IMPACTS AND CORRECTION OF POTASSIUM DEFICIENCY IN NO-TILL AND STRIP-TILL SOYBEAN AND CORN PRODUCTION

by

SHANNON M. BLOCKER

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Approved by:

Major Professor
Dr. David B. Mengel

Abstract

This study was initiated to determine if potassium (K) deficiencies seen in soybeans (*Glycine max* (L.) Merr.) under no-till and strip-till production systems are impacting soybean yields, and if so, what fertilizer application practices including: rate of K application; broadcast or deep band methods of application; and the use of starter fertilizer at planting; could be used to correct the problem. The residual impacts of K fertilization and placement were also evaluated on corn (*Zea mays* L.) grown in rotation with soybeans.

This research was conducted on-farm in cooperation with local producers. Soybeans sites in 2007 were near Harris, Ottawa and Westphalia, Kansas with corn planted in 2008 at the sites near Ottawa and Westphalia. Soybean sites in 2008 were located near Ottawa and Welda, Kansas. Selected sites were generally near or below the current soil test K critical level of 130 mg per kg extractable K, based on sampling histories provided by the cooperators. Sampling in the spring of 2007 confirmed these soil test (ST) K levels. Soybean leaf tissue potassium levels in 2007 were less than the critical level of 17 mg per kg in the unfertilized control plots, and were significantly greater when potassium fertilizer was deep banded or a high-rate of K fertilizer was broadcast. No significant difference in yield of soybeans due to K fertilization was seen, likely due to significant water stress during the grain fill period, which severely limited soybean yield in 2007.

Soil test K levels at all the research sites increased dramatically between 2007 and 2008, even where no K was applied. Different weather conditions experienced these two years may have contributed to this occurrence. No residual impacts of K fertilization in 2007 on soybeans were seen in soil tests, corn leaf tissue K levels or corn yield in 2008.

Soybean sites in 2008 also showed a dramatic increase in K ST levels in 2008 as compared to farmer records. No effects of K fertilization on soybean growth or yield were seen in 2008. The 2008 Ottawa soybean site had very low P soil tests. A significant response to P

fertilization contained in the starter treatments was observed. This suggests that the dominant farmer practice of applying P and K fertilizer to corn, and not applying fertilizer directly to soybeans, even at low soil test levels, may not be supplying adequate P to soybeans, and is likely costing farmers yields and profits.

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CHAPTER 1 - Potassium Fertilization of Soybeans and Corn in Reduced Tillage Crop Production: A Literature Review

Potassium in Plants and Soils

Potassium (K) was discovered by Davy in 1807 and proven to be essential to plants by von Sachs and Knop in 1860 (Mills and Jones, 1996). Potassium controls the opening and closing of stomata to maintain plant water status and cell turgor pressure. Carbon dioxide also enters plant cells through stomata openings and as a result, potassium has an indirect control over photosynthetic activity. Potassium is involved in cellulose synthesis. The accumulation and translocation of newly synthesized carbohydrates, especially important during grain fill, also requires potassium (Mills and Jones, 1996).

Potassium is a macronutrient needed in large quantities by plants. Most soils contain between 11 and 56 Mg of potassium per hectare, but only 0.1 to 2% is readily available for use by plants. Potassium is tied up as a structural component of primary and secondary minerals and can be trapped between the sheets of clay minerals, referred to as K fixation. As much as 1 to 2 g of K may be fixed by 100 g of clay minerals, which makes it of agricultural importance in clay-containing soils. Most available K exists as a solute in the soil solution, or is absorbed as an exchangeable ion at the surface of soil colloids (Mills and Jones, 1996).

Potassium is absorbed as the K+ cation in greater quantities than the other required elements, with the exception of N. 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. Potassium uptake and the K concentration in plants are greatest during vegetative growth, with peak demand occurring during flowering and seed initiation. During peak demand periods, actively growing crops may take up as much as 3.4 to 4.5 kg of K per hectare daily. Potassium concentration in the plant declines as the season progresses due to dilution with starch in the developing grain (Mills and Jones, 1996; Sallam et al. 1985).

Potassium moves through soil primarily through a process known as diffusion – movement in response to concentration gradients in the water films around soil particles. It is a relatively slow process and as a result, rapid plant growth and uptake may deplete K in the soil around root surfaces. Adequate soil moisture and warm temperatures speed up the diffusion process making more K available to the root for uptake under these conditions. Fertilization may be needed to maintain adequate levels of exchangeable K, the primary source of K to the soil solution. Although potassium chloride (KCl) is the dominant potassium fertilizer source used in most of the world, potassium nitrate (KNO_3), potassium sulfate (K_2SO_4), and potassium-magnesium sulfate ($K_2Mg(SO_4)_2$ Sul-Po-Mag) are also used as fertilizer sources of K (Mills and Jones, 1996; Yin and Vyn, 2002).

Diffusion is also involved in the movement of K inside the root cells. Most cellular membranes are highly permeable to K making potassium is extremely mobile throughout the plant with the majority of K moving upward through the xylem to young tissue. Often K is redistributed from older to younger leaves in the plant. As a result, plant K deficiency symptoms first appear in older tissues (Mills and Jones, 1996).

Symptoms of K deficiency usually include a light green to yellow color around the edges and tips of older leaves. Over time, these leaves look as though they have been burned along the edges and become brittle, a deficiency symptom known as scorch. Since potassium is needed for carbohydrate translocation, plant growth is slowed with K deficiency as sugars and starch tend to accumulate where they are formed (Mills and Jones, 1996).

Specifically, potassium deficiency symptoms for soybeans involve yellowing, and then firing or scorching that begins on outer edge of lower leaves. This results in leaf edges that become broken and ragged as the leaf tissue dies. Potassium deficient soybeans are slow to defoliate and have delayed maturity. Soybean grain produced by K deficient plants is often shriveled, lacks uniformity and has low oil content.

Corn potassium deficiency results in visual symptoms including firing or scorching which appears on outer edges of lower leaves, while the midrib remains green. Leaves may appear yellow striped. Stalks are weakened and often lodge. Corn roots and nodal tissue are poorly developed or defective, while ears are chaffy and do not completely fill (International Plant Nutrition Institute, 1998).

Diagnosing K Deficiency

Plant nutrient sufficiency can be evaluated through plant tissue analysis at certain critical growth stages. Plant analysis is an effective tool to diagnose and/or confirm nutrient deficiency in a field crop (Plank, 1979) and can be used to identify nutrient problems before visual symptoms are observed. If problems are detected, actions may be taken to prevent severe nutrient deficiencies (Tisdale et al., 1985; Ulrich and Hills, 1967). To determine whether nutrient concentrations are adequate to produce maximum plant growth or seed yield, measured nutrient concentrations are compared with recommended critical ranges (Plank, 1979). Table 1.1 lists critical nutrient ranges for N, P and K, recommended sample size, plant part and growth stage for soybeans and corn.

Table 1.1 Critical Nutrient Ranges of N, P and K with Sampling Criteria for Soybeans and Corn adapted from Mills and Jones (1996).

Crop	Sample Size	Plant Part	Growth Stage	N	P	K
				g kg^{-1}	g kg^{-1}	g kg^{-1}
Soybean	25	youngest mature leaves	prior to pod set	40.0-55.0	2.5-5.0	17.0-25.0
Corn	12	ear leaves	initial silk	27.0-40.0	2.5-5.0	17.0-30.0

Sometimes a single critical value is used in plant tissue analysis for comparison. The definition of critical nutrient concentration is the concentration of a specific nutrient in a specific plant part at which growth or yield begins to decline (Yin and Vyn, 2004). Table 1.2 reports the critical nutrient concentration of N, P and K and crop development stage for soybeans and corn as reported by Melsted et al. (1969).

Table 1.2 Critical Nutrient Concentrations of N, P and K and Sampling Development Stage for Soybeans and Corn (Melsted et al., 1969).

Crop	Development Stage	N	P	K
		g kg^{-1}	g kg^{-1}	g kg^{-1}
Soybeans	Youngest mature leaves and petioles, on the plant after first pod formation		3.5	22.0
Corn	Leaf at, or opposite and below ear level at tassel	30.0	2.5	19.0

Factors Creating K Deficiency

Adequate to high soil moisture can enhance K availability to the plant. Conversely, dry or drought conditions can result in potassium deficiency symptoms due to reduced K availability. Conditions that impair root growth, such as soil compaction, can also lead to deficiency symptoms. These conditions reduce diffusion of K to plant roots in the soil (Barber, 1984; Sardi and Fulop, 1994; Fixen, 2000; Reetz and Murrell, 1998). Recently the incidence of K deficiency in agronomic crops has increased in Kansas due to drought conditions and soil compaction resulting in lower K diffusion rates. Other situations contributing to increased K deficiency include reduced amounts of applied K fertilizer, lower frequency of soil testing by producers due to low commodity prices, and higher K fertilizer requirements because of increasing corn and soybean yields and larger soybean acreage (Fixen, 2000; Reetz and Murrell, 1998).

Another potential cause of the increased incidence of K deficiency could be nutrient stratification in the soil profile. The increased use of no-till practices, resulting in surface release of nutrients from crop residues and less mixing of the soil in combination with surface K applications, result in greater soil K concentrations at and near the soil surface with reduced levels just a few centimeters below (Bruulsema and Murrell, 2006). This is commonly referred to as vertical nutrient stratification. Under normal conditions, no-till crops tend to obtain a higher percentage of their nutrients from the surface few centimeters of soils, taking advantage of this zone of high nutrient concentration and the higher soil moisture content at the surface maintained by crop reside. Utilizing surface K can create availability problems, however, when conditions are not normal. If the soil surface is dry, plants can compensate by rooting deeper into the soil profile in search of moisture. But this places the roots below the level of high nutrient concentration and may lead to deficiency. On the other hand, if the soil surface layer is too wet and cold, especially early in the growing season, root growth can be inhibited limiting K uptake (Mallarino and Murrell, 1998). Horizontal nutrient stratification can also occur due to uneven crop residue distribution and associated nutrient release. Higher nutrient concentrations are found near previous crop rows versus between rows. In addition, the practice of banded fertilizer placement, especially several applications in nearly the same location, can increase horizontal nutrient stratification (Bruulsema and Murrell, 2006). Consequently, proper placement of fertilizer K may be critical for optimizing yields in no-till systems (Mallarino and Murrell, 1998).

Despite the fact that nutrient stratification, particularly vertical stratification, commonly exists in long-term conservation- and no-till fields (Holanda et al., 1998; Howard et al., 1999; Karathanasis and Wells, 1989; Yin and Vyn, 1999), research has exhibited mixed results regarding its importance for leaf K concentration or grain yield. Yin and Vyn (2004) concluded that greater critical leaf K concentrations were apparently needed for conservation tillage systems compared to conventional tillage (moldboard plow) systems to obtain optimum soybean production, including both yield and grain quality. However, they also reported that neither leaf K nor seed yield was negatively affected by degree of soil K stratification and that there was no yield benefit to replacing narrow-row, no-till surface applied K soybean systems for systems where K could be incorporated or deep placed (Yin and Vyn, 2002).

When considering K placement in a no-till system, particular attention has been paid to significant effects resulting from the coulter and knife pass compared to no soil disturbance. Researchers have designed experiments with two zero fertilizer application controls, one with and one without a coulter and knife pass. Overall, they found that the physical effects of the coulter and knife pass did not create a yield response and that any response to deep-banded K could not be attributed to the related soil disturbance (Bordoli and Mallarino, 1998; Borges and Mallarino, 2003; Buah et al. 2000). Bordoli and Mallarino (1998) reported that for long-term trials at research centers the two controls differed at only two of fifteen sites, while short-term trials on farmer fields differed at only one of eleven sites, with increased yield for the coulter and knife pass control in all three situations. The two controls did not differ for grain yield, early plant growth or K uptake in any trial for Borges and Mallarino (2003). Buah et al. (2000) found that the soil disturbance from deep banding fertilizer only influenced K concentration in the plant at one of four sites and yield at a different one of the four sites. In this study, yields were actually reduced by the coulter and knife pass.

Potassium Fertilization

Research has shown differences in the response to fertilizer application and method of fertilizer application between corn and soybeans. Corn is more responsive in terms of early growth to potassium and/or phosphorus fertilization (Ebelhar and Varsa, 2000; Rehm et al., 1988; Randall and Hoeft, 1988), and grain yield of corn was affected to a greater degree than soybeans by K placement and rate (Ebelhar and Varsa, 2000).

It is a common practice in the Midwest to not directly fertilize soybeans with potassium, but instead rely on residual fertilization from the previous crop. In an effort to evaluate the suitability of this practice, researchers have included both direct and residual K fertilization strategies in their studies. Buah et al. (2000) and Rehm and Lamb (2004) found that residual and direct K fertilization resulted in similar grain yields. Borges and Marllarino (2003) found that in terms of dry weight response, only one of seven soybean sites receiving direct fertilization responded, while three of seven residual sites responded. Potassium fertilization significantly increased K uptake by whole plants at V5 to V6 at four of seven sites receiving direct fertilization and six of seven sites based on residual applications (Borges and Mallarino, 2003). However, it should be noted that soil test K levels were all classified as optimum or above prior to the initiation of these studies, indicating that that response to applied K would not be expected. Interestingly, Rehm and Lamb (2004) also reported that two direct applications (one to corn and one to soybeans) produced higher soil test K values than a single application, which supplied the same rate of K as two direct applications at two of three sites.

As mentioned previously, nutrient concentrations in certain plant parts at specific growth stages is a tool used to evaluate nutrient sufficiency. However, these historic critical levels and/or ranges were estimated based on data from soybeans grown in conventional tillage, wide-row spacing systems. Yin and Vyn (2004) suggest that soil properties resulting from no-till practices such as soil test K distribution together with altered soybean root distribution would influence leaf K concentrations needed for optimum soybean production. Their results showed that soybean produced using a fall disk system had slightly lower critical values of midseason leaf K than those produced under no-till management. Specifically, they reported that when data from both conservation- and no-till practices in all site-years were pooled, the critical leaf K concentration at the initial flowering stage (R1) of development was 24.3 g kg^{-1}, but when using only the no-till treatments in the analysis, the critical leaf K concentration was 25.9 g kg^{-1} for maximum soybean yield. Soil-test K levels were in the low range for all 3 years at one site, medium for all three seasons at another, but were very high, high and medium at the third site, according to the Ontario soil-test K interpretations. They suggested that their use of narrow row widths instead of wide rows and the associated improvement in soybean yield also may have contributed to the greater critical leaf K values in this study compared with the previously reported critical leaf K values. They concluded that greater critical leaf K concentrations for conservation-till production systems may be required to deliver correct interpretations of leaf K analysis results to soybean producers (Yin and Vyn, 2004).

Soil test K is frequently and highly correlated with K concentration in soybean or corn plant tissue and K uptake. For soybeans, this relationship is frequently linear, which suggests soybeans will accumulate K over a wide range of soil K supplies (Borges and Mallarino, 1998).

Potassium fertilization frequently increased leaf K concentrations on medium or low K testing soils (Hudak, 1989; Yin and Vyn, 2002; Yin and Vyn, 2003; Yin and Vyn, 2004). However, conflicting results are reported for soils where K levels were adequate or higher. Some found that potassium fertilization had no significant effect on K leaf concentration when soil test K levels were adequate or higher (Buah et al., 2000; Rehm, 1995; Rehm and Lamb, 2004). In contrast, Borges and Mallarino (2000; 2003) reported that K fertilization increased K uptake at sixteen of thirty total sites (long-term and short-term trials combined) (2000) and ten of fourteen sites (2003) where soil test K levels were optimum or higher. K fertilizer resulted in significantly greater concentrations of K in all plant parts at all stages of growth according to Hanway and Weber (1971).

Potassium fertilization rate often influences K uptake by soybeans, even at sites where soil test K levels were categorized as optimum or higher. Borges and Mallarino (2000) found that at five of twenty long-term trial sites, K uptake increased with higher fertilization rate versus a low rate. Similarly, within the same placement method, the application of a high rate of K fertilizer often produced significantly higher K uptake than the low rate (Borges and Mallarino, 2003). The significance of K uptake differences in these studies was in contrast with other plant measurements such as grain yield and early growth (Borges and Mallarino, 2000; Borges and Mallarino, 2003). Others also found that increasing K fertilizer rate increased soybean plant tissue K content (Ebelhar and Varsa, 2000; Hudak et al., 1989). Corn also responded to increasing K fertilization rates by increasing K uptake (Ebelhar and Varsa, 2000; Rehm and Lamb, 2004).

Generally, response to K placement in terms of leaf K concentration or K uptake was less than the response to K rate, which may account for the wide discrepancies seen between results. Two studies concluded that there were no significant difference at early reproductive stages in leaf K between broadcast and banded treatments (Yin and Vyn, 2002; Ebelhar and Varsa, 2000). However, both an advantage to banded K fertilizer over broadcast placement (Yin and Vyn, 2003; Yin and Vyn 2004) and a disadvantage of banded K over other placement methods (Hudak et al., 1989) in terms of leaf K have also been reported. An advantage for banded K was seen on low to medium testing K soils (Yin and Vyn, 2003; Yin and Vyn 2004), while a disadvantage occurred on high K testing soils (Hudak et al., 1989). Soils that did not respond to K fertilizer placement in leaf K concentration ranged from low to high in K fertility (Yin and Vyn, 2002; and Ebelhar and Varsa, 2000).

