PHOSPHORUS AND POTASSIUM PLACEMENT IN CORN-SOYBEAN SYSTEMS IN THE MIDWEST: POSSIBILITIES WITH AUTOMATIC GUIDANCE TECHNOLOGY

T.S. Murrell, Potash & Phosphate Institute, Woodbury, MN

Introduction

Global positioning system technology available to the public has become more accurate in recent years. Current Real Time Kinematic (RTK) techniques allow relative positions of equipment to be recorded with 3/8 – 2 in. precision (Dana, 1994). Being able to return to the same location in the field year after year with high precision may have implications for corn-soybean systems where banded applications of phosphorus (P) and/or potassium (K) are made at a time other than at planting. The importance of the placement of seed rows in relation to fertilizer bands depends heavily on the type of tillage system used. Before discussing various placement methods under various tillage systems, some background is needed to make sense of the responses seen in field studies.

Growth of Corn and Soybean Roots

The growth of soybean roots has been characterized by a 3-phase system (Mitchell and Russell, 1971), **Figure 1**. These phases were based on greenhouse soil monoliths as well as field trenches dug perpendicular to 30 in. soybean rows in Iowa. In Phase 1, soybean top growth was rapid and the taproot extended downward. Laterals formed in the upper layers of the soil, with heavy accumulation in the 0-3 in. portion of the soil. Phase 2 describes root distributions taken from samples collected 67-80 days after planting. This period was characterized by rapid top growth, flowering, and the beginning of pod formation. Below the soil surface, root development was rapid to depths of 18-30 in. Laterals proliferated in the upper 6-9 in. of soil. As soybean lateral roots encountered roots of adjacent plants near mid-row positions, they turned downward rather than continuing to grow horizontally. This downward turning of roots at mid-row positions has also been observed by others (Raper and Barber, 1970). Phase 3 described root samples taken 80 to 102 days after planting. This was during seed set through maturity. Taproot growth slowed, and the major lateral roots elongated rapidly downward to a depth of 48-72 in. Increased rates of downward growth of soybean roots during reproductive stages have been observed by others (Kaspar et al., 1978). Perhaps the most striking part of the data presented by Mitchell and Russell was that most (71-83%) of the root system of soybean was concentrated in the upper 3 in. of soil.

The growth of corn roots has been characterized in Michigan by a 5-stage system that is much different than soybean (Foth, 1962). Stage 1, observed up to 37 days after planting, was characterized by downward diagonal root growth. In this stage, more than half of the root system was located 3-9 in. below the soil surface and approximately 75% of the root system was within a 9 in. radius from the plant. Stage 2, 37-54 days after planting, showed continued vegetative growth and increased root density in the upper soil layers (0-15 in.), between the earlier developed, diagonally distributed roots and the soil surface. Brace roots also started developing at the end of this stage. Stage 3, 54-67 days after planting, was marked by rapid stem elongation, silking, and pollination and proliferation of roots deeper in the soil profile, below 15 in. Brace roots continued to develop. Stage 4, 67-80 days after planting, was the period in which corn developed to the early milk stage. Brace roots finished developing and no change in roots were observed in the 15-36 in. depth. Brace roots accounted for the changes in root weight observed in the upper soil layers. Stage 5, 80 days to maturity, showed no change in root weight or distribution. In contrast to soybeans, only about 44% of the total corn root system was in the upper 3 in. of soil. Another 44% was located 3-12 in. below the soil surface. The remaining 12% was located 15-36 in. down (the lower limit measured). Mengel and Barber working in Indiana showed that root density peaked in the 0-6 in. layer by about 79 days after planting and about 2 weeks later in the 6-12 in. depth (Mengel and Barber, 1974a). After 79 days, root density decreased as corn matured.

