
110	10	17.90	3.74	151	76.1	9746
201	5	21.94	3.75	152	75.5	8721
202	8	21.38	3.74	148	75.9	8989
203	2	23.44	3.55	156	75.8	9744
204	4	25.22	4.03	154	76.2	7466
205	3	22.00	3.63	149	76.8	9430
206	7	22.59	3.55	155	76.4	9756
207	10	20.35	3.70	149	77.1	9373
208	1	20.23	3.46	147	76.4	9792
209	6	20.36	3.42	148	76.3	10515
210	9	22.50	3.56	145	77.6	9304
301	1	20.50	3.92	155	76.4	8578
302	6	20.94	3.52	148	75.9	9328

Table C.2 continued

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	20.86	3.37	154	75.3	9599
304	10	22.80	3.91	156	76.2	8456
305	7	22.95	3.88	150	75.8	9306
306	9	20.91	3.78	150	77.2	10208
307	5	20.23	3.92	150	77.1	8573
308	8	18.05	3.61	147	76.4	9848
309	2	21.29	3.61	149	75.4	10220
310	4	20.82	3.45	154	75.8	8645
401	2	22.88	3.76	151	76.2	8901
402	10	22.35	3.87	169	74.8	8161
403	5	22.77	3.74	167	75.7	9175
404	8	21.20	4.11	157	76.6	7943
405	1	19.68	3.93	149	76.7	8752
406	6	20.29	3.68	152	76.6	8834
407	4	24.00	4.16	159	75.2	8036
408	9	20.93	3.75	159	74.9	9207
409	3	23.33	3.51	161	75.0	10243
410	7	22.76	3.90	155	76.6	8578

Table C.3 SW Brown corn study 2010

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	19.29	3.51	157	76.7	10740
102	4	20.68	3.46	148	75.4	9611
103	7	20.81	3.44	148	76.8	10176
104	1	20.35	3.47	154	75.8	9880
105	5	19.77	3.33	148	75.9	10119
106	2	20.06	2.95	145	75.8	10722
107	6	19.41	3.58	151	75.3	10534
108	3	21.27	3.14	152	75.7	9847
109	8	19.40	3.48	147	76.3	10075
110	10	18.92	3.33	158	76.1	10727
201	5	20.92	3.23	166	74.9	10127
202	8	18.72	3.16	148	76.2	9158
203	2	20.09	3.14	161	75.2	10911
204	4	21.50	3.26	160	76.3	10311
205	3	18.25	3.63	156	76.2	9464
206	7	23.08	3.32	151	76.4	10140
207	10	24.12	3.35	167	75.0	10723
208	1	18.69	3.41	147	75.9	10754
209	6	18.24	2.97	151	76.2	10253
210	9	18.67	3.24	152	75.3	10635
301	1	25.61	3.17	152	76.7	10353
302	6	23.04	3.36	151	76.2	8957

Table C.3 continued

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	22.99	3.51	156	75.2	10136
304	10	19.98	3.29	153	75.7	10229
305	7	22.92	3.22	150	76.3	9419
306	9	18.35	3.36	148	76.2	9724
307	5	23.46	3.02	152	76.1	10466
308	8	23.29	3.37	147	75.4	10584
309	2	20.29	3.45	151	77.3	9746
310	4	22.39	3.19	157	75.3	10404
401	2	21.23	3.34	152	75.7	10860
402	10	20.80	2.91	152	75.0	9453
403	5	21.08	3.18	161	75.5	10410
404	8	20.99	3.36	153	75.5	9161
405	1	18.06	3.12	163	76.2	10719
406	6	17.68	3.39	152	75.3	10184
407	4	19.59	3.28	164	75.3	10872
408	9	20.39	3.21	148	76.1	10063
409	3	19.98	3.21	158	75.8	8716
410	7	24.54	3.32	150	75.7	10603

Table C.4 Delmont corn study 2010

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	19.19	3.94	154	73.0	8027
102	4	24.27	4.16	172	69.5	9999
103	7	24.15	4.11	159	72.7	9877
104	1	17.04	4.02	153	72.1	8767
105	5	18.28	3.68	172	71.2	8571
106	2	18.02	3.89	164	71.4	8820
107	6	20.16	4.00	163	71.6	8664
108	3	20.62	3.96	187	70.5	10142
109	8	20.04	3.51	168	71.8	7950
110	10	22.86	4.46	160	71.4	8639
201	5	19.13	4.14	148	71.4	8254
202	8	20.18	3.79	172	70.7	10494
203	2	19.49	3.70	165	71.8	8366
204	4	20.56	3.79	150	72.1	9701
205	3	18.89	3.69	168	71.6	10765
206	7	19.83	3.86	154	71.9	9431
207	10	19.99	3.80	167	72.5	8291
208	1	20.58	3.63	180	70.7	10392
209	6	21.04	3.81	171	71.6	8141
210	9	20.88	3.83	173	71.8	8066
301	1	17.40	3.74	174	70.7	9043
302	6	19.15	3.64	174	71.3	9756