Analysis of whole plants to estimate K uptake resulted in similar conflicting results where soil test K levels were all optimum or greater. Borges and Mallarino (2000) reported that K fertilizer placement resulted in a significant response in seven of twenty long-term studies sampled at V5. Of these, K uptake was greater for broadcast placement in six cases and for deep band placement in one case. Short-term studies conducted during the same time-frame found one significant advantage for deep band placement in K uptake out of ten sites (Borges and Mallarino, 2000). Later, Borges and Mallarino (2003) reported that whole plant samples taken at V5 or V6 revealed greater rates of K uptake for deep band placement over broadcast at nine of fourteen sites. They stated that large and frequent K uptake responses to band K compared with broadcast K at many sites indicated that the deep K placement increased fertilizer-use efficiency (Borges and Mallarino, 2003). Broadcast K placement often produced lower whole plant K composition of corn or soybean tissue than banded K, when sampled within a month after emergence. This suggests that broadcast placement is less efficient than other placement methods in providing K in the early stages of plant development (Ebelhar and Varsa, 2000). A crop modeling experiment by Kovar and Barber (1987) found that when K levels in the soil were initially low, the maximum K uptake occurred where the fertilizer was placed in 5 to 20% of the soil volume, a larger soil volume than normally observed with banding.

Despite seeing common responses in K uptake, leaf K and whole plant K concentration to K fertilization, increasing K rate and/or alternative placement methods, these responses do not always correlate with or guarantee yield increases (Rehm and Lamb, 2004; Borges and Mallarino, 2003; Yin and Vyn, 2002). Frequently observed increases in K use efficiency without yield response suggests that young soybean plants have high limits for luxury uptake of K (Borges and Mallarino, 2003). However, increased leaf K at initial flowering was indicative of soybean yield responses to K application in four of six site-years (Yin and Vyn, 2002).

Yield response is the driving force in potassium fertilization decisions made by soybean and corn producers due to its direct impact on potential profits and/or losses. Yield increases due to K fertilization have been commonly reported where soil test K levels were categorized as low and medium (Buah, 2000; Yin and Vyn, 2002), while no yield response often was seen where the soil was high in K fertility (Buah, 2000; Rehm and Lamb, 2004; Yin and Vyn, 2002). However, some yield responses to K fertilization have been seen at high soil test K. In long-term trials, Borges and Mallarino (2000) reported increased soybean yields with K fertilization at five of twenty sites and the analysis across all trials showed a small, significant yield response to K fertilization. In another study, they found that in only two of fourteen sites, potassium fertilization increased soybean yield (Borges and Mallarino, 2003). In neither situation did the greatest potassium fertilizer response occur where the soil test K was the lowest, and the response was not correlated with soil test K at any depth (Borges and Mallarino, 2000; Borges and Mallarino, 2003). Other factors, such as rainfall, may have contributed to the observed yield responses to K fertilization (Borges and Mallarino, 2003). Similar discrepancies have been seen in corn yield response to K fertilization (Bordoli and Mallarino, 1998; Mallarino and Murrell, 1998).

Soybeans often show no or only a minimal yield response to increasing potassium fertilizer rate. Borges and Mallarino (2003) reported no difference in yield response to K rates of 33 and 132 kg ha^{-1}. The lowest of three rates of potassium fertilization rates (56 instead of 112 or 168 kg K ha^{-1}) resulted in the greatest soybean yield when averaged across years and locations for Ebelhar and Varsa (2000). They concluded that this was due to the sensitivity of soybean to salt concentration at high rates of fertilizer. Increasing K fertilizer rate from 0 to 37 kg ha^{-1} K increased grain yield, but another increase to 75 kg ha^{-1} K did not further increase yield in research by Hudak et al. (1989). Corn more often responded to increased K fertilizer rates (Ebelhar and Varsa, 2000), but also displayed no yield response in cases of high soil K fertility (Bordoli and Mallarino, 1998; Rehm and Lamb 2004).

Most of the research using starter K fertilizer has been conducted in soils categorized as high in potassium. Ham et al. (1973) reported that starter placed either in-furrow, 5 cm to the side and 5 cm deep, or both starter placements in combination without broadcast fertilization did not result in a yield response greater than broadcast fertilization alone in high K soils. No yield advantage to banded starter was seen by Buah et al. (2000). However, Gordon (1999) found that starter fertilizer (7-21-7) increased yields of both soybeans and corn in ridge-till, except where excessive amounts were applied in contact with the seed, which reduced stands due to the high salt content of the fertilizer. In contrast, in the only soybean study reporting low fertility, no soybean yield response was reported by Rehm et al. (1988) to 7-21-7 starter fertilizer.

Soybean yield response to concentrated fertilizer placement (deep or surface banding) as reported in published research literature has been highly variable. Yin and Vyn (2003) reported a 10 to 15% soybean yield increase when K fertilizer was deep-banded in or near the row compared with zero K fertilization or surface broadcasting of similar rates, which were not significantly different. At the lower of two K fertilizer rates, Hudak et al. (1989) found that the three more concentrated placements (deep band, 12% surface, and 25% surface coverage) produced greater yields than the zero K rate, while the three less concentrated placements (50% surface, 75% surface, and 100% surface coverage) did not. Two of three Mississippi soils in no-till soybeans responded to banded P and K over broadcast applications (Hairston et al., 1990). Responses, though significant, were generally small. In some cases, the number (or percentage) of individual site-years showing a significant advantage to deep-band placement was small (Borges and Mallarino, 2000; Borges and Mallarino, 2003; Rehm et al., 1988), but an over all analysis across all site-years was significant (Borges and Mallarino, 2000). This likely occurred due to the additive effect of many small non-significant yield advantages seen with deep-band placement. Differences in row spacing (Borges and Mallarino, 2000), K fertilizer rate (Hudak et al., 1989), tillage (Hairston et al., 1990) and soil K fertility (Rehm et al., 1988) have been proposed as reasons for conflicting or contrasting responses to K fertilizer placement. However, even in a case where lower soil K fertility might cause one to expect a significant yield response to K deep-band placement over broadcast, none was observed (Yin and Vyn, 2002). In contrast to a response seen in long-term trials, no yield response to placement was seen in short-term trials planted in narrow rows by Borges and Mallarino (2000). Ebelhar and Varsa (2000) even reported a small significant yield advantage at one of four sites in favor of broadcast over surface banding.

Corn yield response to K containing fertilizer placement also varied between studies. In one study, placement of P and K had a significant effect on corn yield when soil test levels for P and K were in the low range, but not when they were high. Greatest yield responses generally resulted from a combination of subsurface band with a starter fertilizer (Rehm et al., 1988). In contrast, responses observed by Bordoli and Mallarino (1998) have seemed more related with deficient rainfall in late spring and early summer than with soil test K. Often corn yield advantages with deep band K placement were small (Bordoli and Mallarino, 1998; Mallarino and Murrell, 1998) and would rarely offset the higher application costs (Bordoli and Mallarino, 1998). Potassium placement had no significant effect on corn yields in research by Ebelhar and Varsa (2000).

Soybean protein and oil are becoming increasingly important as new and expanding soybean markets are continually developed. However, the impact of K fertilization and/or placement on these seed quality factors has been evaluated in few research studies. Ham et al. (1973) reported that seed protein and oil were not significantly influenced by treatments, which included two application methods of K-containing starter and broadcast K fertilizer applications. In contrast, Yin and Vyn (2003) reported small, but significant decreases in soybean seed protein resulting from K fertilization. Deep-banded K treatments lowered protein concentrations more than surface broadcast K. Soybean oil concentrations responded exactly opposite to the response observed for protein. Banded K treatments significantly increased oil concentrations, while surface broadcast did not increase oil levels relative to zero K (Yin and Vyn, 2003). Adequate K availability increases the rate of carbohydrate transport and production which enhances oil content. The increased oil content dilutes protein content in the seed, resulting in lower protein concentrations.

Consideration also must be given to the impacts that fertilizer placement methods have on future soil tests and soil testing procedures. In no-till production, concentrated placement methods such as deep-banding, surface-banding and use of starter fertilizer have altered both horizontal and vertical stratification of nutrients (Mallarino and Borges, 2006). Potassium is known as an immobile soil nutrient. This was confirmed by a detailed soil sampling procedure showing limited or no movement of K from the placement of the band (Rehm and Lamb, 2004). A shallow sampling depth (i.e., 5-7 cm) has sometimes been recommended for vertically stratified no-till fields (Borges and Mallarino, 2006), but research has shown that the 15-20 cm sampling depth recommended for tilled soils is more appropriate for fields where deep-band fertilizer has been used (Borges and Mallarino, 2006; Rehm and Lamb, 2004). In addition, both no-till and chisel-disk tillage has been found to significantly increase K soil test levels in the row as compared with between rows, with a greater degree of difference found where no-till practices were implemented (Mallarino and Borges, 2006). Contradictory results for fields in ridge-till were reported by Mallarino and Borges (2003), in that broadcast K usually did not increase soil test K in the valleys between rows and deep-banded K did not increase soil test K in the 15- to 30-cm layer of the ridges. Current soil sampling procedure recommendations for plots or fields that have received deep-banded fertilizer applications include the use of 15- to 20-cm deep cores (Mallarino and Borges, 2006; Rehm and Lamb, 2004) and in-the-band/row sampling when the location of the bands are approximately known. A random sampling pattern with more cores per composite sample is suggested if the location of the bands in uncertain or unknown (Mallarino and Borges, 2006).

Summary

Short- and long-term potassium availability limitations have led to potassium deficiency symptoms in both soybeans and corn. These limitations can include dry soils, low temperatures, soil compaction, decreasing native levels of K in the soil, and vertical and horizontal stratification of nutrients.

Potassium uptake is often increased with increasing K fertilization rate. Also, as soil test K increases up to optimum levels, K uptake increases. This trend also occurs where soils have more than adequate soil test K levels. Potassium uptake is less responsive to different methods of K placement and there is discrepancy within the literature concerning the most effective placement method. In a study with lower soil test K levels, a positive response to banded K fertilizer was seen. However, at high soil test K levels, responses included an increase in K uptake due to both banding and broadcast K fertilization. Studies that revealed no significant differences in potassium uptake due to K placement strategies ranged from low to high K fertility.

Increases in leaf K and/or K uptake were commonly seen in corn and soybeans with K fertilization, increasing rate of K fertilization and sometimes with alternative placement such as surface or deep banding. However, increases in yield were less common, as yield also was influenced by environment.

A yield increase resulting from K fertilization was most common on low to medium K testing soils, but sometimes occurred at high soil test K sites. Soybeans rarely had an increased yield response due to increased K fertilization rates. Corn responded to increased K rates more often. Much like K uptake, yield response due to K fertilizer placement was highly variable. Where significant differences were reported, a small yield advantage was most often seen resulting from banded placement, but was also seen for broadcast treatments. Several studies reported no significant differences. Only one of four studies showed a yield response to starter fertilizer. K fertilizer placement response was not well correlated with soil test. Soil moisture, compaction and tillage all seem to have additional effects on K response.

The stratification of potassium, both vertically with depth and horizontally with greater concentrations near the row area and lower levels in row middles is common today due to expanded use of no-till or reduced till production systems. The impact of K deep banding to offset effects of stratification have been mixed. However most of this research has been done in the eastern US and Canada, where frequent and adequate rainfall helps create an environment near the soil surface, where K is concentrated, that allows or promotes root activity and nutrient uptake.

Soybeans contain large quantities of P and K in the seed, and as a result have been shown to be less responsive to starter fertilizers, especially early in the growing season, than corn. Responses to small quantities of K-containing starter fertilizer have been mixed.

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CHAPTER 2 - Potassium Fertilizer Placement for No-till and Strip-till Soybeans in East Central Kansas

Introduction

Potassium deficiency has been increasing in Kansas over the past decade. Although many Kansas soils were naturally high in K, continued removal of K from soils by crops, especially high K extracting crops such as soybeans, have reduced soil test K levels over time. Deficiency symptoms are becoming more common, especially on the older, more highly weathered soils of East Central and Southeastern Kansas.

The use of reduced tillage systems has raised a second concern: potassium stratification and positional unavailability. Vertical stratification is when greater soil K concentrations are at and near the soil surface with reduced levels just a few centimeters below (Bruulsema and Murrell, 2006). Uptake of K from the root zone coupled with surface fertilization and deposition from residue on the surface often results in vertical stratification of K in no-till fields (Holanda et al., 1998; Howard et al., 1999; Karathanasis and Wells, 1989; Yin and Vyn, 1999). Although crop residue left on the soil surface helps maintain soil moisture and allows soybeans to utilize this zone of concentrated K, when this zone is either too wet or very dry, K uptake is limited and K deficiency can occur (Mallarino and Murrell, 1998). Residue nutrient deposition in relation to former crop rows or the use of repeated banded K treatments may lead to horizontal stratification. This could limit K availability if roots cannot reach this high K zone. Although nutrient stratification has been shown to occur (Holanda et al., 1998; Howard et al., 1999; Karathanasis and Wells, 1989; Yin and Vyn, 1999), in many cases the degree of stratification present did not have a significant impact on soybean leaf K content or yield (Yin and Vyn, 2002).

Potassium fertilizer deep placement has been proposed as a method to combat K availability problems. A band of K-containing fertilizer is placed 10-20 cm below the soil surface, near or directly under the intended crop row. In vertically stratified soils this is often a K deficient zone. By placing the K at this depth, moisture extremes which might limit K uptake from the soil surface are less likely to occur.

Potassium fertilization often increases K uptake (Borges and Mallarino 2000; Borges and Mallarino, 2003) and K plant tissue content (Ebelhar and Varsa, 2000; Hudak et al., 1989) in soybeans, even at sites where soil test K levels were categorized as optimum or higher. Responses to K fertilization are frequently greater than responses to K placement in terms of leaf K concentration or K uptake. These smaller differences due to placement may contribute to the wide range of responses reported to K placement. Increases in leaf K concentration or K uptake from deep banding as compared to broadcast placement occurred most frequently on low to medium K testing soils (Yin and Vyn, 2003; Yin and Vyn 2004), while the response was reversed, with lower soybean leaf K concentration from deep banding as compared to broadcasting on a high K testing soil (Hudak et al., 1989). No significant differences in K uptake or leaf K attributed to K placement were reported on sites ranging from low to high soil test K by Yin and Vyn (2002) and Ebelhar and Varsa (2000).

A K uptake or leaf tissue K response to K fertilization and/or placement of banded K does not always carry over into yield responses (Rehm and Lamb, 2004; Borges and Mallarino, 2003; Yin and Vyn, 2002). Where soil test K levels were categorized as low and medium, yield increases due to K fertilization have been reported (Buah, 2000; Yin and Vyn, 2002), while no yield response was often seen where the soil was high in K fertility (Buah, 2000; Rehm and Lamb, 2004; Yin and Vyn, 2002). Borges and Mallarino (2000; 2003) reported a small number of yield responses to K fertilization at high soil test K, but state that other factors, such as rainfall, may have led to the K fertilization yield responses.

Soybeans often show no or only a minimal response to increasing K fertilizer rate (Bordoli and Mallarino, 1998; Borges and Mallarino 2003; Ebelhar and Varsa 2000; Hudak et al. 1989; Rehm and Lamb 2004).

Rarely has there been a yield response to starter K fertilizer, but most of the research has been conducted on optimum or higher K fertility soils where a response to K would not be expected (Buah et al. 2000; Ham et al. 1973). One site reported as low fertility also did not have a significant response to starter K fertilizer (Rehm et al. 1988). The only significant response to starter fertilizer occurred with soybeans grown in a ridge-till system. Soils at this site were categorized as high K (Gordon 1999).

Banded K fertilizer, either surface band or deep band, has resulted in highly variable yield responses. Small, but statistically significant increases in yield due to banded or more concentrated fertilizer application treatments were reported in some studies (Borges and Mallarino, 2000; Hairston et al., 1990; Hudak et al., 1989; Yin and Vyn, 2003). The portion of site-years within a study with significant increased yield response to banded K fertilizer was small in many cases (Borges and Mallarino, 2000; Borges and Mallarino, 2003; Rehm et al., 1988). However, in research where a treatment response would be expected due to low K fertility, no significant differences were seen between banded and broadcast fertilizer treatments (Yin and Vyn, 2002). Long-term versus short-term studies conducted by the same researchers even had different results. In long-term trials, banded fertilizer significantly increased yield, but no significant differences were found for the short-term trials (Borges and Mallarino, 2000). Broadcast treatment even resulted in a significantly greater yield over surface banding at one of four research sites in a study by Ebelhar and Varsa (2000).

The impact of K fertilization and/or placement on soybean protein or oil content has been studied in only a few trials. No significant differences to treatments were reported by Ham et al. (1973). Yin and Vyn (2003) reported small significant increases in oil and decreases in protein content resulting from K fertilization. Likewise, banded K increased oil content and decreased protein content relative to broadcast treatments (Yin and Vyn 2003).

Generally, the largest responses to treatment have occurred due to K fertilization rather than placements, especially on low soil test K soils. Alternative potassium fertilizer placement methods, such as deep banding and K-containing starters, have had highly variable impacts on many factors, including leaf K concentration and yield.

This study was initiated to determine if the observed K deficiencies seen in soybeans under no-till and strip till in East Central Kansas are impacting soybean yields and if so, what fertilizer application practices, including rates of broadcast, deep band, or starter may be used to correct the problem.

Materials and Methods

Research was conducted on-farm in cooperation with local producers. Research sites were established near Harris, Ottawa, and Westphalia, Kansas, in 2007, and near Ottawa and Welda, Kansas, in 2008. Soils at the selected sites were classified as:

Table 2.1 Soil Classification by Site.