Effects of Nutrient Distribution on Corn and Soybean Root Growth

An important concept to nutrient placement is that roots proliferate where soil P supplies are higher. **Figure 2** shows experimental results where roots of both corn and soybean proliferated more in zones of higher P concentration (Anghinoni and Barber, 1980a; Borkert and Barber, 1985a). These data come from two growth chamber experiments where pots contained various proportions of P-enriched soil. Root length measurements were taken when corn and soybean were 18 and 24 days old, respectively. Both experiments were conducted on a Raub silt loam with an initial soil test of 9.1 ppm Bray P-1. The P-enriched soil ranged from 31.1 to 602.5 ppm Bray P-1. The lowest soil test P in the treated soil was for the entire soil fraction fertilized (1.00) and the highest soil test level was associated with the lowest soil fraction fertilized (0.625). The total amount of P was kept constant at 0.9 x 10^{-3} lb P_2O_5 per pot. If P did not stimulate root proliferation, then there should have been an equal proportion of the soybean and corn roots in the fertilized and unfertilized soil volume. If this were the case, then the data points should have fallen along the 1:1 line. Instead, the data points all fell above this line, indicating that a greater proportion of the total root length was located in the P-enriched soil.

Potassium supply may have an effect on soybean root growth, although it is not well defined. In pot studies of corn grown for 21 days, it was observed that when soil bulk density was higher, K additions increased root weight and root surface area per pot (Hallmark and Barber, 1981). On a lower bulk density soil, K additions did not affect total root weight nor root surface area per pot but did decrease the root surface area per unit weight of root. This means that K additions created roots with a larger diameter. Conversely, roots grown in a low K soil had a finer root system with more surface area. It was hypothesized that this change in root morphology under low soil K conditions may have been a plant compensation mechanism. In a no-till field study in Kentucky, greater root length density was measured in the 0-2 in. depth on a low K soil compared to the same soil receiving K fertilizer (Coale and Grove, 1990). Differences were seen at the R1, R5, and R7 growth stages. Soil P levels at this depth were 82 ppm Bray P-1, and soil test K levels in the unfertilized and fertilized treatments were 101 and 316 ppm ammonium acetate-extractable ($NH_4C_2H_3O_2$) K, respectively.

Effect of Tillage System on Corn Root Growth

Type of tillage system may influence the distribution of corn roots in the soil. In a Minnesota study, no-till, ridge-till, fall-chiseled, and fall-moldboard-plowed soil were compared (Bauder et al., 1985). Root length density was measured in the row as well as 7.5 and 15 in. to the side in a perpendicular direction. Corn was planted in 30 in. rows. One side of the row received wheel traffic while the other did not. In the upper 3 in. of soil, no-till and ridge-till had higher root length densities and greater calculated root lengths than where soil had been moldboard plowed or chiseled (**Figure 3**). In addition, most of the roots were located directly below the row, with very little of them 7.5-15 in. away. Greater root length densities near the surface and below the rows in ridge-till systems was also seen in an Iowa study (Kaspar et al., 1991). Compared to no-till, chisel tillage, and moldboard plowing, ridge-till had the greatest overall root length and the greatest penetration of roots through the soil profile. In contrast, no-till had the greatest root length density below the row at the shallowest depth and the lowest root length density in all lower layers. A higher distribution of roots under the row at shallow depths in no-till has been observed by others (Anderson, 1987; Barber, 1971).

No-till may have important effects on root morphology. In an Indiana study, root weight density, root length density, and root length per unit root length were measured for several tillage systems over a range of depths. In the 0-2 in. depth, no-till had the highest root weight density as well as the highest root length density, but it had the lowest root length per unit root weight. These data indicate that no-till systems tended to have larger numbers of larger diameter roots in the surface soil layer, an observation confirmed by others (Holanda et al., 1998). Larger diameter roots are usually associated with soil layers that have higher mechanical impedance and lower temperatures (Marschner, 2002). Increased root diameter could impact nutrient uptake. If the increase in root length is not great enough to compensate for the decrease in surface area per unit weight of root, then decreased uptake could occur. However, such impacts have not been well documented for no-till systems and research in Maryland indicated that the effects of tillage on root diameter may change through the season, making generalizations difficult (Anderson, 1987).