Table C.4 continued

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	20.71	3.71	168	72.7	10489
304	10	19.98	3.73	165	71.0	8532
305	7	19.38	3.55	169	70.9	9594
306	9	19.00	3.68	161	71.3	10132
307	5	19.36	3.80	163	72.2	9108
308	8	19.54	3.86	193	69.2	9424
309	2	17.75	3.60	163	71.0	9164
310	4	20.61	3.90	164	71.9	8820
401	2	16.90	3.78	169	71.4	9649
402	10	18.06	3.94	170	70.1	10904
403	5	19.78	3.58	184	71.3	9746
404	8	18.98	3.66	184	70.1	8446
405	1	16.15	3.78	164	70.3	9042
406	6	21.69	3.75	185	70.4	9788
407	4	20.06	3.74	191	69.0	8642
408	9	21.19	3.96	217	66.5	10287
409	3	19.45	3.93	181	69.6	10162
410	7	20.97	4.15	175	69.9	8704

Table C.5 NW of Dad corn study 2011

Plot	Treatment	R1 Leaf K	Grain K	Moisture	Test Weight	Yield
		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	kg ha^{-1}
101	9	11.64	3.66	20	64.5	975
102	4	11.97	3.92	36	66.4	1727
103	7	14.64	3.32	23	66.5	1232
104	1	7.36	3.97	39	69.2	1084
105	5	8.19	3.70	24	66.4	1230
106	2	11.80	3.73	38	69.4	957
107	6	12.04	3.98	24	67.3	1360
108	3	10.35	3.71	28	66.7	709
109	8	12.77	4.17	28	63.6	1354
110	10	14.69	3.59	25	66.0	1035
201	5	10.35	3.92	36	65.1	1151
202	8	12.19	4.00	21	62.7	1104
203	2	12.73	3.31	39	71.7	893
204	4	12.56	3.97	30	68.1	1609
205	3	10.19	3.78	28	67.3	1999
206	7	16.43	3.69	49	70.9	1136
207	10	13.72	3.75	29	66.4	1095
208	1	10.68	3.99	30	63.7	386
209	6	14.74	3.80	40	70.8	1847
210	9	12.16	3.73	22	66.0	649
301	1	9.51	3.78	26	65.9	1163
302	6	12.71	4.17	14	62.9	1243

Table C.5 continued

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	12.60	3.72	29	61.5	1224
304	10	13.23	3.98	29	68.3	2319
305	7	13.29	3.98	31	66.8	2122
306	9	13.92	3.87	18	65.5	1564
307	5	11.22	4.19	17	62.4	1174
308	8	11.33	3.87	28	60.2	1096
309	2	11.99	3.72	35	68.7	1345
310	4	14.34	3.95	33	67.4	1027
401	2	9.47	3.48	26	65.3	1163
402	10	13.15	3.98	36	65.5	1535
403	5	13.23	3.98	18	64.4	1564
404	8	10.29	4.25	24	65.1	1360
405	1	9.74	3.91	21	65.4	1949
406	6	14.96	4.41	27	63.1	1420
407	4	13.77	3.88	34	64.7	1602
408	9	12.82	3.94	27	66.4	1291
409	3	14.19	4.20	26	64.4	1228
410	7	15.28	4.19	34	67.6	1410

Table C.6 East Mark corn study 2011

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
101	9	18.75	3.56	28	70.5	3031
102	4	20.29	3.96	25	70.1	2394
103	7	21.00	3.89	29	69.2	2448
104	1	15.23	3.85	40	70.0	1911
105	5	17.30	3.94	36	68.6	1983
106	2	17.05	3.80	33	69.0	1989
107	6	21.18	3.53	29	69.0	1740
108	3	15.72	3.59	40	70.1	1529
109	8	16.88	3.66	29	71.3	1997
110	10	17.37	3.76	26	70.5	1357
201	5	18.45	3.91	32	71.7	2762
202	8	18.95	3.52	47	72.3	2529
203	2	16.25	3.86	29	71.3	2319
204	4	18.16	3.48	35	70.1	2369
205	3	17.11	3.87	31	69.5	2057
206	7	20.58	3.76	28	70.1	2515
207	10	21.67	3.80	46	71.9	2216
208	1	14.65	3.69	25	69.4	970
209	6	18.82	3.49	36	72.5	1471
210	9	17.51	3.51	31	71.0	836
301	1	17.14	3.76	22	70.3	3374
302	6	21.44	3.90	32	71.3	1798

Table C.6 continued

Plot	Treatment	R1 Leaf K g kg^{-1}	Grain K g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield kg ha^{-1}
303	3	17.55	3.78	29	72.1	2642
304	10	21.53	3.95	27	71.0	2647
305	7	23.02	3.87	27	71.0	2131
306	9	19.48	3.99	30	70.9	2639
307	5	18.56	3.94	23	71.0	2723
308	8	19.39	3.77	32	70.3	2184
309	2	15.19	3.74	30	71.4	1673
310	4	15.80	3.70	28	70.7	1225
401	2	18.62	3.75	29	70.7	3415
402	10	24.22	3.57	34	72.8	2307
403	5	19.77	3.57	34	71.4	2692
404	8	17.28	3.96	27	70.3	2389
405	1	18.26	3.56	35	72.5	2049
406	6	21.87	3.99	41	70.3	2736
407	4	20.11	3.99	31	70.7	2379
408	9	21.69	3.69	27	69.9	1679
409	3	18.29	3.88	33	71.0	1155
410	7	18.97	3.87	27	66.7	1420