Location	Series Name	Scientific Classification
2007 Soybeans		
Harris	Woodson silt loam	Fine, montmorillonitic, thermic, Abruptic Argiaquoll
Ottawa	Woodson silt loam	Fine, montmorillonitic, thermic, Abruptic Argiaquoll
Westphalia	Summit silty clay loam	Fine, smectitic, thermic Oxyaquic Vertic Argiudolls
2008 Soybeans		
Ottawa	Lula silt loam	Fine-silty, mixed, active, thermic Typic Argiudolls
Welda	Kenoma silt loam	Fine, smectitic, thermic Vertic Argiudolls

Sites near Harris, Welda and Westphalia were all in Anderson County, Kansas, while sites near Ottawa were in Franklin County, Kansas. All were rainfed and received no supplemental irrigation. In Anderson County, the 30-year mean annual rainfall total is 1016 mm. At Ottawa, the 30-year mean annual rainfall total is 996 mm (Kansas Weather Data Library, 2009). Each site had at least a four-year history of no-till production practices before the experiments were initiated. Selected sites were generally near or below the currently used Kansas soil test K critical level of 130 mg kg^{-1} extractable K.

A randomized complete block design with four replications was used at each site. Crops were planted in 0.76-m rows and each plot consisted of four rows (3.0-m) and was 15.2-m long. At least one 3.0-m border flanked the plots and a full plot length (15.2-m) separated each replication. Eight different combinations of K rates and fertilizer placement methods were applied to soybeans at each location in both years (Table 2.2).

Table 2.2 Potassium Fertilizer Rate and Placement Method Treatments.

Treatment No.	Treatment Abv.	Treatment Description
1	C	Unfertilized Check
2	B55.9	Broadcast 55.9 kg ha^{-1} K
3	B112	Broadcast 112 kg ha^{-1} K
4	D55.9	Deep Band 55.9 kg ha^{-1} K
5	D112	Deep Band 112 kg ha^{-1} K
6	S9.8	Starter 9.8 kg ha^{-1} K
7	S9.8+B55.9	Starter 9.8 kg ha^{-1} + Broadcast 55.9 kg ha^{-1}
8	S9.8+D55.9	Starter 9.8 kg ha^{-1} + Deep Band 55.9 kg ha^{-1}

Starter treatments were applied at planting 5-cm to the side and 5-cm below the row. Liquid 7-21-7 fertilizer was the starter source. Deep band fertilizer was placed approximately 15-cm directly below and less than 5-cm to the side of the row with a strip-till applicator. Dry potassium chloride (0-0-60) fertilizer was used for both broadcast and deep band treatments. Separate control treatments to evaluate the soil disturbance resulting from the use of the strip-till applicator and/or starter attachments on the planter were not used as a review of all similar published studies showed very little or no significant response to these practices.

One composite soil sample consisting of 0.15-m deep cores randomly collected from each replication at all soybean sites prior to planting was used to determine initial soil fertility. Soil pH was measured using a 1:1 (soil:water) method. Other soil analysis and methods used include phosphorus by Mehlich-3, potassium by NH_4OAc extraction, and organic matter by modified Walkley-Black. Additional analysis and methods completed on the 2007 soybean sites included texture by hydrometer and cation exchange capacity by summation.

Varieties planted were adapted to the region and selected by the cooperating producers. Seeding rates, planting dates, harvest dates, varieties and relative maturity are summarized in the following table:

Table 2.3 Soybean Varieties, Characteristics, Planting and Harvest Details.

Location	**Variety**	**Relative Maturity**	**Seeding Rate (seeds ha^{-1})**	**Planting Date**	**Harvest Date**
2007 Soybeans					
Harris	Taylor 477RR/STS	4.7	296,500	6/13/07	10/26/07
Ottawa	NK S49-Q9	4.9	296,500	6/7/07	10/24/07
Westphalia	Taylor 477RR/STS	4.7	296,500	6/5/07	10/26/07
2008 Soybeans					
Ottawa	NC+ 4A42RR	4.4	296,500	6/19/08	10/28/08
Welda	Hoegemeyer 425NRS	4.2	296,500	6/4/08	11/3/08

Fertilizer treatments were applied at Harris on June 13, 2007, at Ottawa on May 22, 2007, and at Westphalia on June 5, 2007. Treatments for 2008 soybeans were applied on May 21, 2008, at both the Ottawa and Welda sites.

Herbicide application(s) were applied to the plots along with the surrounding bulk field by the producer. Although the soybean variety planted at Welda was glyphosate-tolerant, control of marestail (*Conyza canadensis*) was poor and were hand-pulled from the plot on June 30, 2008, and July 1, 2008.

Fields were scouted for signs of K deficiency on an approximately weekly basis by walking between non-harvest rows, but none were observed. Thirty trifoliate leaves without the petioles were collected from each plot twice during each growing season from non-harvest border rows of each plot, once at pod set (early) and once at pod fill (late). Samples were dried in a forced air oven at 60°C for a minimum of 4 days and once dry, were ground with a Wiley grinder, digested with a sulfuric acid and hydrogen peroxide digest and analyzed for N, P and K content.

In 2007, whole plant samples from C, S9.8+B55.9 and S9.8+D55.9 treatment were taken at pod fill by cutting four 0.9-m row lengths (non-harvest rows) off at ground level from the Harris and Ottawa sites. The Westphalia site was excluded due to environmental conditions resulting in very small plants. This subset of treatments was selected to include starter treatments likely to show increased early growth and to consider broadcast versus deep-band treatment impacts. Plants were weighed and dried in a forced air oven at 60°C for a minimum of four days and weighed for biomass calculation. Once dry, the plants were ground with a Wiley grinder, digested with a sulfuric acid and hydrogen peroxide digest and analyzed for N, P and K content. Tissue samples for soybeans were collected on the following dates:

Table 2.4 Soybean Tissue Sampling Dates.

Location	Early Trifoliate	Late Trifoliate	Whole Plant
2007 Soybeans			
Harris	7/19/07	8/30/07	9/20/07
Ottawa	7/19/07	8/30/07	9/20/07
Westphalia	7/19/07	8/30/07	-
2008 Soybeans			
Ottawa	7/23/08	8/28/08	-
Welda	7/23/08	8/28/08	-

The two center rows (22.3-m^2) of each plot were machine harvested for soybean yield. Grain weight was recorded and adjusted to 130 g kg^{-1} moisture. Soybean test weight data was also recorded. Grain was dried at 60°C for a minimum of four days, ground to a powder and digested with a sulfuric acid and hydrogen peroxide digest. Samples were then analyzed as previously described for leaf samples. In 2007, soybean grain protein and oil content in samples from the Harris and Ottawa sites were evaluated by a commercial laboratory.

Each site was separately analyzed using SAS proc GLM and Fisher's Protected LSD (SAS, 2007) to determine if there was a response to K treatments for soybean leaf tissue K concentration, biomass, harvest index, yield, grain K concentration, protein and oil ($\alpha = 0.05$). All site years together were then analyzed for treatment, location and treatment x location interaction effects.

Results and Discussion

Initial soil test K levels are presented in table 2.5. The critical soil test K value is 130 mg kg^{-1}. One site, Harris, had K concentrations in the low category, two sites, Ottawa 2007 and Westphalia, were in the medium category, and one site, Ottawa 2008, had K concentrations classified in the very high category (Leikam et al., 2003). The mean of replications 1-3 at Welda was 119 mg kg^{-1} K, which would be classified as medium K concentration, while replication 4 at 182 mg kg^{-1} K was very high. The mean of all replications for the Welda site would be classified as sufficient K concentration (Leikam et al., 2003). Harris, Ottawa 2007, Westphalia, and replications 1-3 at Welda would be expected to respond to K fertilizer.

Table 2.5 Initial Soil Test K by Site.

		2007			2008	
Plots	Depth	Harris	Ottawa	Westphalia	Ottawa	Welda
	(cm)	K (mg kg^{-1})				
101-108	0-15	89	100	104	153	116
201-208	0-15	63	102	105	169	124
301-308	0-15	74	106	102	179	117
401-408	0-15	53	94	89	178	182
Mean	0-15	70	100	100	170	135

Other soil test data averaged by site is presented in Table 2.6. The soil pH at all sites except 2008 Ottawa were in the recommended range for soybean growth. Soil pH for 2008 at Ottawa was low, but no lime was applied. Phosphorus levels were above the critical value of 20 mg kg^{-1} (Leikam et al., 2003) at three sites: Harris, Westphalia and Welda. At both Ottawa sites, P concentration would be classified as low (Leikam et al., 2003). No uniform applications of P were applied, but starter treatments contained 15.4 kg ha^{-1} P. Corresponding results will be discussed later. Organic matter contents were at commonly observed levels for these soils.

Table 2.6 Average Soil Test Values by Site.

Year	Site	pH	Buffer pH	P (mg kg^{-1})	O.M. (g kg^{-1})
2007	Harris	7.2		21	31
2007	Ottawa	7.6		10	29
2007	Westphalia	6.9		22	23
2008	Ottawa	5.9	6.5	7	
2008	Welda	6.8		22	26

Environmental conditions in the two years of this study were very different. In 2007, conditions early in the growing season were generally dry, but a non-uniform rainfall pattern severely impacted soybean growth and development at the Westphalia site. The soybeans at this site remained less than 0.4 m in height and never closed the canopy. Then in late June, over a 3 day-period, the area received approximately 53 cm of rainfall. At the Harris site, the West half of the plot was under standing water for about 5 days. On this half of the plot, the soybeans did not die, but instead grew noticeably bigger than those on the East half. Following the large rainfall event, it turned dry again. Inadequate moisture at critical stages likely limited soybean yields more than K fertility at this site.

In 2008, growing conditions were very good. Soils were wet at the Ottawa 2008 site which delayed planting about 1 ½ weeks. Rainfall was generally timely and allowed for excellent soybean yields under dryland conditions. The sites selected in 2008 were expected to have low to medium K soil tests, but were found to have soil test K levels of optimum or higher when tested at planting. Again, K fertility likely was not the limiting yield factor.

None of the sites in either year had visual potassium deficiency symptoms when scouted throughout the growing season.

Leaf tissue potassium concentration measured at two times during the growing period provides a relative comparison of potassium uptake by the soybean plants. Treatment means for each location are presented in Table 2.7.

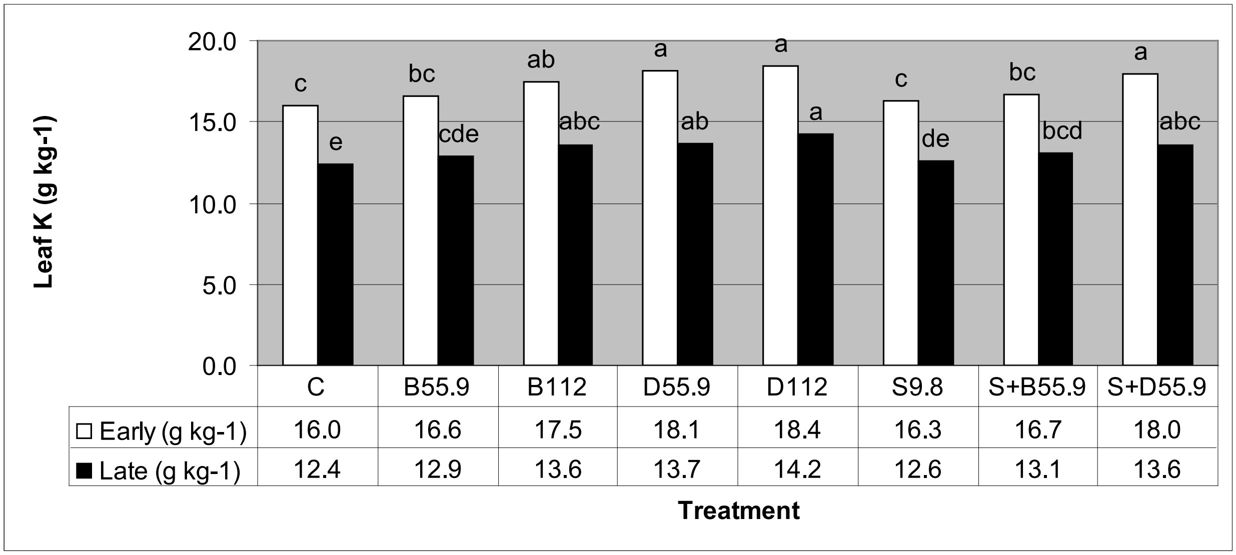
Five of the six site-samplings had significant differences in leaf tissue K concentration in 2007. At Harris, there were no significant differences at the early sampling, but for the late sampling, the high-rate deep band treatment had a significantly greater K concentration than all other treatments. For Ottawa 2007, the three deep placement treatments were significantly greater in K concentration at the early sampling than the other treatments. High-rate deep band was also significantly greater at the late sampling. At Westphalia, there was a significant advantage to K deep placement at the early sampling. For the late sampling, K concentration was significantly greater with the deep band placement and high-rate broadcast treatments than the control. There were no significant differences in leaf tissue potassium concentration at either sampling time for both 2008 sites.

Table 2.7 Average K Concentration in Soybean Leaf Tissue at Pod Set (Early) and Pod Fill (Late) by Treatment and Site.

	g kg^{-1} K in Leaf Tissue									
	2007						2008			
K App.	Harris		Ottawa		Westphalia		Ottawa		Welda	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
C	19.5	9.3	13.0	7.2	13.3	7.2	17.4	20.1	17.0	18.0
B55.9	21.0	10.3	13.9	7.8	14.1	7.8	18.0	19.9	16.0	18.9
B112	21.6	10.6	15.3	8.1	14.2	8.0	19.0	20.9	17.4	20.2
D55.9	20.9	11.0	16.8	9.0	17.1	8.4	18.4	20.7	17.5	19.3
D112	21.2	12.3	17.9	10.9	16.1	8.8	18.0	19.8	18.7	19.4
S9.8	18.8	9.3	13.3	6.8	14.8	7.7	17.7	20.6	17.1	18.7
S9.8+B55.9	20.0	10.8	14.9	7.5	14.0	7.0	17.9	20.8	17.0	19.4
S9.8+D55.9	19.7	10.7	17.3	8.9	17.3	8.4	18.4	20.6	17.1	19.4
LSD .05	**NS**	**1.1**	**1.2**	**0.8**	**1.9**	**0.8**	**NS**	**NS**	**NS**	**NS**

Leaf tissue potassium concentration was significantly higher when potassium fertilizer was deep banded or a high-rate of K fertilizer was broadcast on soybeans using all five site-years for both early and late sampling times. There was a significant location x treatment interaction for the early sampling time, but the interaction was not significant for the late sampling. In 2007, treatment differences were larger, particularly at the early sampling time, due to the low soil test K levels. In 2008, there were no significant differences in leaf K levels due to treatment, likely due to the high K availability that year. Thus the location x treatment interaction is based on differences in soil test levels between the locations (years). The main effects of treatments are presented in Figure 2.1.

Figure 2.1 Average K Concentration in Soybean Leaf Tissue at Pod Set (Early) and Pod Fill (Late) by Treatment for 5 Site Years.



	C	B55.9	B112	D55.9	D112	S9.8	S+B55.9	S+D55.9
□ Early (g kg-1)	16.0	16.6	17.5	18.1	18.4	16.3	16.7	18.0
■ Late (g kg-1)	12.4	12.9	13.6	13.7	14.2	12.6	13.1	13.6

The early sampling time used was generally at the same soybean stage of growth as recommended by Melsted et al. (1969) and slightly later than Mills and Jones (1996) for determining tissue K content relative to the critical levels. Petioles were included in their samples and excluded in these. Noticeably, all the observed K leaf concentrations in these experiments were less than the 22.0 g kg^{-1} K critical nutrient content value reported by Melsted et al. (1969) and several were below the critical nutrient content range of 17.0-25.0 g kg^{-1} K reported by Mills and Jones (1996). Importantly, however, the soybean leaf tissue K concentrations of the five site-year treatment averages for high rate broadcast and all deep band rates were within the Mills and Jones (1996) range, while those of the control, low-rate broadcast, starter and starter with low-rate broadcast were all less than this range. In 2007, the K leaf concentrations were all lower in the late sampling than the early. This is to be expected as the soybean plant transfers significant amounts of K from vegetation to developing seed during pod fill, especially when moisture stress limits K uptake. The opposite was true in 2008, however. Growing conditions in 2008 were much better than in 2007, and soybean plants likely continued to take up potassium later into the growing season, making the transfer of K from leaf to seed less evident.

Soybean biomass of the control, broadcast plus starter and deep band plus starter treatments were compared for the Harris and Ottawa sites in 2007 (Table 2.8). Biomass samples were not collected at Westphalia because plants at this site were all very small. This site did not receive the timely rains which fell at the other sites in 2007, negatively impacting both growth and yields. No significant differences in biomass or vegetative growth were observed at Harris, but at Ottawa, the total amount of biomass was significantly greater for the deep band plus starter treatment compared to the control and broadcast plus starter treatments. The same significant advantage to deep band plus starter was seen when the two site years were combined.

Table 2.8 Soybean Biomass of Select Treatments.

	Soybean Biomass (kg ha^{-1})		
	2007		
K App.	Harris	Ottawa	2 Site Years
C	4583.9	4078.6	4331.2
S9.8+B55.9	4988.5	3970.6	4479.5
S9.8+D55.9	5269.1	4505.5	4887.3
LSD .05	**NS**	**382.0**	**346.6**

Harvest index was calculated by dividing grain harvest mass by total biomass. No significant differences were seen at either site or when site years were combined (Table 2.9).