To what extent differences in root distributions can be seen when comparing tillage systems depends greatly on the distribution and amount of wheel traffic. Several studies have shown that wheel traffic restricts root growth and can lead to more vertical root distributions (Bauder et al., 1985; Chaudhary and Prihar, 1974; Kaspar et al., 1995; Kaspar et al., 1991). The effect of compaction can overshadow any effects of tillage upon extent of roots into interrow positions (Kaspar et al., 1995).

Impacts of Broadcast Fertilizer Applications on P and K Distribution

Tillage systems vary in the way P and K are distributed after being broadcast over the soil surface. Long-term studies in Ohio, Iowa, and Kentucky have shown higher P and K levels near the soil surface compared to those deeper in the soil profile, which contrasts to the more even distribution of nutrient with depth in more aggressive tillage systems (Blevins et al., 1983; Dick et al., 1991; Karlen et al., 1991; Robbins and Voss, 1991). This stratification of P and K arises from uptake of these nutrients from lower in the soil profile coupled with subsequent surface deposition of P and K-containing crop residues at the surface. This condition is also exacerbated by broadcast and unincorporated or shallowly incorporated P and K fertilizer applications.

While nutrient stratification is a common characteristics of reduced tillage systems, not all of these systems have the same distribution of nutrients downward and/or from crop row to crop row. In no-till systems, repeated broadcast P and K applications can result in fertility gradients that are fairly uniform from row to row (Holanda et al., 1998: Robbins and Voss, 1991). Gradients reported in these studies are fairly steep, with ranges of approximately 40-120 and 80-420 ppm soil test P and K, respectively.

The distribution of soil test P and K in ridge-till systems is varied. In several studies, broadcast P in ridge-till systems has produced higher soil tests between rows (Borges and Mallarino, 2001; Rehm et al., 1995; Robbins and Voss, 1991). However, for K, repeated broadcast applications over time may produce higher soil test K levels between rows (Robbins and Voss, 1991), in the rows (Mackay et al.. 1987) or no differences (Borges and Mallarino, 2003; Borges and Mallarino, 2001).

Impacts of Banded Fertilizer on P and K Distribution

Repeated applications of low rates of starter fertilizer placed near the seed can create localized zones of higher soil test levels. In a Pennsylvania study, no-till, fall chisel/spring disk, and fall moldboard plow/spring disk systems were examined after 26 years of cropping, which was mostly continuous corn with a few exceptions (Duiker and Beegle, in press). Effort was made to plant in the same rows every year. Broadcast P and K applications were made only once during the study, 2 years prior to assessing soil test level distributions. Rates of P and K in the starter fertilizer varied from 22-33 lb P_2O_5/A/yr and 11-23 lb K_2O/A/yr, except for 3 intermittent years when corn was not grown. Nitrogen (N)-P-K starters were applied 2x2, or approximately 4 in. below the surface and 2 in. to the side of the row. Soil samples were taken every 3 in. starting at the row and going to mid-row positions in 30 in. corn rows. In all three tillage systems, higher soil test P levels were observed in samples taken 3 in. from the row and 0-2 in. deep on the side where starter fertilizer had been placed. In the no-till system, higher levels were also observed 6 in. away from the crop row at this depth. Levels were approximately 50-75 ppm Mehlich-3 P higher than in other areas of the soil. with greatest differences existing for the moldboard plow/disk system.

Repeated applications of starter fertilizer did not result in discreet zones of higher soil test K. Instead, soil test K levels were highest in the crop row and decreased rather symmetrically on either side out 6-9 in. from the row. In the chisel/spring disk system, there was some evidence of an enriched zone in samples taken 3 in. from the row where starter fertilizer had been applied. Levels in the row were approximately 50-75 ppm Mehlich-3 K higher than positions closer to and including the mid-row. Greater uptake of K and greater mobility of K, compared to P, were given as reasons for the differences.