Table 2.9 Soybean Harvest Index of Select Treatments.

	Soybean Harvest Index		
	2007		
K App.	Harris	Ottawa	2 SiteYears
C	0.44	0.38	0.41
S9.8+B55.9	0.40	0.41	0.41
S9.8+D55.9	0.38	0.41	0.40
LSD .05	**NS**	**NS**	**NS**

No significant differences in yield of soybeans due to K fertilization treatments in 2007 or 2008 were observed at any site or all five site years combined (Table 2.10).

There were significant yield differences at Ottawa in 2008, but they are attributed to phosphorus included in the starter treatments. Soil test P was 16 mg kg^{-1} in replication 1, 5 mg kg^{-1} in replication 2, and 4 mg kg^{-1} in replications 3 and 4. This is much below the critical soil test level of 20 mg kg^{-1} (Leikam et al. 2003). The corresponding sufficiency phosphorus fertilizer recommendations would be 7.3 kg P ha^{-1} for block 1, 26.9 kg P ha^{-1} for block 2, and 29.4 kg P ha^{-1} for blocks 3 and 4 (Leikam et al. 2003). The 15.4 kg ha^{-1} of P included in the starter fertilizer source was just over half the recommended rate for blocks 2-4 and resulted in highly significant differences between treatments that received starter fertilizer and those that did not.

This yield advantage can be logically attributed to added phosphorus on low P soil test soil and not potassium in the starter treatments. The advantage was not seen at any other sites and treatments at Ottawa 2008 receiving even higher K rates placed below the soil surface had significantly lower yields than those receiving starter fertilizer. Only the starter treatments were significantly different than the control.

Table 2.10 Average Soybean Yield by Treatment.

	Yield (kg ha^{-1})					
	2007			2008		All
K App.	Harris	Ottawa	Westphalia	Ottawa	Welda	5 Site Years
C	2240	1750	455	2110	3810	2070
B55.9	2380	2040	449	2080	3740	2140
B112	2260	1690	507	2040	3740	2050
D55.9	2270	1910	437	2090	3810	2100
D112	2350	1920	498	2000	3790	2110
S9.8	2220	1750	595	2530	3890	2200
S9.8+B55.9	2250	1840	581	2500	3900	2210
S9.8+D55.9	2250	2090	443	2460	3810	2210
LSD .05	**NS**	**NS**	**NS**	**188**	**NS**	**NS**

To increase confidence that this yield difference was indeed a phosphorus effect, leaf tissue P and grain P concentrations were compared for the Ottawa 2008 site. In each case, a significant increase in P concentration was seen for the treatments receiving starter fertilizer (Table 2.11).

Table 2.11 Average P Concentration in Soybean Leaf Tissue at Pod Set (Early) and Pod Fill (Late) and Grain by Treatment for Ottawa 2008 Site.

	g kg^{-1} P in Leaf Tissue and Grain		
	Ottawa 2008		
K App.	Early Leaf	Late Leaf	Grain
C	3.3	2.3	4.3
B55.9	3.1	2.2	4.3
B112	3.3	2.3	4.3
D55.9	3.3	2.3	4.4
D112	3.1	2.3	4.2
S9.8	3.8	2.6	4.7
S9.8+B55.9	3.7	2.5	4.5
S9.8+D55.9	3.6	2.6	4.5
LSD .05	**0.4**	**0.2**	**0.2**

The K concentration in soybean seed at each site is summarized in Table 2.12. The average K concentration in soybean grain was significantly impacted by treatment in only one of five site-years. At Westphalia, both broadcast treatments, both deep band treatments and the deep band plus starter treatment all significantly increased the K concentration in the grain over the control. However, the starter fertilizer alone treatment and the broadcast plus starter treatment did not. Different results at this site could be attributed to poor soybean growth due to weather patterns as compared to all other sites.

Although not significantly different, the trend at most sites was higher K concentrations in grain for deep placement treatments. Differences in the five site-years combined were also not significant, but the higher concentrations tended to be the deep placement treatments (Table 2.12).

The impact of K fertilizer on protein and oil content of the seed is summarized in Tables 2.13 and 2.14. There was no significant difference in protein or oil content due to treatment at Harris or Ottawa 2007 or for the two site-years combined.

Table 2.12 Average K Concentration in Soybean Grain by Treatment.

	g kg^{-1} K in Grain					
	2007			2008		All
K App.	Harris	Ottawa	Westphalia	Ottawa	Welda	5 Site Years
C	17.8	18.3	17.7	18.9	19.0	18.3
B55.9	17.4	18.3	18.3	19.0	18.9	18.4
B112	18.1	18.6	18.3	18.9	19.2	18.6
D55.9	18.1	19.0	18.1	19.7	19.0	18.8
D112	18.1	18.7	18.3	18.6	19.4	18.6
S9.8	17.8	18.4	17.8	19.4	19.1	18.5
S9.8+B55.9	17.5	18.7	17.8	18.7	19.4	18.4
S9.8+D55.9	18.3	18.9	18.3	19.1	19.1	18.7
LSD .05	**NS**	**NS**	**0.4**	**NS**	**NS**	**NS**

Table 2.13 Average Soybean Grain Protein Content by Treatment.

	Soybean Grain Protein g kg^{-1} at 130 g kg^{-1} moisture		
	2007		
K App.	Harris	Ottawa	2 Site Years
C	41.1	41.9	41.5
B55.9	41.5	42.0	41.7
B112	41.1	42.5	41.8
D55.9	41.2	42.2	41.7
D112	41.1	42.0	41.6
S9.8	41.5	42.1	41.8
S9.8+B55.9	41.2	42.5	41.9
S9.8+D55.9	40.8	41.5	41.1
LSD .05	**NS**	**NS**	**NS**

Table 2.14 Average Soybean Grain Oil Content by Treatment.

	Soybean Grain Oil g kg^{-1} at 130 g kg^{-1} moisture		
	2007		
K App.	Harris	Ottawa	2 Site Years
C	24.2	22.3	23.2
B55.9	23.7	22.5	23.1
B112	24.0	22.3	23.2
D55.9	23.8	22.4	23.1
D112	24.0	22.6	23.3
S9.8	23.9	22.4	23.2
S9.8+B55.9	24.0	22.5	23.3
S9.8+D55.9	24.2	22.8	23.5
LSD .05	**NS**	**NS**	**NS**

Conclusions

In this study, K was never a yield limiting factor. In 2007, when soil test K was low, leaf tissue potassium concentration was significantly higher when potassium fertilizer was deep banded or a high-rate of K fertilizer was broadcast on soybeans. However, this advantage did not transfer to corresponding differences in yield, due to a lack of water during the critical pod filling period limited yields. There were also no significant differences in grain K concentration, protein or oil content resulting from potassium fertilizer treatments. In 2008, K availability increases dramatically and was adequate based on soil test K.

At the 2008 Ottawa site, with a very low soil test P, a highly significant positive response to P fertilization was documented in terms of yield, leaf tissue phosphorus concentration and grain P content.

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CHAPTER 3 - Residual Effects of Soybean Potassium Fertilizer Placement on Rotation Corn

Introduction

No-till crop production practices have led to stratification of plant nutrients near the soil surface. Potassium is known as an immobile soil nutrient and generally remains at or near the soil surface when fertilizers and crop residues, sources of K, are surface applied and not incorporated (Bruulsema and Murrell, 2006). Potassium also remains close to bands created by concentrated placement methods such as deep-banding, surface banding and use of starter fertilizer (Rehm and Lamb, 2004). In optimal growing conditions this is not a problem as crop roots can utilize K from these zones of high nutrient concentration. However, when soil in these zones is hot and dry or too wet or cold to support high levels of root activity, K uptake is limited and deficiency symptoms may occur.

Corn and soybean producers in the Midwest rely heavily on multi-year fertilizer application practices as a means of saving time and fuel. Corn is usually the crop fertilized, and soybeans are grown on residual fertility applied to the rotational corn crop. Occasionally the sequence is reversed. In areas where soil tests are above the critical level and the intention is to simply replace the nutrients removed in harvested grain, the system has worked well. However, when soil tests are below the critical level, questions exist as to how adequate this system is to supply the needed fertilizer nutrients, especially potassium, to the second or third crop in the rotation.

Native levels of potassium in Kansas have generally been high, but intensive cropping and high yields over many years have resulted in depletion of the K supplies in many soils, particularly in East Central and Southeast Kansas. However, without soil tests, a producer may be unaware of the K fertilization need. Additionally, if a producer prefers to use liquid fertilizer on corn, commonly available sources may contain a ratio of N-P-K inappropriate for their needs or situation. As a result, a producer may want to apply enough dry potassium fertilizer to meet crop needs for several years all at one time. In these situations, knowledge about the response of corn to residual K fertilization may be important. Very few residual K studies have been conducted for corn. In one study, corn had a greater residual response to K applied the previous season than wheat or rice (Chen and Zhou, 1999). Fertilizer application strategies may also impact soil test K. Rehm and Lamb (2004) reported that two direct applications (one to corn and one to soybeans) produced greater soil test K values than a single application supplying the same total amount of K at two of three sites in their study.

Soil test K and corn plant tissue K concentration are frequently correlated (Borges and Mallarino, 1998). Increasing K fertilization rates also significantly increases ear-leaf K concentration and/or K uptake (Borges and Mallarino, 1998; Ebelhar and Varsa, 2000). Rehm and Lamb (2004) found that potassium uptake by young corn plants was increased by K rate, but this enhanced early season uptake was not related to yield. Broadcast K application resulted in lower whole plant K composition than band K application when sampled within a month of emergence, indicating it was less efficient than other placement methods in providing K in the early stages of plant development. However, there were no significant differences in corn leaf K concentrations by the reproductive stage of development (Ebelhar and Varsa, 2000).

Corn tends to be more responsive than soybeans to potassium fertilization based on early growth (Rehm et al., 1988; Randall and Hoeft, 1988) and grain yield (Ebelhar and Varsa, 2000), application rate, and placement techniques. However, yield response at optimum or higher K fertility often has been challenging to predict. As expected, some studies have shown no yield response to K fertilization when soil test K levels were categorized as high (Rehm et al. 1988; Rehm and Lamb, 2004). However, others have seen a low percentage of site-years within trials respond to K fertilization, but when a combined analysis was done, a positive yield response to K fertilization was seen (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000; Borges and Mallarino, 2001; Mallarino and Murrell, 1998). The yield response to K fertilization was not correlated with soil test K at any depth (Borges and Mallarino, 2000). Corn also has been shown to respond to increased K fertilizer rates through increases in yield (Ebelhar and Varsa, 2000), but increasing K application rates also resulted in no yield response in cases of high soil K fertility (Bordoli and Mallarino, 1998; Rehm and Lamb 2004).

Yield response to K fertilizer placement occurred at very few individual sites, but combined analysis revealed a significant response to deep-band placement, producing slightly greater yields than broadcasting in research by Bordoli and Mallarino (1998). Placement of bands deeper in the soil produces more consistent corn yield benefits for K than for P (Bruulsema and Murrell, 2006). However, other researchers have seen no significant effect resulting from K placement on corn yields (Ebelhar and Varsa, 2000). Most would agree that the small yield advantages occasionally seen resulting from deep-band placement rarely would offset the associated higher fertilizer application costs (Bordoli and Mallarino, 1998).

In addition to the direct effect of K fertilization on soybeans, it is also important to understand the residual effects of fertilizer application on rotation crops. In the second year of this study the impact of the previous year fertilizer applications on the K utilization by no-till corn were studied.

Materials and Methods

Research was conducted on-farm in cooperation with local producers. In 2008, corn was planted on sites used in 2007 to evaluate the effects of K rate and placement on soybeans near Ottawa and Westphalia, Kansas. Soils at the selected sites were classified as:

Table 3.1 Soil Classification by Site.

Location	Series Name	Scientific Classification
2008 Corn		
Ottawa	Woodson silt loam	Fine, montmorillonitic, thermic, Abruptic Argiaquoll
Westphalia	Summit silty clay loam	Fine, smectitic, thermic Oxyaquic Vertic Argiudolls

Corn was also planted at the site used near Harris, Kansas in 2008, but wet weather delayed planting and emergence within the plot was irregular. Shortly after emergence it was deemed too late to replant corn on the entire site and the cooperator chose to replant to soybeans.

The site near Westphalia was in Anderson County, Kansas, while the site near Ottawa was in Franklin County, Kansas. Sites were rainfed and received no supplemental irrigation. In Anderson County, the 30-year mean annual rainfall total is 1016 mm. At Ottawa, the 30-year mean annual rainfall total is 996 mm (Kansas Weather Data Library, 2009). Each site had at least a four-year history of no-till production practices. Selected sites were generally near or below the currently used Kansas soil test K critical level of 130 mg kg^{-1} extractable K when sampled in 2007.

No fertilizer treatments were applied to corn so that residual effects from K fertilizer treatments on soybeans could be observed. Previous year fertilizer treatments are included in Table 3.2.

Table 3.2 K Fertilizer Treatments Applied to Preceding Crop, Soybeans

Treatment No.	Treatment Abv.	Treatment Description
1	C	Unfertilized Check
2	B55.9	Broadcast 55.9 kg ha^{-1} K
3	B112	Broadcast 112 kg ha^{-1} K
4	D55.9	Deep Band 55.9 kg ha^{-1} K
5	D112	Deep Band 112 kg ha^{-1} K
6	S9.8	Starter 9.8 kg ha^{-1} K
7	S9.8+B55.9	Starter 9.8 kg ha^{-1} + Broadcast 55.9 kg ha^{-1}
8	S9.8+D55.9	Starter 9.8 kg ha^{-1} + Deep Band 55.9 kg ha^{-1}

Soil samples were collected from both sites prior to planting corn in 2008. The unfertilized control plots, high-rate broadcast (B112), and high-rate deep band (D112) treatments were sampled both in the row and between the rows (row middle) at depths of 0-0.08, 0.08-0.15, and 0.15-0.23-m resulting in six composite samples from each sampled plot. Analysis for potassium by the NH_4OAC extraction method was conducted by the Kansas State University Soil Testing Lab.

Corn hybrids planted were adapted to the region and recommended by the cooperating producers. Seeding rates, planting dates, harvest dates, hybrids and relative maturity are summarized in the following table:

Table 3.3 Corn Hybrids, Characteristics, Planting and Harvest Details.

Location	**Hybrid**	**Relative Maturity**	**Seeding Rate (seeds ha^{-1})**	**Planting Date**	**Harvest Date**
2008 Corn					
Ottawa	NC+ 1773RB NC+ 1772R (Plots 104, 204, 304, 404)	97 97	61,800	4/16/08	9/17/08
Westphalia	Mycogen 2C591	106	61,800	5/1/08	10/8/08

At Ottawa the plot was located near the edge of a large corn field and adjacent to the required BT refuge area for the field. As a result plots 104, 204, 304 and 404 were planted to a non-BT sister line to the BT hybrid used on the balance of the plot. No insect damage was observed in the non-BT plot areas. No K was applied to corn in 2008 so that residual effects of K rate and placement applications made the previous year to soybeans could be evaluated. A uniform rate of nitrogen was applied to all plots at each site. At the Ottawa site, 112 kg ha^{-1} of N was applied as anhydrous ammonia prior to planting. An additional application of 10-34-0 liquid ammonium polyphosphate starter fertilizer was made at planting. At the Westphalia site, 135 kg ha^{-1} of N was sidedressed as UAN post-planting on 6/4/08.

Herbicide application(s) were applied to the plots along with the surrounding bulk field by the producer. However, grass control became a problem at the Westphalia corn site and the hybrid planted was not glyphosate-tolerant. Steadfast was applied using a hand boom at a rate of 54.8 ml ha^{-1} on 6/25/08. Weed control was still inadequate, so weeds between the rows were mowed on 6/30/08 and 7/1/08.

Fields were scouted for signs of K deficiency on an approximately weekly basis by walking between non-harvest rows, but none were observed. Fifteen ear leaves were collected from each plot at silking. Ear leaf tissue samples for corn were collected on 7/8/08 at Ottawa, KS, and 7/18/08 at Westphalia, KS. Samples were dried in a forced air oven at 60°C for a minimum of four days and once dry, were ground with a Wiley grinder, digested with a sulfuric acid and hydrogen peroxide digest and analyzed for P and K content.

Each plot was hand harvested, collecting all ears from 5.3-m of the two center rows (8.1-m^2) of each plot. Grain weight was adjusted to 155 g kg^{-1} moisture. A small sample of the grain was dried at 60°C for a minimum of four days, ground to a powder and digested with a sulfuric acid and hydrogen peroxide digest. Samples were analyzed as previously described for leaf samples.

Each site was separately analyzed using SAS Proc GLM and Fisher's Protected LSD (SAS, 2007) to determine if there was a response to previous year K treatments for corn ear leaf tissue K concentration, yield and grain K concentration. Both site years were also pooled and analyzed for treatment effects ($\alpha = 0.05$). Each site was also separately analyzed using Proc GLM and Fisher's Protected LSD (SAS, 2007) to determine if there was a response in terms of soil test K for year, depth, location relative to the crop row and previous year treatment ($\alpha = 0.05$).

Results and Discussion

Soil test K levels by depth and location relative to the row for selected treatments at Ottawa and Westphalia are presented in Tables 3.4 and 3.6. The control, high-rate broadcast and high-rate deep-band treatments were chosen as they represented the greatest potential for treatments applied in 2007 to be reflected in soil test K.