The lack of discreet zones of higher soil test K after banded applications may be due to the low rate of K used in this study. In other studies examining banded K applications in ridge-till systems, localized zones of higher soil test K levels were observed. After two or more years of annually banded K at rates from 80-160 lb K_2O/A/yr, Minnesota research showed elevated K levels in the row (Rehm, 1995; Rehm and Lamb, 2004). In some cases elevated levels were also seen in inter-row positions (Rehm and Lamb, 2004). Repeated annual applications produced higher K levels in the 0-6 in increment in the row than a single application of the same total rate applied periodically. In Iowa ridge-till studies, higher soil test levels at deeper positions in the row were usually not seen after only a single application of K (Borges and Mallarino, 2003; Borges and Mallarino, 2001).

For P, many studies have shown higher soil test levels near, rather than between, rows after banded P applications in ridge-till systems. Work in Iowa showed that single applications of banded P in the row produced higher P concentrations in the row than between rows (Borges and Mallarino, 2003). This is expected because of the lack of tillage in the row as well as the lack of residue cover during parts of the growing season. An Indiana study examining a corn-soybean rotation also showed that after 5 biannual applications of 30 lb P_2O_5/A applied in a band 2 in. to the side and 1 in. below the seed, P levels to a depth of 9 in. were higher in the row than between rows (Mackay et al., 1987). Concentrated zones in the soil where P had been repeatedly banded for 3 years have also been observed in a Minnesota study (Rehm et al., 1995).

Most of the work examining how banded nutrient applications affect soil test levels over time has been done with P. In a Missouri study, the residual effects of low liquid starter P rates (20 and 40 lb P_2O_5/A) applied 2x2 were studied at 6 month intervals after the initial application in the spring with corn in 30 in. rows (Stecker et al., 2001). Soybean was planted in the following season. The P fertilized soil volume for the 40 lb P_2O_5/A rate was calculated to be 2.6-4.1% of the total soil volume between the 30 in. rows and from 0-6 in. deep. The cross-sectional profile of the bands showed they tended to be longer (2-5 in.) than wider (2-3 in.) (**Figure 4**). Phosphorus concentration decreased exponentially from the band center, which ranged in concentration from 70-179 and 188-415 ppm Bray P-1 colorimetric P for the 20 and 40 lb P_2O_5/A rates, respectively. Exponential decreases in P concentration from the band center have also been observed in other studies (Kitchen et al., 1990). Over time, P concentrations in the band decreased, but after 18 months were still greater than 100 ppm.

In the same study, calculations were made for changes in fertilized soil volume under various schedules and rates of P fertilization for a Mexico silty clay loam soil. These estimates assumed that as banding was performed over time, the increased volume of fertilized soil was additive. This assumption is most appropriate for approaches that place bands in different positions with each application. Decreases in fertilized soil volume over time in a given band were accounted for. The results are shown in **Figure 5**. This figure predicts that annual applications of either 20 or 40 lb P_2O_5/A will increase the fertilized soil volume, with the 40 lb P_2O_5/A rate doing so much more rapidly.

A study in Nebraska investigated how long higher concentrations of P might exist in soils after initial banded applications (Eghball et al., 1990). Isotopically labeled P (^{32}P) was applied in bands on 3 soils with very different abilities to adsorb P. Six rates of P were applied, ranging from 30-120 lb P_2O_5/A, and allowed to diffuse for 94 days under field conditions. No crops were grown. Longevity was defined as the duration of time that the concentration of P in the band was maintained at a level at least 5 times the original water-soluble P concentration. The distance that P diffused from the band increased linearly with P application rate, with band diameters ranging from about 1.5 in. at the 30 lb P_2O_5/A rate to about 6 in. at the 120 lb P_2O_5/A rate. Longevity of bands was modeled and predicted, based on the data collected from the experiment. Predicted longevities were highest for the soil with the lowest capacity to adsorb P. As rate increased, so did longevity. Across all soils and rates, the average longevity was a little over 4 years. Actual longevities of various P rate and soil combinations will likely be shorter under cropped conditions because of nutrient uptake.