There were no significant differences between soil test K levels due to K application treatments, or location relative to previous crop row for the Ottawa site (Table 3.4 and 3.5). This is likely due to a combination of factors such as: crop removal, soil buffering and the lack of adequate sensitivity in soil testing techniques. There was, however, a significant difference in K levels with depth in the treated plots, with soil test K at the 8 to 15 cm depth being significantly less than that found at the 0-8 or 15-23 cm depths.

Table 3.4 Soil Test K Levels at Different Depths, Positions in Relation to the Previous Crop Row from Three Treatments Applied in 2007 Prior to Planting Corn, Ottawa 2008.

	K (mg kg^{-1})					
Depth	C		B112		D112	
Cm	Row	Middle	Row	Middle	Row	Middle
0-8	147	135	171	161	167	154
8-15	145	140	127	158	138	126
15-23	164	178	164	182	173	144

Table 3.5 Main Effects of Soil Test K Levels Prior to Planting Corn, Ottawa 2008.

	K (mg kg^{-1})	
Treatment	**Mean**	
C	152	**NS**
B112	161	**NS**
D112	150	**NS**
Depth (cm)		
0-8	156	**a**
8-15	139	**b**
15-23	168	**a**
Position		
Row	155	**NS**
Middle	153	**NS**

Table 3.6 Soil Test K Levels at Different Depths, Positions in Relation to the Previous Crop Row from Three Treatments Applied in 2007 Prior to Planting Corn, Westphalia 2008.

	K (mg kg^{-1})					
Depth	C		B112		D112	
(cm)	Row	Middle	Row	Middle	Row	Middle
0-8	223	230	247	244	246	255
8-15	208	202	220	198	199	223
15-23	228	233	243	229	233	241

Table 3.7 Main Effects of Soil Test K Levels Prior to Planting Corn, Westphalia 2008.

	K (mg kg^{-1})	
Treatment	**Mean**	
C	221	**NS**
B112	230	**NS**
D112	233	**NS**
Depth (cm)		
0-8	241	**a**
8-15	208	**b**
15-23	235	**a**
Position		
Row	227	**NS**
Middle	228	**NS**

Similar soil sampling results for the Westphalia site are summarized in Table 3.6 and 3.7. As with Ottawa, no significant impact of the K treatments applied in 2007 were observed in 2008 soil tests. However, as at Ottawa, soil test K levels were again found to be lower at the 8-15 cm depth than above or below. One possible explanation is that both these soils have “clay pans” which would restrict both water movement and root activity at depths below 15 cm. It is likely that roots would be concentrated near the aerated soil surface and K uptake would be greatest from the top 15 cm of soil. Since both sites have a history of no-till production, K uptake from the 0-15 cm depth could have depleted this zone. With no tillage to mix K fertilizers and K containing crop residues into the soil, any fertilizer or plant cycled K would have accumulated in the top few cm of soil, raising or maintaining that soil test, while the 8 to 15 cm layer would have slowly been reduced.

There were no statistically significant differences in K content of corn ear leaf tissue in response to 2007 K applications found in 2008 at either site or the two site years combined (Table 3.8). However, a clear trend showing higher leaf K levels with the high-rate deep-band and the deep-band plus starter was seen, particularly with the combined data. Although not statistically significant, it appears that K fertilization the previous year did impact K tissue content of corn as the content was numerically lowest for the control treatments at both sites and when data was combined. Unfortunately, our sampling and statistical approach was not adequate to measure this. Noticeably, all treatments were below the critical nutrient concentration of 19.0 g kg^{-1} K according to Melsted et al. (1969) and below the critical range reported by Mills and Jones (1996) of 17.0-30.0 g kg^{-1} K.

Table 3.8 Average K Concentration in Corn Leaf Tissue at Silking by Treatment.

	g kg^{-1} K in Leaf Tissue		
	2008		
K App.	Ottawa	Westphalia	2 Site Years
C	13.8	13.3	13.5
B55.9	15.4	13.8	14.6
B112	15.5	14.1	14.8
D55.9	14.9	14.6	14.8
D112	15.2	15.6	15.4
S9.8	14.1	15.0	14.5
S9.8+B55.9	14.8	14.3	14.6
S9.8+D55.9	16.9	14.0	15.5
LSD .05	**NS**	**NS**	**NS**

Table 3.9 Average Corn Yield by Treatment.

	Yield (kg ha^{-1})		
	2008		
K App.	Ottawa	Westphalia	2 Site Years
C	7200	5200	6200
B55.9	7300	5590	6440
B112	6570	4090	5330
D55.9	7630	6180	6900
D112	7140	6400	6780
S9.8	7320	4820	6070
S9.8+B55.9	7820	5450	6640
S9.8+D55.9	7170	5630	6400
LSD .05	**NS**	**NS**	**NS**

Table 3.10 Average K Concentration in Corn Grain by Treatment.

	g kg^{-1} K in Grain		
	2008		
K App.	Ottawa	Westphalia	2 Site Years
C	3.9	4.4	4.2
B55.9	4.0	4.6	4.3
B112	4.1	4.1	4.1
D55.9	3.8	4.6	4.2
D112	4.0	4.1	4.1
S9.8	4.2	4.0	4.1
S9.8+B55.9	4.2	4.1	4.1
S9.8+D55.9	4.1	4.0	4.0
LSD .05	**NS**	**NS**	**NS**

Corn yields (Table 3.9) and corn grain K content (Table 3.10) also were not significantly impacted by residual effects from fertilizer treatments the previous year. No trends of any kind were observed.

Recall that the sites were originally selected based on several factors including soil test K at or below the critical value of 130 mg kg^{-1}. The mean soil test K at planting in 2007 at both the Ottawa and Westphalia sites was 100 mg kg^{-1}. In 2008, soil samples from the control plots at these sites, which had not received any K fertilizer, increased to 142 and 215 mg kg^{-1}at Ottawa and Westphalia respectively. These dramatic changes in soil test levels may well explain why no response to applied K was seen in corn leaf K concentration or yield in 2008. It also raise questions regarding the value of K soil testing, if the soil tests can double from year to year with no obvious explanation due to management.

Table 3.11 Changes in soil test levels at Ottawa and Westphalia between 2007 and 2008.

		K (mg kg^{-1})	
Location	Depth (cm)	2007	2008
Ottawa	0-15	100 b	142 a
Westphalia	0-15	100 b	216 a
Year (site) Prob > F <.0001			

Although the changes in soil test K are troubling, it is important to note that in 2007 soil testing indicated that K was deficient and that a response to K was likely. Plant tissue levels in soybeans grown on those sites responded significantly to the application of K (Chapter 2). While no yield response was seen, likely that was a result of moisture stress during the pod fill period, not the inadequate levels of K. In 2008, the soil test suggested that no response to K would be expected, and none was seen. No increase in K levels in the leaf, or yields of corn, were observed due to residual effects of 2007 K applications. This suggests that the problem may have little to due with problems of soil testing, and have more to do with actual changes in K availability in the soil as a response to some environmental trigger. The soil test actually worked both years. It measured a change in apparent availability of K in the soil that occurred during the two crop years.

Changes in soil test K have been observed by other researchers also. Several researchers have proposed that seasonal differences (Murdock and Call, 2006) and/or soil moisture at sampling time may impact soil test K levels (Vitko et al., 2009). These differences may be attributed to K fixation between the lattice layers in clay soils. Further research is necessary to support or question this hypothesis.

Conclusions

No significant response was seen in terms of corn leaf K content, grain K content or yield due to previous year (residual) K fertilization in soybeans. Soil test K at these sites with at least a four-year history of no-till practices showed significant stratification of soil test K, with lowest levels 8-15 cm below the soil surface, compared to both the 0-8 cm and 15-23 cm depths. No significant differences were observed due to treatment or position relative to crop row. An unintentional outcome from the second year of cropping was the observation of a significant increase in soil test K and K availability between the two cropping seasons, even where no K was applied. Routine K fertilizer recommendations for both these sites would have been dramatically different depending on which year the fields were sampled.

Additional research is clearly needed to characterize or explain the dramatic differences seen in the two years of this study. Based on my observations, producers should be encouraged to soil sample at the same time of year and at approximately the same soil moisture levels throughout their sampling history to get a more consistent and accurate soil test K reading. However, in areas where these “swings” in K test and availability are known to occur, they may want to sample more frequently and closer to the time of planting or consider regular “insurance” applications equal to crop removal as a means of preventing crop loss.

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CHAPTER 4 - Research Conclusions and Impacts

Fertilizer Recommendations and Financial Implications

Potassium and phosphorus fertilizer recommendations from Kansas State University historically have been based on a philosophy of nutrient sufficiency. Based on long-term averages, this strategy provides a fertilizer recommendation that intends to optimize economic return in the year of nutrient application while achieving approximately 95 percent of maximum yield for the given crop (Leikam et al. 2003). While nutrient sufficiency-based recommendations often achieve the goal of having the greatest return over fertilizer cost (Kilgore and Stites, 2002) in the year of application, future soil test values are not considered and tend to stabilize below the critical soil test value, where crops are highly responsive to fertilization (Leikam et al. 2003). When soil test values are below the critical soil test value, an annual application of P and/or K fertilizer is needed to achieve acceptable yields.

However, it is common practice in East Central and Southeast Kansas to not directly fertilize soybeans and instead rely on residual fertility to provide for the plants even when using the nutrient sufficiency strategy. When soil test values are below critical levels, yields can be limited by fertility instead of other factors. In these cases, producers are sacrificing yield increases that are economically beneficial. In other words, the financial value of the increased yield seen with fertilization is greater than the fertilization costs – a positive return on investment. Additionally, by not fertilizing a crop grown were soil test levels are below the critical value, more nutrients are used than are applied or replaced, further lowering future soil test values over time. It may be possible to prevent or limit this soil nutrient mining by applying enough P and K to the previous crop to include the expected removal of the soybean crop, but this is very rarely done. Again, the assumption with a nutrient sufficiency philosophy is that fertilizer will be applied each year.

In 2003, Kansas State University proposed a second option for fertilizer recommendations referred to as build-maintenance. With this strategy, enough P and/or K fertilizers are applied to increase soil test levels over a given period of time to a target zone, at or just above the critical soil test value. Once the target range is achieved, fertilizer applications approximate crop removal so that soil test levels are maintained in the target zone. Build-maintenance fertility programs are designed to minimize the probability that phosphorus or potassium will limit yield and therefore, allow for near maximum yield potential (Leikam et al., 2003). However, they do not necessarily provide optimum economic returns in a given year, but require an investment in fertilizer. Once soil test levels are above critical levels, yields are normally not reduced when soybeans are not directly fertilized. There is also some potential to manage input costs. With sufficiency the producer should apply fertilizer every year including years where the costs are extremely high. A build-maintenance program allows a producer to either skip or make only a minimal P and/or K application when fertilizer prices are high. Although the build-maintenance phosphorus and potassium interpretations were introduced in 2003, to date very few producers are requesting recommendations for this strategy. Recently P and K fertilizer prices have been high, which results in fewer producers interested in a build-maintenance program.

When producers do not annually fertilize soils below the critical P and K soil test levels, they are missing positive financial returns. This is particularly true in cases where soil test levels would be categorized as very low and soil test levels fall dramatically below the critical levels. This situation was evidenced at the Ottawa 2008 soybean site. Soil test P for this plot averaged 7 mg kg^{-1}. An application of 15.4 kg ha^{-1} P resulted in an average of 430 kg ha^{-1} increased yield. At $0.29 per kg soybeans, that is $126.54 more income per hectare. With a fertilizer cost of $1.26 per kg P, that is a $19.42 investment per hectare. Even at $2.01 per kg P cost, the fertilizer investment is $31.06 per hectare. Fertilizer application costs, according the 2008 Kansas custom rates were approximately $14.00 per hectare. At the lower P fertilizer cost, that is a total cost of fertilization of $33.42 per hectare which is a 390% return. Even at the higher P fertilizer cost, the total fertilization cost was $45.06 per hectare, resulting in a 280% return. Since the P application was just over half the nutrient sufficiency recommendation, it is likely that higher P fertilization rates would have also resulted in a positive return to fertilization. Thus if the Ottawa site truly represents the yield response one can expect from P at low soil tests in Eastern Kansas, an opportunity exists for Extension to educate farmers regarding this issue, and for farmers to enhance both yield and profits.

K Soil Test

This project was initiated with the hypothesis that K stratification in reduced tillage systems was limiting K uptake in some years, and that the current ammonium acetate soil test for K has some significant issues with providing variable results from year to year, or from one sampling to another sampling. We found that placement of fertilizer deeper in the soil through deep banding enhanced uptake in long-term no-till fields in dry years, but that water may have ultimately been the primary yield limiting factor in those situations. Although the K soil test varied dramatically between the two years of this project, the issue was not a problem of the test, but rather significant swings in K availability. Thus changes in soil tests may not be needed as much as changes in our fertilizer management strategies.

Generally, Kansas State University recommends soil testing every 3 to 4 years. However, it should be clear that in this work the soil test interpretations and fertilizer recommendations given varied dramatically depending upon which of these two years a soil sample was taken. This is particularly concerning since a producer will generally follow the fertilizer recommendations from a given test until they have another soil test. It is clear that research is needed to identify which soils or situations are most likely to have this soil test K fluctuation from year to year, and we need to develop or evaluate “new” management strategies to address this problem. Some potential options may include annual K soil tests or annual K applications that approximate K removal.

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Appendix A - Potassium Management in No-till and Strip-till Soybeans and Residual Impacts on Corn – Raw Data

2007 K Placement for Soybeans in Reduced Tillage

Table A.1 2007 K Placement for Soybeans in No-till and Strip-till.

Trt. No.	Trt. Abv.	Starter K ($kg\ ha^{-1}$)	Broadcast K ($kg\ ha^{-1}$)	Deep Band K ($kg\ ha^{-1}$)	Total K ($kg\ ha^{-1}$)
1	C	0	0	0	0
2	B55.9	0	55.9	0	55.9
3	B112	0	112	0	112
4	D55.9	0	0	55.9	55.9
5	D112	0	0	112	112
6	S9.8	9.8	0	0	9.4
7	S9.8+B55.9	9.8	55.9	0	65.7
8	S9.8+D55.9	9.8	0	55.9	65.7

Plot length = 15.2 m, Plot width = 3.05 m, Alley = 15.2 m

Figure A.1 2007 Soybean Plot Plan.

B	401	402	403	404	405	406	407	408	B
	3	6	5	4	7	1	2	8	

B	301	302	303	304	305	306	307	308	B
	1	2	4	8	5	3	7	6	

B	201	202	203	204	205	206	207	208	B
	8	3	7	1	6	5	4	2	

B	101	102	103	104	105	106	107	108	B
	4	7	1	6	2	3	8	5	

Table A.2 2007 Soybean Tissue Data from near Harris, KS.

			Early Trifoliate			Late Trifoliate		
			N	P	K	N	P	K
Plot No.	Trt. No.	Trt. Abv.	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
101	4	D55.9	48.4	3.6	19.1	38.8	2.2	10.1
102	7	S9.8+B55.9	50.1	4.1	18.7	40.2	2.2	8.8
103	1	C	53.3	3.8	13.8	39.2	2.3	6.8
104	6	S9.8	47.3	4.2	17.7	40.9	2.4	7.6
105	2	B55.9	44.2	3.7	20.1	41.8	2.5	8.3
106	3	B112	48.4	3.8	20.9	43.4	2.6	8.5
107	8	S9.8+D55.9	44.6	4.1	20.4	41.0	2.5	9.9
108	5	D112	46.0	3.9	21.0	43.9	2.5	11.0
201	8	S9.8+D55.9	43.1	3.9	19.6	40.3	2.3	10.0
202	3	B112	42.0	3.9	22.0	41.0	2.4	10.6
203	7	S9.8+B55.9	44.3	3.6	18.3	41.4	2.4	9.5
204	1	C	43.6	4.0	21.9	39.7	2.4	9.5
205	6	S9.8	43.7	3.9	20.5	39.5	2.3	8.6
206	5	D112	44.4	3.5	23.1	41.3	2.3	12.7
207	4	D55.9	46.9	4.0	23.5	40.6	2.5	11.4
208	2	B55.9	48.0	3.7	19.6	42.1	2.6	9.6
301	1	C	43.8	3.2	21.2	39.5	2.3	10.6
302	2	B55.9	43.8	3.0	21.5	40.6	2.3	11.2
303	4	D55.9	45.3	3.1	20.3	40.8	2.3	10.9
304	8	S9.8+D55.9	42.7	3.2	20.2	38.1	2.3	11.3
305	5	D112	39.3	3.0	20.1	38.6	2.3	13.8
306	3	B112	43.5	3.3	22.4	41.9	2.4	11.4
307	7	S9.8+B55.9	40.6	3.5	21.9	40.1	2.5	12.6
308	6	S9.8	42.7	3.2	18.3	41.9	2.6	10.0
401	3	B112	40.7	3.3	20.9	40.4	2.3	12.0
402	6	S9.8	42.9	3.3	18.6	40.2	2.4	10.8
403	5	D112	46.7	3.4	20.5	40.9	2.3	11.8
404	4	D55.9	44.2	3.4	20.6	43.4	2.5	11.6
405	7	S9.8+B55.9	47.0	3.5	20.9	39.1	2.4	12.1
406	1	C	48.8	3.5	21.2	42.2	2.4	10.3
407	2	B55.9	42.1	3.5	22.7	40.1	2.4	11.9
408	8	S9.8+D55.9	47.5	3.5	18.7	40.9	2.4	11.5

Table A.3 2007 Soybean Grain Data from near Harris, KS.

							Grain Analysis		
Plot No.	Trt. No.	Trt. Abv.	Harvest Weight kg 23.2$(m^2)^{-1}$	Moisture g kg^{-1}	Test Weight kg	Yield kg ha^{-1}	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}
101	4	D55.9	5.26	139	24.4	2240	56.1	4.4	17.9
102	7	S9.8+B55.9	5.22	137	25.3	2230	54.1	4.5	17.2
103	1	C	5.03	134	24.9	2160	59.6	4.5	16.5
104	6	S9.8	5.44	135	24.5	2330	56.9	5.5	17.4
105	2	B55.9	5.53	135	24.9	2370	54.5	4.3	16.2
106	3	B112	5.62	138	24.1	2400	53.6	4.3	17.1
107	8	S9.8+D55.9	5.94	138	24.8	2540	55.8	4.5	17.9
108	5	D112	5.62	141	24.3	2390	54.6	4.8	18.3
201	8	S9.8+D55.9	5.17	137	24.5	2210	55.6	4.6	18.2
202	3	B112	5.44	138	25.2	2320	56.7	4.2	17.8
203	7	S9.8+B55.9	5.62	136	24.4	2410	55.3	4.6	16.9
204	1	C	5.53	138	24.9	2360	57.4	4.7	18.0
205	6	S9.8	5.58	136	24.8	2390	55.0	4.4	17.0
206	5	D112	6.03	139	24.7	2570	55.2	4.3	18.1
207	4	D55.9	5.94	140	24.9	2530	59.1	4.6	18.0
208	2	B55.9	6.62	140	24.5	2820	56.9	5.1	17.8
301	1	C	5.08	136	24.9	2170	57.1	4.7	18.2
302	2	B55.9	5.13	136	24.7	2190	50.3	5.0	17.5
303	4	D55.9	5.22	137	24.4	2230	54.3	4.4	18.0
304	8	S9.8+D55.9	4.99	137	24.9	2130	55.0	5.1	18.5
305	5	D112	5.26	139	24.8	2240	55.6	4.5	18.3
306	3	B112	5.22	137	24.4	2230	57.1	4.8	18.6
307	7	S9.8+B55.9	5.08	137	24.5	2170	53.4	4.6	17.8
308	6	S9.8	5.03	136	24.6	2150	56.6	5.0	18.1
401	3	B112	4.85	137	25.0	2070	56.4	4.7	18.8
402	6	S9.8	4.72	136	24.7	2020	55.9	5.6	18.6
403	5	D112	5.17	139	24.4	2200	51.6	4.3	17.7
404	4	D55.9	4.90	138	24.4	2090	55.5	4.4	18.2
405	7	S9.8+B55.9	5.13	137	24.8	2190	55.5	4.7	18.2
406	1	C	5.35	138	24.8	2280	55.5	4.8	18.4
407	2	B55.9	5.03	138	24.0	2150	53.6	4.5	17.9
408	8	S9.8+D55.9	4.99	140	24.6	2120	56.7	5.8	18.6

Table A.4 2007 Soybean Protein and Oil Data from near Harris, KS.

Plot No.	Trt. No.	Trt. Abv.	Protein g kg^{-1}	Oil g kg^{-1}	Moisture g kg^{-1}
101	4	D55.9	388	213	67.0
102	7	S9.8+B55.9	389	213	66.5
103	1	C	378	223	64.6
104	6	S9.8	386	223	60.8
105	2	B55.9	403	207	67.5
106	3	B112	377	222	61.5
107	8	S9.8+D55.9	386	224	63.4
108	5	D112	376	227	61.5
201	8	S9.8+D55.9	377	228	63.7
202	3	B112	390	218	65.5
203	7	S9.8+B55.9	383	225	63.1
204	1	C	388	220	63.3
205	6	S9.8	395	208	66.3
206	5	D112	395	217	65.4
207	4	D55.9	382	222	63.6
208	2	B55.9	385	220	66.7
301	1	C	380	231	63.1
302	2	B55.9	374	230	63.3
303	4	D55.9	380	228	62.5
304	8	S9.8+D55.9	380	220	64.5
305	5	D112	378	225	60.2
306	3	B112	382	220	64.3
307	7	S9.8+B55.9	374	233	61.9
308	6	S9.8	382	229	63.3
401	3	B112	378	232	61.3
402	6	S9.8	380	228	62.5
403	5	D112	377	223	64.2
404	4	D55.9	382	223	66.0
405	7	S9.8+B55.9	386	220	62.2
406	1	C	381	225	62.6
407	2	B55.9	380	226	60.5
408	8	S9.8+D55.9	372	225	61.8

Table A.5 2007 Soybean Whole Plant at Maturity Data from near Harris, KS.

Plot No.	Trt. No.	Trt. Abv.	Dry Weight g	Dry Biomass Yield kg ha^{-1}	Harvest Index grain $biomass^{-1}$
102	7	S9.8+B55.9	1600	5740	0.39
103	1	C	1430	5120	0.42
107	8	S9.8+D55.9	1650	5920	0.43
201	8	S9.8+D55.9	1670	5980	0.37
203	7	S9.8+B55.9	1730	6210	0.39
204	1	C	1300	4660	0.51
301	1	C	1550	5560	0.39
304	8	S9.8+D55.9	1550	5560	0.38
307	7	S9.8+B55.9	1460	5220	0.42
405	7	S9.8+B55.9	1450	5200	0.42
406	1	C	1450	5210	0.44
408	8	S9.8+D55.9	1720	6160	0.34

Table A.6 2007 Soybean Initial Soil Sample Data from near Harris, KS.

Plots	Depth m	pH	Buffer pH	P mg kg^{-1}	K mg kg^{-1}	O.M. g kg^{-1}	Texture Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	Summation CEC meq/100g
101-108	0-0.15	7.8	-	34	89	3.3	14	67	18	12.9
201-208	0-0.15	7.3	-	12	63	3.0	18	66	16	9.8
301-308	0-0.15	6.9	-	25	74	3.2	18	67	14	9.5
401-408	0-0.15	6.6	-	14	53	3.0	18	66	16	9.0

Table A.7 2007 Soybean Tissue Data from near Ottawa, KS.

			Early Trifoliate			Late Trifoliate		
			N	P	K	N	P	K
Plot No.	Trt. No.	Trt. Abv.	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
101	4	D55.9	51.1	3.1	15.5	38.4	1.9	8.9
102	7	S9.8+B55.9	51.1	3.3	13.6	40.7	2.0	7.6
103	1	C	51.5	3.3	11.3	40.9	2.0	7.4
104	6	S9.8	51.5	3.6	12.6	39.2	1.9	7.4
105	2	B55.9	52.1	3.3	13.0	38.6	1.7	8.0
106	3	B112	50.3	3.1	15.6	37.2	1.7	9.1
107	8	S9.8+D55.9	49.4	3.2	17.1	38.8	1.8	8.6
108	5	D112	52.5	3.0	16.9	36.8	1.9	11.0
201	8	S9.8+D55.9	50.5	2.8	17.0	39.2	1.9	8.6
202	3	B112	50.4	2.9	15.7	36.6	1.7	8.1
203	7	S9.8+B55.9	51.1	2.9	14.9	36.5	1.7	7.5
204	1	C	52.3	3.0	15.1	33.9	1.9	7.5
205	6	S9.8	49.3	3.0	13.8	36.6	1.8	6.3
206	5	D112	48.6	2.9	20.2	33.2	1.7	10.6
207	4	D55.9	48.8	2.9	17.7	38.4	1.7	8.7
208	2	B55.9	50.5	2.9	14.7	36.7	1.8	7.7
301	1	C	54.4	3.1	13.5	35.3	1.7	7.1
302	2	B55.9	54.3	3.0	14.5	35.2	1.6	8.4
303	4	D55.9	52.8	2.9	17.6	36.2	1.8	10.6
304	8	S9.8+D55.9	52.3	2.9	17.9	37.9	1.8	9.4
305	5	D112	53.7	2.8	17.4	35.2	1.7	11.9
306	3	B112	52.0	3.0	15.1	39.8	1.9	8.0
307	7	S9.8+B55.9	53.0	3.0	14.5	40.5	2.0	7.2
308	6	S9.8	52.9	3.2	13.6	35.4	2.0	7.0
401	3	B112	53.5	2.8	14.7	40.2	2.0	7.3
402	6	S9.8	51.7	3.0	13.1	34.1	1.8	6.6
403	5	D112	53.7	2.7	17.2	39.3	1.8	9.9
404	4	D55.9	54.0	2.8	16.2	41.2	2.0	7.7
405	7	S9.8+B55.9	53.3	3.0	16.4	39.4	2.0	7.6
406	1	C	54.1	2.8	12.0	37.4	1.9	6.7
407	2	B55.9	52.9	2.9	13.2	37.5	2.0	7.1
408	8	S9.8+D55.9	52.9	2.9	17.0	35.7	2.0	9.1

Table A.8 2007 Soybean Grain Data from near Ottawa, KS.

							Grain Analysis		
Plot No.	Trt. No.	Trt. Abv.	Harvest Weight kg 23.2(m^2)$^{-1}$	Moisture g kg^{-1}	Test Weight kg	Yield kg ha^{-1}	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}
101	4	D55.9	4.54	141	24.2	1930	62.2	4.9	19.1
102	7	S9.8+B55.9	4.08	131	25.6	1760	61.7	4.9	18.3
103	1	C	4.45	122	27.1	1930	58.7	4.6	17.9
104	6	S9.8	3.13	136	25.4	1340	63.8	5.0	18.5
105	2	B55.9	5.62	125	25.7	2440	60.1	5.3	18.2
106	3	B112	4.49	133	24.9	1930	59.9	4.4	18.8
107	8	S9.8+D55.9	5.17	129	25.2	2230	59.7	4.6	19.0
108	5	D112	5.31	133	25.5	2280	55.2	4.4	17.7
201	8	S9.8+D55.9	4.35	134	24.9	1870	58.3	5.2	18.3
202	3	B112	3.63	137	24.5	1550	53.5	4.0	17.6
203	7	S9.8+B55.9	4.13	132	25.0	1770	57.7	4.5	18.3
204	1	C	3.67	134	25.0	1580	58.2	4.6	18.1
205	6	S9.8	4.22	129	25.4	1820	51.9	4.1	16.8
206	5	D112	4.13	129	24.9	1780	60.3	4.8	19.3
207	4	D55.9	4.58	132	25.1	1970	60.2	4.3	18.8
208	2	B55.9	4.49	131	25.6	1930	55.7	4.5	18.0
301	1	C	3.90	128	25.3	1680	60.1	4.9	18.5
302	2	B55.9	4.08	132	25.5	1750	62.4	5.1	19.4
303	4	D55.9	4.22	131	25.0	1810	61.0	5.2	19.5
304	8	S9.8+D55.9	4.81	136	25.6	2060	62.3	5.2	19.2
305	5	D112	4.54	135	25.3	1940	62.1	4.7	19.3
306	3	B112	4.13	131	25.9	1780	61.1	4.8	18.9
307	7	S9.8+B55.9	4.58	132	25.5	1970	58.7	4.6	18.6
308	6	S9.8	4.81	134	25.6	2060	63.2	5.7	19.5
401	3	B112	3.49	133	23.6	1500	56.9	4.8	18.9
402	6	S9.8	4.13	133	25.2	1770	62.9	5.2	18.8
403	5	D112	3.95	129	25.5	1700	55.3	4.6	18.6
404	4	D55.9	4.49	135	25.4	1920	58.4	5.0	18.6
405	7	S9.8+B55.9	4.35	134	25.3	1870	61.6	5.4	19.4
406	1	C	4.22	129	25.6	1820	61.7	5.2	18.7
407	2	B55.9	4.72	130	25.8	2030	54.2	4.5	17.7
408	8	S9.8+D55.9	5.17	134	25.4	2220	59.8	5.2	19.1

Table A.9 2007 Soybean Protein and Oil Data from near Ottawa, KS.

Plot No.	Trt. No.	Trt. Abv.	Protein g kg^{-1}	Oil g kg^{-1}	Moisture g kg^{-1}
101	4	D55.9	395	209	61.6
102	7	S9.8+B55.9	379	213	60.1
103	1	C	378	211	61.5
104	6	S9.8	388	211	62.9
105	2	B55.9	394	211	63.9
106	3	B112	398	210	62.1
107	8	S9.8+D55.9	378	213	62.2
108	5	D112	390	212	65.5
201	8	S9.8+D55.9	389	211	66.5
202	3	B112	395	206	64.5
203	7	S9.8+B55.9	396	211	65.0
204	1	C	400	205	66.2
205	6	S9.8	392	207	62.8
206	5	D112	379	211	61.6
207	4	D55.9	385	210	63.9
208	2	B55.9	382	209	63.2
301	1	C	388	204	62.5
302	2	B55.9	402	207	66.0
303	4	D55.9	396	202	64.2
304	8	S9.8+D55.9	381	214	61.6
305	5	D112	392	209	66.3
306	3	B112	391	208	65.4
307	7	S9.8+B55.9	403	206	64.0
308	6	S9.8	383	207	65.5
401	3	B112	396	205	64.5
402	6	S9.8	402	207	62.8
403	5	D112	402	209	65.3
404	4	D55.9	393	211	64.8
405	7	S9.8+B55.9	401	207	65.6
406	1	C	391	208	64.8
407	2	B55.9	385	212	63.8
408	8	S9.8+D55.9	393	210	64.9

Table A.10 2007 Soybean Whole Plant at Maturity Data from near Ottawa, KS.

Plot No.	Trt. No.	Trt. Abv.	Dry Weight g	Dry Biomass Yield kg ha^{-1}	Harvest Index grain $biomass^{-1}$
102	7	S9.8+B55.9	1340	4820	0.36
103	1	C	1280	4600	0.42
107	8	S9.8+D55.9	1430	5130	0.43
201	8	S9.8+D55.9	1330	4780	0.39
203	7	S9.8+B55.9	1170	4180	0.42
204	1	C	1140	4080	0.39
301	1	C	1250	4480	0.38
304	8	S9.8+D55.9	1470	5250	0.39
307	7	S9.8+B55.9	1220	4370	0.45
405	7	S9.8+B55.9	1240	4430	0.42
406	1	C	1430	5130	0.35
408	8	S9.8+D55.9	1410	5040	0.44

Table A.11 2007 Soybean Initial Soil Sample Data from near Ottawa, KS.

Plots	Depth m	pH	Buffer pH	P mg kg^{-1}	K mg kg^{-1}	O.M. g kg^{-1}	Texture Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	Summation CEC meq/100g
101-108	0-0.15	7.4	-	8	100	3.3	18	60	22	12.7
201-208	0-0.15	7.6	-	7	102	3.0	18	60	22	13.3
301-308	0-0.15	7.6	-	15	106	2.5	20	56	24	12.9
401-408	0-0.15	7.7	-	8	94	2.7	18	60	22	12.8

Table A.12 2007 Soybean Tissue Data from near Westphalia, KS.

			Early Trifoliate			Late Trifoliate		
			N	P	K	N	P	K
Plot No.	Trt. No.	Trt. Abv.	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
101	4	D55.9	51.5	2.9	17.5	33.7	2.0	7.7
102	7	S9.8+B55.9	53.7	3.3	13.8	37.8	2.1	6.5
103	1	C	55.1	3.2	12.1	36.9	2.1	7.1
104	6	S9.8	53.5	3.3	13.3	34.3	2.1	7.5
105	2	B55.9	53.8	3.3	11.5	34.6	2.0	7.2
106	3	B112	55.7	3.4	13.4	37.6	2.2	8.0
107	8	S9.8+D55.9	51.5	3.2	19.1	35.9	2.1	8.9
108	5	D112	54.0	3.3	14.6	36.1	2.1	8.7
201	8	S9.8+D55.9	44.4	3.1	16.0	32.1	2.0	7.7
202	3	B112	47.5	3.4	13.8	32.5	2.0	6.4
203	7	S9.8+B55.9	46.1	3.3	14.2	32.6	2.0	6.5
204	1	C	48.1	3.3	13.4	32.3	2.0	6.6
205	6	S9.8	47.9	3.3	14.5	32.6	1.9	7.8
206	5	D112	47.9	3.3	17.3	31.0	1.9	8.6
207	4	D55.9	47.1	3.2	17.1	31.6	1.9	8.8
208	2	B55.9	43.8	3.4	15.6	36.1	2.1	8.2
301	1	C	45.7	3.1	14.4	37.3	2.0	7.6
302	2	B55.9	47.1	3.2	15.5	33.7	1.9	8.4
303	4	D55.9	45.3	2.8	17.9	35.2	1.9	8.7
304	8	S9.8+D55.9	46.9	3.0	17.1	34.5	2.0	8.8
305	5	D112	44.3	2.7	18.1	35.3	1.9	8.6
306	3	B112	48.8	3.1	14.1	32.8	1.9	8.6
307	7	S9.8+B55.9	48.2	3.3	15.3	33.1	2.0	7.8
308	6	S9.8	47.5	3.3	14.4	32.1	1.9	8.0
401	3	B112	49.8	3.3	15.4	32.1	2.0	9.0
402	6	S9.8	46.1	3.1	16.8	32.5	1.9	7.3
403	5	D112	49.9	3.3	14.3	31.4	1.9	9.3
404	4	D55.9	49.4	2.9	15.7	30.9	1.9	8.4
405	7	S9.8+B55.9	49.2	3.0	12.7	32.2	1.9	7.1
406	1	C	50.5	3.2	13.3	32.7	2.0	7.6
407	2	B55.9	51.9	3.5	13.8	32.1	2.0	7.2
408	8	S9.8+D55.9	47.8	3.3	17.0	32.3	1.9	8.3

Table A.13 2007 Soybean Grain Data from near Westphalia, KS.