P and K Nutrient Absorption Rates by Corn and Soybean Roots

An important concept for understanding the effectiveness of fertilizer placement is nutrient influx (Barber, 1984). Nutrient influx is a term used to describe the rate of nutrient absorption by plant roots (**Figure 6**). The type of uptake shown in this figure is active uptake. Active uptake requires an expenditure of energy by the plant. Examples of ions absorbed by active uptake are orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) and the potassium ion (K^+). Simply increasing the concentration of these ions in the soil solution does not result in a directly proportional increase in uptake rate. Rather, as solution concentration increases, absorption rates decrease and slowly approach a maximum rate, termed I_{max}, which stands for maximum influx. I_{max} is an important parameter, because it quantifies just how quickly a root is capable of taking up nutrients.

Corn and soybean have very different abilities to take up nutrients, especially early in the season. Two compatible field studies examined P and K influx by corn and soybean roots under field conditions (Barber, 1978; Mengel and Barber, 1974b). The corn and soybean studies were conducted for 2 and 3 years, respectively (**Figures 7 and 8**). Both P and K influx by corn were greatest at 20 days and fell off rapidly, with K influx about 3 times that of P. These high, early season influx rates may partially explain why corn tends to respond to starters containing P and K placed near the developing root system early in the season. A much less rapid reduction occurred from 30 to about 70 or 80 days. After 70 to 80 days, P and K influx rates were low, but fairly constant.

Phosphorus and K influx by soybean was also greatest at the first sampling (18 days) then decreased. However, early season influx of these nutrients by soybean was much less than that of corn. From about 50 to 80 days, P influx into soybean roots increased, in contrast to corn. During this same period, K influx leveled off, then began decreasing but was still higher than K influx by corn. This period of higher P and K influx by soybean corresponds roughly with growth stages R1 to R6 (beginning bloom to full seed). The increase in P influx during early to mid reproductive stages, along with a leveling off of K influx, may indicate a later-season requirement for plant available P and K, needed by a greater portion of the soybean root system.

Predicting the Most Effective Nutrient Placement for Corn and Soybean

Much of the current theory on best placement of P and K for corn and soybean was developed by Barber and associated scientists (Anghinoni and Barber, 1980b; Borkert and Barber, 1985b). Studies were conducted on early growth and nutrient uptake of corn and soybean. In pot studies, soil was mixed with various nutrients, including N and K. A portion of this soil was set aside and mixed with various rates of P. To study the impact of volume of soil fertilized with P, the P treated soil was placed in the same pot with non-treated soil. Phosphorus-treated and P-untreated soils were separated vertically in the pots by 16-mesh fiberglass screen, which minimized mixing of the two soils. A constant P rate per pot was applied, meaning that as the P-treated soil volume decreased, the concentration of P in that volume increased, as with field applications of banded fertilizer.

For both corn and soybean, these studies showed that maximum nutrient uptake and dry matter yield could be attained when a fraction of the soil volume was fertilized. Just how much volume needed to be fertilized with P varied with rate, shown conceptually in **Figure 9.** The model demonstrates that when a low P rate is applied to a low testing soil, a small fertilized soil volume (like that attained with banding), maximizes dry matter yield. The reason for this is less soil-fertilizer contact, increasing the probability that more P will remain in more readily soluble forms. In addition, roots that find localized P supplies will proliferate. However, the localized P supply may not provide P to enough of the roots to maximize yield, compared to a higher rate of P broadcast and incorporated. Higher rates applied to a greater proportion of the soil provide P in positions that are available throughout the season.