Plot No.	Trt. No.	Trt. Abv.	Harvest Weight kg 23.2$(m^2)^{-1}$	Moisture g kg^{-1}	Test Weight kg	Yield kg ha^{-1}	Grain Analysis		
							N g kg^{-1}	P g kg^{-1}	K g kg^{-1}
101	4	D55.9	0.77	126	23.5	334	59.2	5.5	17.9
102	7	S9.8+B55.9	0.86	134	24.5	369	59.3	5.5	17.6
103	1	C	0.73	130	24.2	312	60.3	5.5	16.9
104	6	S9.8	0.82	131	24.4	351	59.1	5.6	17.0
105	2	B55.9	0.68	132	24.5	292	61.3	5.7	18.1
106	3	B112	0.68	154	23.8	285	64.0	5.6	17.8
107	8	S9.8+D55.9	0.54	148	23.6	230	62.1	5.5	18.0
108	5	D112	0.54	155	23.9	228	64.0	5.7	17.9
201	8	S9.8+D55.9	1.04	139	24.4	445	59.0	5.8	18.5
202	3	B112	1.18	131	23.2	507	60.6	5.8	18.6
203	7	S9.8+B55.9	1.41	136	24.5	601	59.7	5.8	18.0
204	1	C	1.18	135	23.8	505	57.6	5.7	18.3
205	6	S9.8	0.91	140	23.9	386	61.7	5.6	17.7
206	5	D112	0.77	131	24.9	332	60.1	5.5	18.0
207	4	D55.9	0.50	136	24.5	213	59.8	5.7	17.9
208	2	B55.9	0.54	141	23.9	231	62.9	5.7	18.4
301	1	C	1.04	120	24.1	454	58.5	5.2	17.9
302	2	B55.9	1.54	127	24.7	666	58.4	5.1	18.6
303	4	D55.9	1.22	127	24.6	529	59.0	5.3	18.3
304	8	S9.8+D55.9	1.18	125	24.8	511	62.1	5.1	18.3
305	5	D112	1.68	129	25.4	723	59.5	5.6	18.8
306	3	B112	1.54	129	24.9	665	58.0	5.6	18.5
307	7	S9.8+B55.9	1.68	130	24.5	723	60.3	5.4	17.8
308	6	S9.8	1.68	130	24.3	723	59.1	5.4	18.0
401	3	B112	1.32	123	24.4	571	58.9	5.3	18.2
402	6	S9.8	2.13	127	24.9	921	57.8	5.4	18.3
403	5	D112	1.63	123	25.2	709	57.0	5.4	18.3
404	4	D55.9	1.54	121	24.9	671	59.9	5.4	18.3
405	7	S9.8+B55.9	1.45	123	24.2	630	59.4	5.3	17.8
406	1	C	1.27	126	24.1	549	60.5	5.3	17.7
407	2	B55.9	1.41	132	23.9	604	60.2	5.3	17.9
408	8	S9.8+D55.9	1.36	131	24.4	585	60.2	5.3	18.2

Table A.14 2007 Soybean Initial Soil Sample Data from near Westphalia, KS.

Plots	Depth m	pH	Buffer pH	P mg kg^{-1}	K mg kg^{-1}	O.M. g kg^{-1}	Texture Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	Summation CEC meq/100g
101-108	0-0.15	6.9	-	25	104	2.8	44	34	2.8	16.6
201-208	0-0.15	7.3	-	13	105	2.8	40	38	2.8	16.8
301-308	0-0.15	6.4	6.7	32	102	3.4	44	32	3.4	17.6
401-408	0-0.15	6.8	-	19	89	3.2	48	30	3.2	14.3

2008 K Placement for Soybeans in Reduced Tillage

Table A.15 2008 K Placement for Soybeans in No-till and Strip-till.

Trt. No.	Trt. Abv.	Starter K ($kg\ ha^{-1}$)	Broadcast K ($kg\ ha^{-1}$)	Deep Band K ($kg\ ha^{-1}$)	Total K ($kg\ ha^{-1}$)
1	C	0	0	0	0
2	B55.9	0	55.9	0	55.9
3	B112	0	112	0	112
4	D55.9	0	0	55.9	55.9
5	D112	0	0	112	112
6	S9.8	9.8	0	0	9.8
7	S9.8+B55.9	9.8	55.9	0	65.7
8	S9.8+D55.9	9.8	0	55.9	65.7

Plot length = 15.2 m, Plot width = 3.05 m, Alley = 15.2 m

Figure A.2 2008 Soybean Plot Plan.

B	401	402	403	404	405	406	407	408	B
	3	5	2	4	7	8	6	1	

B	301	302	303	304	305	306	307	308	B
	7	1	5	8	3	4	2	6	

B	201	202	203	204	205	206	207	208	B
	4	6	3	5	2	1	7	8	

B	101	102	103	104	105	106	107	108	B
	1	4	6	7	8	3	5	2	

Table A.16 2008 Soybean Tissue Data from near Ottawa, KS.

			Early Trifoliate			Late Trifoliate		
			N	P	K	N	P	K
Plot No.	Trt. No.	Trt. Abv.	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
101	1	C	49.1	4.0	16.9	38.8	2.5	21.5
102	4	D55.9	50.6	4.3	17.9	34.8	2.2	21.5
103	6	S9.8	49.0	5.0	18.3	37.1	2.7	21.4
104	7	S9.8+B55.9	51.1	4.8	17.9	39.2	2.7	20.3
105	8	S9.8+D55.9	49.8	4.4	18.0	39.3	2.6	19.4
106	3	B112	52.5	4.1	20.0	40.3	2.4	21.2
107	5	D112	55.2	3.2	17.4	41.2	2.4	19.6
108	2	B55.9	52.4	3.2	16.0	41.5	2.6	20.9
201	4	D55.9	49.1	3.4	18.5	38.9	2.6	20.8
202	6	S9.8	54.6	3.8	16.2	39.9	2.7	19.8
203	3	B112	50.5	3.3	18.0	41.3	2.6	21.4
204	5	D112	54.0	3.5	17.9	42.2	2.6	21.0
205	2	B55.9	51.7	3.3	18.5	32.7	2.0	17.1
206	1	C	56.2	3.4	16.8	41.6	2.5	20.6
207	7	S9.8+B55.9	54.9	3.8	18.6	41.5	2.7	21.1
208	8	S9.8+D55.9	55.6	3.7	17.3	43.7	2.8	20.6
301	7	S9.8+B55.9	52.2	3.2	18.3	37.7	2.4	21.7
302	1	C	54.8	3.0	17.4	39.4	2.2	19.5
303	5	D112	53.5	2.9	19.8	38.8	2.1	19.8
304	8	S9.8+D55.9	53.7	3.3	19.3	39.6	2.5	20.9
305	3	B112	53.7	3.0	18.4	38.0	2.1	21.6
306	4	D55.9	52.8	2.9	18.8	42.7	2.3	21.4
307	2	B55.9	53.4	3.0	19.6	37.7	2.2	21.7
308	6	S9.8	54.0	3.4	17.5	41.8	2.6	21.4
401	3	B112	50.4	2.8	19.4	35.4	1.9	19.2
402	5	D112	55.5	2.8	16.7	40.9	2.1	18.9
403	2	B55.9	54.1	2.8	18.0	41.0	2.1	19.7
404	4	D55.9	53.2	2.8	18.3	39.6	2.0	19.1
405	7	S9.8+B55.9	55.0	3.0	16.9	42.2	2.3	20.0
406	8	S9.8+D55.9	54.1	3.0	18.9	39.3	2.3	21.4
407	6	S9.8	52.6	3.0	18.6	42.3	2.4	19.9
408	1	C	56.4	2.8	18.6	40.6	2.1	18.8

Table A.17 2008 Soybean Grain Data from near Ottawa, KS.

							Grain Analysis		
Plot No.	Trt. No.	Trt. Abv.	Harvest Weight kg 23.2(m^2)$^{-1}$	Moisture g kg^{-1}	Test Weight kg	Yield kg ha^{-1}	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}
101	1	C	4.63	123	25.5	2010	58.6	4.9	19.9
102	4	D55.9	4.99	118	25.7	2180	58.1	4.7	20.1
103	6	S9.8	5.94	130	25.7	2560	60.8	5.1	19.8
104	7	S9.8+B55.9	5.99	125	25.9	2590	58.3	4.9	19.0
105	8	S9.8+D55.9	5.35	126	25.4	2320	56.5	4.8	18.8
106	3	B112	4.81	125	25.3	2080	58.8	4.6	19.3
107	5	D112	4.67	127	25.2	2020	54.7	4.4	18.1
108	2	B55.9	4.76	124	25.5	2070	58.8	4.8	19.6
201	4	D55.9	5.03	127	25.4	2180	58.8	4.8	19.5
202	6	S9.8	6.30	126	25.7	2730	60.0	4.9	19.3
203	3	B112	5.81	133	25.6	2490	58.6	4.7	19.2
204	5	D112	5.72	123	25.6	2480	56.2	4.3	18.8
205	2	B55.9	5.81	122	25.8	2520	58.1	4.5	19.1
206	1	C	5.81	128	25.2	2510	56.4	4.2	19.1
207	7	S9.8+B55.9	6.35	119	25.7	2770	59.5	4.8	19.0
208	8	S9.8+D55.9	6.80	116	25.8	2980	60.1	4.6	19.4
301	7	S9.8+B55.9	5.17	118	25.8	2260	51.8	4.1	17.8
302	1	C	4.90	117	26.0	2140	58.2	4.1	19.0
303	5	D112	4.40	121	25.7	1910	58.6	4.1	18.9
304	8	S9.8+D55.9	5.40	122	25.9	2350	58.5	4.3	19.1
305	3	B112	4.40	115	25.7	1930	57.5	4.0	18.8
306	4	D55.9	4.90	114	25.8	2150	59.9	4.1	19.8
307	2	B55.9	4.49	115	25.7	1970	58.7	4.0	18.9
308	6	S9.8	5.72	116	25.7	2500	59.2	4.4	19.1
401	3	B112	3.86	121	25.7	1680	57.5	4.0	18.4
402	5	D112	3.63	118	25.6	1580	56.8	4.0	18.6
403	2	B55.9	4.04	115	25.8	1770	54.9	3.8	18.3
404	4	D55.9	4.26	114	25.8	1870	57.5	3.9	19.2
405	7	S9.8+B55.9	5.40	112	25.8	2370	57.8	4.2	19.0
406	8	S9.8+D55.9	5.03	112	25.9	2210	56.4	4.1	18.9
407	6	S9.8	5.35	115	25.7	2340	57.2	4.2	19.2
408	1	C	4.08	115	25.7	1790	52.0	3.9	17.7

Table A.18 2008 Soybean Initial Soil Sample Data from near Ottawa, KS.

Plots	Depth m	pH	Buffer pH	P mg kg^{-1}	K mg kg^{-1}
101-108	0-0.15	5.9	6.6	16	153
201-208	0-0.15	5.9	6.4	5	169
301-308	0-0.15	5.9	6.6	4	179
401-408	0-0.15	5.9	6.5	4	178

Table A.19 2008 Soybean Tissue Data from near Welda, KS.

			Early Trifoliate			Late Trifoliate		
			N	P	K	N	P	K
Plot No.	Trt. No.	Trt. Abv.	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
101	1	C	52.0	4.5	18.1	44.7	3.5	18.7
102	4	D55.9	53.5	4.4	16.8	48.1	3.7	20.4
103	6	S9.8	55.4	4.4	14.8	50.3	3.6	18.9
104	7	S9.8+B55.9	57.5	4.9	16.9	50.4	3.8	21.3
105	8	S9.8+D55.9	52.1	4.4	16.4	47.2	3.8	22.4
106	3	B112	50.8	4.3	17.1	55.3	3.9	20.3
107	5	D112	50.8	4.4	19.4	49.6	3.6	20.0
108	2	B55.9	54.5	4.7	13.1	53.0	3.7	17.2
201	4	D55.9	54.0	5.0	17.3	50.0	3.6	18.7
202	6	S9.8	57.8	5.2	17.0	50.4	3.7	18.7
203	3	B112	54.4	4.7	17.4	52.3	3.7	19.0
204	5	D112	54.7	5.3	19.3	45.6	3.5	19.7
205	2	B55.9	55.5	4.6	17.1	49.2	3.6	18.4
206	1	C	59.9	4.7	15.1	52.4	3.6	16.3
207	7	S9.8+B55.9	57.0	4.7	15.7	45.4	3.5	18.1
208	8	S9.8+D55.9	55.7	4.7	16.5	51.5	3.5	17.2
301	7	S9.8+B55.9	52.5	4.4	16.6	46.2	3.5	18.7
302	1	C	53.0	4.7	15.5	49.1	3.7	16.9
303	5	D112	53.7	4.6	17.6	49.1	3.7	19.0
304	8	S9.8+D55.9	55.7	5.0	17.2	46.4	3.5	17.8
305	3	B112	59.1	5.3	16.8	47.0	3.6	18.5
306	4	D55.9	56.9	4.7	16.6	49.5	3.6	18.1
307	2	B55.9	55.0	4.7	16.1	45.0	3.3	18.6
308	6	S9.8	57.0	4.9	17.1	42.8	3.4	18.2
401	3	B112	54.7	5.3	18.4	42.3	3.6	22.9
402	5	D112	54.9	5.5	18.3	49.6	3.5	18.9
403	2	B55.9	56.9	5.3	17.7	45.5	3.9	21.5
404	4	D55.9	60.3	6.1	19.4	47.6	3.8	20.0
405	7	S9.8+B55.9	58.0	6.0	18.8	49.3	3.7	19.6
406	8	S9.8+D55.9	58.0	5.9	18.4	48.5	3.9	20.2
407	6	S9.8	56.3	4.7	19.3	46.7	3.5	19.1
408	1	C	54.1	4.7	19.3	46.5	3.5	19.9

Table A.20 2008 Soybean Grain Data from near Welda, KS.

							Grain Analysis		
Plot No.	Trt. No.	Trt. Abv.	Harvest Weight kg 23.2$(m^2)^{-1}$	Moisture g kg^{-1}	Test Weight kg	Yield kg ha^{-1}	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}
101	1	C	8.66	130	24.9	3730	59.7	6.4	19.8
102	4	D55.9	9.07	129	25.1	3910	59.0	6.0	18.8
103	6	S9.8	8.12	128	25.2	3500	61.0	5.9	19.1
104	7	S9.8+B55.9	8.75	128	25.2	3780	61.8	6.2	19.8
105	8	S9.8+D55.9	8.85	127	25.0	3820	62.3	6.0	19.3
106	3	B112	8.44	125	25.2	3650	61.9	5.8	19.3
107	5	D112	8.57	125	25.2	3710	62.8	5.8	19.2
108	2	B55.9	7.67	124	25.4	3320	62.0	5.8	18.5
201	4	D55.9	8.35	131	25.1	3590	64.8	5.8	19.2
202	6	S9.8	9.03	129	25.0	3890	63.7	6.0	18.9
203	3	B112	8.66	129	25.1	3730	60.8	5.5	18.3
204	5	D112	9.12	128	24.8	3930	64.6	6.1	19.7
205	2	B55.9	8.57	125	24.9	3710	62.4	5.8	18.8
206	1	C	8.44	126	25.3	3650	64.7	5.9	18.5
207	7	S9.8+B55.9	9.07	126	25.2	3920	65.6	6.0	19.5
208	8	S9.8+D55.9	8.66	127	25.4	3740	63.1	5.5	18.5
301	7	S9.8+B55.9	8.98	129	25.3	3870	63.7	5.9	18.7
302	1	C	8.57	129	25.3	3700	62.6	6.0	19.1
303	5	D112	8.89	129	25.2	3830	61.8	5.7	18.9
304	8	S9.8+D55.9	9.16	128	25.2	3950	64.4	6.2	19.5
305	3	B112	9.25	126	24.9	4000	62.1	5.9	18.9
306	4	D55.9	8.62	127	25.3	3720	63.9	5.9	19.1
307	2	B55.9	9.30	125	25.0	4030	56.7	5.4	18.2
308	6	S9.8	9.25	125	25.2	4010	62.0	6.0	19.3
401	3	B112	8.26	129	24.9	3560	61.9	6.3	20.1
402	5	D112	8.57	130	25.0	3690	60.7	6.1	19.7
403	2	B55.9	9.07	129	25.1	3910	66.4	6.4	20.0
404	4	D55.9	9.34	129	25.0	4030	58.1	6.0	18.9
405	7	S9.8+B55.9	9.34	126	24.6	4040	68.2	6.1	19.6
406	8	S9.8+D55.9	8.57	126	24.9	3710	64.7	6.1	19.1
407	6	S9.8	9.62	127	25.1	4160	60.0	6.0	19.0
408	1	C	9.62	126	25.0	4160	61.7	5.8	18.5

Table A.21 2008 Initial Soybean Soil Sample Data from near Welda, KS.