Comparing the volumes necessary to maximize dry matter production for young corn and soybean plants reveals that soybean requires less fertilized soil volume than does corn (**Figure 10**). This figure combines information from separate studies using the same soil, fertilizer rates, and experimental procedures (Anghinoni and Barber, 1980a; Borkert and Barber, 1985a). This difference is due in part to the different P influx rates of corn and soybean. Corn has very high P influx rates early in the season, while soybean does not. For nutrient uptake, this means corn can take better advantage of concentrated supplies than can soybean; however, it also implies that a corn root can deplete a given supply of P that lies within short diffusion distances from it faster than can a soybean root exposed to the same conditions. This means that in shorter periods of time, more of the P supply for a corn root is coming from greater distances and may be harder to access, particularly in a concentrated zone where more competition exists by other roots. Since both corn and soybean allocate approximately equal proportions of their root system to enriched supplies of P, corn may require that more of its total root system be in close contact with P supplies. This reasoning may explain why small fertilized volumes maximize dry matter production for soybeans but do not do so for corn.

These concepts can be extended to K by noting some important differences. First, K can diffuse farther in soils than can P. That means a given plant root can take advantage of K supplies farther from it compared to P. It also means that competition for uptake by other roots may be more important than for P, since roots can be farther away and still compete (Silburbush and Barber, 1983). Another important difference is that corn and soybean nutrient influx rates are much higher for K than for P. While the K influx rate of soybean roots is still much less than for corn early in the season, it is nearly as high as the P influx rate for corn early in the season and stays at elevated levels longer than does both the corn P and K influx rates. This implies that soybean may require higher volumes of soil enriched with K than it does with P.

An important interaction occurs between N and P for corn. In pot studies conducted earlier than Barber's work, Ohlrogge and coworkers banded P 1.5-2 in. to the side of the seed (Miller and Ohlrogge, 1958). Nitrogen in an ammonium form was either not applied, banded with the P, or banded 1.5-2 in. to the side of the seed opposite the P band. It was found that N and P applied in the same band resulted in the greatest plant utilization of band-applied P as well as the highest early season dry matter yield. Nitrogen applied on the side opposite the P band produced nearly as high a dry matter yield but reduced P recovery from the band by about 25-30%. Banding P alone without N resulted in the lowest dry matter yield and P recovery from the band.

Later studies demonstrated the importance N form on P nutrition of soybean and corn (Riley and Barber, 1971; Soon and Miller, 1977). The results of these investigations showed that when N was applied in the ammonium form, the pH in the soil zone adjacent to the root, termed the rhizosphere, was reduced, sometimes more than 1 pH unit, depending on the soil. This lower pH resulted in greater orthophosphate concentrations and greater P uptake. Nitrogen applied in the nitrate form had the opposite effect, increasing the rhizosphere pH and decreasing P uptake.

Influence of Mycorrhizae on Response to P Fertilization

Mycorrhizae are fungi that form associations with host plants. Both corn and soybean commonly form these associations to varying degrees. Although the associations formed are often referred to as symbiotic, they are not always. When symbiosis does occur, the host plant, corn or soybean, gains an increased supply of nutrients, primarily P, from the fungus, while the fungus gains an increased supply of carbohydrates from the host plant (Marschner, 2002). Because the fungus is a sink for carbohydrates, root growth of infected plants may decrease; however, external hyphae of the mycorrhizae, which are small in diameter and have a high surface area per unit weight, can absorb and translocate P to the host plant from soil outside the normal P depletion zone of uninfected roots. When host plants grow in nutrient-poor soil, mycorrhizae help the plants gain access to more P.

Tillage and P level have been shown to affect the extent of mycorrhizal colonization of host plant roots. Mycorrhizal infection is generally enhanced by pre-existing networks in the soil. These networks are disturbed by tillage practices, resulting in delayed and or reduced infection rates (Marschner, 2002). In addition, higher soil test P levels generally depress infection rates. Consequently, lower P soils that are undisturbed by tillage have increased chances of mycorrhizal infection.

Field Studies Illustrating Principles of Nutrient Placement

In the following section, examples of field studies are given that demonstrate how the processes discussed above are thought to work in the field.

Example: Response of Corn and Soybean to Deep-Banded K in Ridge-Till

Banding K below the seed in ridge-till systems has been shown improve K nutrition of both corn and soybean and increase yields. This has sometimes occurred at soil test levels greater than those previously thought to be sufficient.