Plots	Depth m	pH	Buffer pH	P mg kg^{-1}	K mg kg^{-1}	O.M. g kg^{-1}
101-108	0-0.15	6.7	-	15	116	2.2
201-208	0-0.15	6.9	-	15	124	2.7
301-308	0-0.15	6.9	-	21	117	2.4
401-408	0-0.15	6.5	-	37	182	2.9

2008 Residual K for Corn in No-Tillage

Table A.22 2008 Residual K for Corn in No-till.

Trt. No.	Trt. Abv.	Starter K ($kg\ ha^{-1}$)	Broadcast K ($kg\ ha^{-1}$)	Deep Band K ($kg\ ha^{-1}$)	Total K ($kg\ ha^{-1}$)
1	C	0	0	0	0
2	B55.9	0	55.9	0	55.9
3	B112	0	112	0	112
4	D55.9	0	0	55.9	55.9
5	D112	0	0	112	112
6	S9.8	9.8	0	0	9.8
7	S9.8+B55.9	9.8	55.9	0	65.7
8	S9.8+D55.9	9.8	0	55.9	65.7

Plot length = 15.2 m, Plot width = 3.05 m, Alley = 15.2 m

Figure A.3 2008 Residual K Corn Plot Plan.

B	401	402	403	404	405	406	407	408	B
	3	6	5	4	7	1	2	8	

B	301	302	303	304	305	306	307	308	B
	1	2	4	8	5	3	7	6	

B	201	202	203	204	205	206	207	208	B
	8	3	7	1	6	5	4	2	

B	101	102	103	104	105	106	107	108	B
	4	7	1	6	2	3	8	5	

Table A.23 2008 Residual K Corn Tissue Data from near Ottawa, KS.

Plot No.	Trt. No.	Trt. Abv.	Ear Leaf g kg^{-1}
101	4	D55.9	15.0
102	7	S9.8+B55.9	14.0
103	1	C	13.6
104	6	S9.8	15.2
105	2	B55.9	16.2
106	3	B112	16.3
107	8	S9.8+D55.9	15.9
108	5	D112	14.6
201	8	S9.8+D55.9	15.6
202	3	B112	15.1
203	7	S9.8+B55.9	14.8
204	1	C	13.6
205	6	S9.8	13.4
206	5	D112	15.3
207	4	D55.9	14.2
208	2	B55.9	14.6
301	1	C	13.8
302	2	B55.9	16.5
303	4	D55.9	15.5
304	8	S9.8+D55.9	21.5
305	5	D112	15.7
306	3	B112	15.4
307	7	S9.8+B55.9	14.3
308	6	S9.8	13.4
401	3	B112	15.2
402	6	S9.8	14.2
403	5	D112	15.1
404	4	D55.9	14.9
405	7	S9.8+B55.9	15.9
406	1	C	14.1
407	2	B55.9	14.2
408	8	S9.8+D55.9	14.5

Table A.24 2008 Residual K Corn Grain Data from near Ottawa, KS.

Plot No.	Trt. No.	Trt. Abv.	Harvest Weight kg 8.09$(m^2)^{-1}$	Moisture g kg^{-1}	Yield kg ha^{-1}	Grain Analysis		
						N g kg^{-1}	P g kg^{-1}	K g kg^{-1}
101	4	D55.9	7.21	157	8890	11.4	2.47	4.01
102	7	S9.8+B55.9	6.67	153	8260	11.5	2.20	3.86
103	1	C	6.94	155	8580	12.5	1.91	3.66
104	6	S9.8	4.85	160	5960	10.5	2.79	4.40
105	2	B55.9	5.35	155	6620	9.6	2.24	3.99
106	3	B112	4.81	156	5940	9.6	2.68	4.23
107	8	S9.8+D55.9	5.90	160	7250	10.8	2.42	3.79
108	5	D112	6.94	156	8570	11.7	2.15	3.95
201	8	S9.8+D55.9	5.08	148	6330	11.0	2.60	4.45
202	3	B112	5.44	149	6780	10.5	2.17	3.94
203	7	S9.8+B55.9	5.67	146	7080	9.9	2.36	4.27
204	1	C	4.72	151	5860	9.8	2.31	3.89
205	6	S9.8	6.17	151	7660	12.5	2.02	3.78
206	5	D112	4.40	150	5470	12.7	2.61	4.26
207	4	D55.9	5.49	148	6840	10.8	2.52	4.09
208	2	B55.9	5.94	153	7360	10.8	2.26	3.94
301	1	C	5.40	147	6740	10.5	2.47	4.21
302	2	B55.9	6.89	152	8550	12.0	1.99	3.78
303	4	D55.9	5.81	158	7150	11.2	2.08	3.71
304	8	S9.8+D55.9	5.58	154	6900	10.0	2.21	3.79
305	5	D112	6.26	147	7810	11.1	2.05	3.93
306	3	B112	5.72	151	7100	10.8	2.05	3.85
307	7	S9.8+B55.9	5.67	153	7030	10.3	2.35	4.10
308	6	S9.8	6.58	149	8190	12.9	2.42	4.14
401	3	B112	5.22	151	6480	10.7	2.74	4.57
402	6	S9.8	5.99	147	7470	12.8	2.56	4.34
403	5	D112	5.44	154	6740	11.9	2.29	3.89
404	4	D55.9	6.12	149	7620	10.0	1.91	3.52
405	7	S9.8+B55.9	7.21	154	8930	12.7	2.53	4.29
406	1	C	6.12	150	7610	12.7	2.22	3.80
407	2	B55.9	5.40	154	6680	10.8	2.32	4.09
408	8	S9.8+D55.9	6.58	148	8200	13.0	2.81	4.30

Table A.25 Soil Sample Data from Ottawa, KS, collected in 2008 prior to Corn.

Plot No.	Depth (m)	Trt. No.	Trt. Abv.	Location	K (mg kg^{-1})
103	0-0.08	1	C	Row	170
103	0.08-0.15	1	C	Row	143
103	0.15-0.23	1	C	Row	138
103	0-0.08	1	C	Row Middle	151
103	0.08-0.15	1	C	Row Middle	133
103	0.15-0.23	1	C	Row Middle	146
106	0-0.08	3	B112	Row	203
106	0.08-0.15	3	B112	Row	156
106	0.15-0.23	3	B112	Row	175
106	0-0.08	3	B112	Row Middle	205
106	0.08-0.15	3	B112	Row Middle	169
106	0.15-0.23	3	B112	Row Middle	190
108	0-0.08	5	D112	Row	185
108	0.08-0.15	5	D112	Row	164
108	0.15-0.23	5	D112	Row	149
108	0-0.08	5	D112	Row Middle	178
108	0.08-0.15	5	D112	Row Middle	139
108	0.15-0.23	5	D112	Row Middle	141
202	0-0.08	3	B112	Row	214
202	0.08-0.15	3	B112	Row	144
202	0.15-0.23	3	B112	Row	194
202	0-0.08	3	B112	Row Middle	182
202	0.08-0.15	3	B112	Row Middle	202
202	0.15-0.23	3	B112	Row Middle	218
204	0-0.08	1	C	Row	143
204	0.08-0.15	1	C	Row	187
204	0.15-0.23	1	C	Row	199
204	0-0.08	1	C	Row Middle	147
204	0.08-0.15	1	C	Row Middle	189
204	0.15-0.23	1	C	Row Middle	210
206	0-0.08	5	D112	Row	156
206	0.08-0.15	5	D112	Row	120
206	0.15-0.23	5	D112	Row	182
206	0-0.08	5	D112	Row Middle	89
206	0.08-0.15	5	D112	Row Middle	78
206	0.15-0.23	5	D112	Row Middle	118
301	0-0.08	1	C	Row	139
301	0.08-0.15	1	C	Row	140
301	0.15-0.23	1	C	Row	164

Table A.25 Soil Sample Data from Ottawa, KS, collected in 2008 prior to Corn (continued).

Plot No.	Depth (m)	Trt. No.	Trt. Abv.	Location	K (mg kg^{-1})
301	0-0.08	1	C	Row Middle	143
301	0.08-0.15	1	C	Row Middle	151
301	0.15-0.23	1	C	Row Middle	192
305	0-0.08	5	D112	Row	181
305	0.08-0.15	5	D112	Row	136
305	0.15-0.23	5	D112	Row	154
305	0-0.08	5	D112	Row Middle	179
305	0.08-0.15	5	D112	Row Middle	134
305	0.15-0.23	5	D112	Row Middle	135
306	0-0.08	3	B112	Row	120
306	0.08-0.15	3	B112	Row	81
306	0.15-0.23	3	B112	Row	141
306	0-0.08	3	B112	Row Middle	127
306	0.08-0.15	3	B112	Row Middle	141
306	0.15-0.23	3	B112	Row Middle	149
401	0-0.08	3	B112	Row	148
401	0.08-0.15	3	B112	Row	126
401	0.15-0.23	3	B112	Row	147
401	0-0.08	3	B112	Row Middle	129
401	0.08-0.15	3	B112	Row Middle	118
401	0.15-0.23	3	B112	Row Middle	170
403	0-0.08	5	D112	Row	147
403	0.08-0.15	5	D112	Row	132
403	0.15-0.23	5	D112	Row	205
403	0-0.08	5	D112	Row Middle	171
403	0.08-0.15	5	D112	Row Middle	154
403	0.15-0.23	5	D112	Row Middle	183
406	0-0.08	1	C	Row	135
406	0.08-0.15	1	C	Row	111
406	0.15-0.23	1	C	Row	153
406	0-0.08	1	C	Row Middle	97
406	0.08-0.15	1	C	Row Middle	85
406	0.15-0.23	1	C	Row Middle	163

Table A.26 2008 Residual K Corn Tissue Data from near Westphalia, KS.

Plot No.	Trt. No.	Trt. Abv.	Ear Leaf g kg^{-1}
101	4	D55.9	14.1
102	7	S9.8+B55.9	13.5
103	1	C	13.3
104	6	S9.8	13.6
105	2	B55.9	14.6
106	3	B112	13.5
107	8	S9.8+D55.9	12.9
108	5	D112	15.8
201	8	S9.8+D55.9	13.4
202	3	B112	15.0
203	7	S9.8+B55.9	13.8
204	1	C	12.5
205	6	S9.8	16.5
206	5	D112	15.2
207	4	D55.9	13.9
208	2	B55.9	14.3
301	1	C	13.5
302	2	B55.9	14.3
303	4	D55.9	16.3
304	8	S9.8+D55.9	14.7
305	5	D112	16.2
306	3	B112	14.2
307	7	S9.8+B55.9	14.0
308	6	S9.8	16.7
401	3	B112	13.6
402	6	S9.8	13.2
403	5	D112	15.4
404	4	D55.9	14.2
405	7	S9.8+B55.9	16.1
406	1	C	13.8
407	2	B55.9	12.1
408	8	S9.8+D55.9	15.1

Table A.27 2008 Residual K Corn Grain Data from near Westphalia, KS.

Plot No.	Trt. No.	Trt. Abv.	Harvest Weight kg 8.09(m^2)$^{-1}$	Moisture g kg^{-1}	Yield kg ha^{-1}	Grain Analysis		
						N g kg^{-1}	P g kg^{-1}	K g kg^{-1}
101	4	D55.9	6.21	143	7790	10.8	2.92	3.99
102	7	S9.8+B55.9	5.76	144	7210	11.3	2.68	3.72
103	1	C	6.03	145	7550	13.5	3.06	3.89
104	6	S9.8	4.76	141	5990	12.0	3.03	3.99
105	2	B55.9	4.90	141	6160	13.0	3.36	4.29
106	3	B112	3.76	142	4730	11.1	2.96	4.19
107	8	S9.8+D55.9	4.81	142	6040	12.2	3.31	4.43
108	5	D112	5.22	142	6550	10.7	3.17	4.24
201	8	S9.8+D55.9	4.08	142	5120	9.5	2.82	4.37
202	3	B112	3.86	143	4830	9.9	3.15	4.92
203	7	S9.8+B55.9	4.90	139	6170	10.0	2.77	4.41
204	1	C	3.18	141	3990	9.9	3.17	4.74
205	6	S9.8	3.27	140	4110	10.7	3.18	4.61
206	5	D112	3.18	144	3980	9.2	2.85	4.84
207	4	D55.9	3.22	144	4030	9.9	3.07	5.13
208	2	B55.9	3.76	140	4740	10.9	3.16	5.34
301	1	C	3.45	144	4320	12.2	3.29	5.39
302	2	B55.9	4.45	140	5590	9.9	2.89	4.71
303	4	D55.9	5.58	143	6990	10.6	3.23	5.64
304	8	S9.8+D55.9	3.36	144	4200	9.7	2.52	3.54
305	5	D112	4.35	142	5470	10.6	2.67	3.76
306	3	B112	2.13	139	2690	9.2	2.31	3.36
307	7	S9.8+B55.9	3.04	146	3800	10.6	2.83	4.27
308	6	S9.8	4.22	144	5280	10.2	2.44	3.87
401	3	B112	3.31	146	4140	10.2	2.74	3.97
402	6	S9.8	3.13	143	3920	11.7	2.73	3.55
403	5	D112	7.67	143	9610	11.7	2.51	3.56
404	4	D55.9	4.72	140	5940	10.9	2.61	3.83
405	7	S9.8+B55.9	3.72	145	4650	10.3	2.71	3.97
406	1	C	3.95	140	4970	9.0	2.31	3.62
407	2	B55.9	4.72	147	5890	11.1	2.79	4.15
408	8	S9.8+D55.9	5.72	142	7170	11.0	2.54	3.65

Table A.28 Soil Sample Data from Westphalia, KS, collected in 2008 prior to Corn.

Plot No.	Depth (m)	Trt. No.	Trt. Abv.	Location	K (mg kg^{-1})
103	0-0.08	1	C	Row	213
103	0.08-0.15	1	C	Row	190
103	0.15-0.23	1	C	Row	219
103	0-0.08	1	C	Row Middle	221
103	0.08-0.15	1	C	Row Middle	205
103	0.15-0.23	1	C	Row Middle	222
106	0-0.08	3	B112	Row	217
106	0.08-0.15	3	B112	Row	209
106	0.15-0.23	3	B112	Row	226
106	0-0.08	3	B112	Row Middle	236
106	0.08-0.15	3	B112	Row Middle	205
106	0.15-0.23	3	B112	Row Middle	224
108	0-0.08	5	D112	Row	221
108	0.08-0.15	5	D112	Row	185
108	0.15-0.23	5	D112	Row	211
108	0-0.08	5	D112	Row Middle	231
108	0.08-0.15	5	D112	Row Middle	180
108	0.15-0.23	5	D112	Row Middle	214
202	0-0.08	3	B112	Row	239
202	0.08-0.15	3	B112	Row	235
202	0.15-0.23	3	B112	Row	223
202	0-0.08	3	B112	Row Middle	251
202	0.08-0.15	3	B112	Row Middle	196
202	0.15-0.23	3	B112	Row Middle	220
204	0-0.08	1	C	Row	231
204	0.08-0.15	1	C	Row	218
204	0.15-0.23	1	C	Row	239
204	0-0.08	1	C	Row Middle	232
204	0.08-0.15	1	C	Row Middle	223
204	0.15-0.23	1	C	Row Middle	244
206	0-0.08	5	D112	Row	232
206	0.08-0.15	5	D112	Row	197
206	0.15-0.23	5	D112	Row	241
206	0-0.08	5	D112	Row Middle	244
206	0.08-0.15	5	D112	Row Middle	241
206	0.15-0.23	5	D112	Row Middle	249
301	0-0.08	1	C	Row	223
301	0.08-0.15	1	C	Row	235
301	0.15-0.23	1	C	Row	243

Table A.28 Soil Sample Data from Westphalia, KS, collected in 2008 prior to Corn (continued).

Plot No.	Depth (m)	Trt. No.	Trt. Abv.	Location	K (mg kg^{-1})
301	0-0.08	1	C	Row Middle	230
301	0.08-0.15	1	C	Row Middle	208
301	0.15-0.23	1	C	Row Middle	250
305	0-0.08	5	D112	Row	288
305	0.08-0.15	5	D112	Row	234
305	0.15-0.23	5	D112	Row	261
305	0-0.08	5	D112	Row Middle	280
305	0.08-0.15	5	D112	Row Middle	225
305	0.15-0.23	5	D112	Row Middle	264
306	0-0.08	3	B112	Row	284
306	0.08-0.15	3	B112	Row	217
306	0.15-0.23	3	B112	Row	287
306	0-0.08	3	B112	Row Middle	267
306	0.08-0.15	3	B112	Row Middle	209
306	0.15-0.23	3	B112	Row Middle	255
401	0-0.08	3	B112	Row	249
401	0.08-0.15	3	B112	Row	220
401	0.15-0.23	3	B112	Row	235
401	0-0.08	3	B112	Row Middle	221
401	0.08-0.15	3	B112	Row Middle	181
401	0.15-0.23	3	B112	Row Middle	218
403	0-0.08	5	D112	Row	242
403	0.08-0.15	5	D112	Row	178
403	0.15-0.23	5	D112	Row	217
403	0-0.08	5	D112	Row Middle	265
403	0.08-0.15	5	D112	Row Middle	247
403	0.15-0.23	5	D112	Row Middle	238
406	0-0.08	1	C	Row	223
406	0.08-0.15	1	C	Row	187
406	0.15-0.23	1	C	Row	211
406	0-0.08	1	C	Row Middle	235
406	0.08-0.15	1	C	Row Middle	171
406	0.15-0.23	1	C	Row Middle	215