Research in Minnesota used a coulter-knife assembly to place granular potash (0-0-60) 4 in. below the soil surface in the center of existing ridges during the fall, prior to the next season's corn crop (Rehm, 1995). Corn yield increased significantly where K had been banded on a soil with average soil tests (averaged across all row and interrow positions) ranging from 176 ppm in the surface 3 in. to 106 ppm in the 9-12 in. layer. Two of the 3 hybrids studied required 40 lb K_2O/A to maximize yield response, while one required 80 lb K_2O/A. The hybrid with the higher banded rate requirement was later found to have greater root activity lower in the soil profile while one of the less responsive hybrids studied had more root activity closer to the soil surface, where K supplies were already higher because of stratification (Allan et al., 1997). Thus, effectiveness of banded K applications depended on how well bands were positionally matched to active roots. Later studies in Minnesota did not find corn yield responses to subsurface bands of K when soil test levels ranged from greater than 150 ppm $NH_4C_2H_3O_2$ K at the surface to less than 100 ppm 12 in. down (Rehm and Lamb, 2004). The lack of response compared to the previous study was attributed to the use of different hybrids.

Minnesota research has shown ridge-till soybean to be more responsive to recently applied, banded K than to K banded ahead of the previous corn crop (Rehm, 1995). Soybean responded linearly to banded K rates up to 160 lb K_2O/A on a soil with average $NH_4C_2H_3O_2$ soil tests (averaged across all row and interrow positions) ranging from 176 ppm in the surface 3 in. to 106 ppm K in the 9-12 in. layer. Later studies showed no significant yield response in soybeans to fresh or residual K when soil test levels were above 140 ppm (Rehm and Lamb, 2004).

These studies illustrate that providing an additional pool of K that is lower in the soil profile may be needed to augment the contribution of higher K levels near the surface to plant nutrition. Both corn and soybean may be more sensitive to K supply because of their higher influx rates of that nutrient. The fact that soybean responded more to freshly banded K may reflect greater dissipation of banded K over time, due to its greater diffusion distances as well as to higher K influx rates of soybean roots.

Example: Lack of Response of Corn to Deep-Banded P in Ridge-Till and No-Till

Corn responses to banded P in ridge-till systems have not been as striking as those for K. In Iowa studies, responses to P occurred on soils where responses would have traditionally been expected (6.2-20.7 ppm Bray P1) based on soil samples coming from the ridge only (Borges and Mallarino, 2001). There was little to no advantage of P banded compared to broadcast.

Deep bands of P in no-till provide little benefit over broadcast applications. Research from Iowa indicated greater chances of response to deeply banded P existed at lower soil test levels, but this placement method was seldom superior to broadcast applications (Bordoli and Mallarino, 1998).

A possible explanation for lack of sensitivity of corn to P placement may be that reduced tillage systems provide a good environment for early season P nutrition of corn following soybean. In a South Dakota study, early season P uptake, dry matter production, and vesicular-arbuscular mycorrhizal (VAM) colonization were measured where no P fertilizer had been applied to various tillage and crop rotation combinations (Vivekananden and Fixen, 1991). At a soil test level of 12 ppm Bray P-1, the highest P uptake and DM accumulation occurred in ridge –till corn-soybean rotations. Greater VAM colonization occurred in ridge-till than in soil that had been moldboard plowed. Early growth responses to P fertilization were inversely related to VAM colonization, meaning that the better VAM colonization of roots in the ridge-till system may have led to reduced corn response to added P. Very similar relationships were seen in a Canadian study examining no-till and conventional tillage systems (McGonigle and Miller, 1996).

Example: Dryland Soybean Response to Banded P in a Calcareous Soil

A field study examined several different P placement methods at 2 sites in Manitoba: 1) Brandon and 2) Neepawa (Bullen et al., 1983). The Brandon site had 4.9 ppm sodium bicarbonate (Olsen) extractable P and a soil pH of 7.5. The Neepawa site had 4.4 Olsen P and a soil pH of 7.0. Placement methods were a) fall broadcast and worked in, b) spring broadcast and worked in, c) with the seed, d) banded 1 in. to the side and 1 in. below the seed, and e) 1 in. directly below the seed. Within each placement method, P was applied at 4 rates: 18, 27, 54, and 107 lb $P2O5$/A. Results from both sites followed the same trends. Broadcast applications (both fall and spring) did not produce any significant responses in soybean yield. Placement with the seed reduced seedling emergence at the highest rate, which reduced yield. At low P rates, both band placements performed similarly. However, as P rate increased, banding directly below the seed was the superior placement method.

This study demonstrates the importance of smaller volumes of concentrated P supplies to soybean under conditions of higher P fixation by soils. Under the dryland conditions of this study, greater root activity would be expected lower in the soil profile. As discussed previously, early season soybean root growth occurs by tap root elongation downward. Therefore the taproot and associated laterals would be more likely to encounter P supplies placed directly below the seed. Banding of P, particularly at higher rates, likely kept more P in a readily-available form in the band, since less soil mineral surface area would have come in contact with the fertilizer.

Example: Irrigated Soybean Response to Broadcast P in a Calcareous Soil

A study was conducted in Nebraska over 10 site-years (Rehm, 1986). Five rates of P (0-90 lb P_2O_5/a) were either broadcast or applied in a band 2 in. below and 2 in. to the side of the seed (2x2). Phosphorus increased soybean yield in 3 of 10 site-years. The soil where responses were observed was a Crofton silt loam with pH ranges of 7.6 to 8.1, and $NaHCO_3$-extractable (Olsen) P soil test of 5.6-10.7 ppm. Responses to rates and placement methods were similar in all 3 site years. Under the irrigated conditions in this study, broadcast applications produced superior yield responses to banded applications.

This study and its contrast to the previous example performed at similar P rates demonstrates the importance of placing nutrients in the soil where soybean roots are expected to be actively taking up nutrients. Under irrigation, active uptake is expected to be near the surface. Even though broadcast applications increase fertilizer-soil contact and may have lowered short-term availability, there was still enough P present to maximize yields with a broadcast application, perhaps due to the low P influx rates of soybean.

Example: Matching Band Spacing to Row Spacing for K Fertilization of No-Till Soybean

A study was conducted in Ontario, Canada, on fields with a 6-8 year history of no-till production and low soil test K levels (Yin and Vyn, 2003). Potassium was applied in the spring in 4 different ways: 1) no K applied, 2) surface broadcast, 3) banded 4 in. deep with 30 in. spacing between bands, and 4) banded 4 in. deep with 15 in. spacing between bands. Soybean was planted in 7.5, 15, and 30 in. rows. Significant responses to K occurred only when K had been banded 4 in. deep, soybean was grown in 15 or 30 in. rows, and bands were spaced either 30 or 15 in. apart.

Consequently, highest yield occurred when soybean rows and K bands were matched. Soybean plants grown in positions between fertilizer bands had lower K uptake and yield.

Results of this study are consistent with the growth habits of soybean. It was shown above that when soybean roots encountered roots of plants in adjacent rows, they turned downward. This would imply that as soybean row spacing becomes narrower, the soybean root system is oriented more downward than outward. Such a distribution of roots at narrower row spacings would increase the effectiveness of K supplies placed directly below the row.

Implications for Automatic Guidance

In this section, an attempt is made to outline some primary considerations for using automatic guidance technology to change nutrient management practices. This area will require more research to validate or nullify some of the considerations given.

Can Automatic Guidance Eliminate Starter Fertilizer Applications?
Many farmers prefer not to use starter fertilizer because it slows planting. Fertilizer tanks or bins must be refilled with a schedule that may or may not match the schedule for refilling seed bins. Also, preparation and maintenance of equipment is greater with starter attachments. High precision automatic guidance technology offers a new alternative. Bands of fertilizer could be applied ahead of planting. In a subsequent operation, seed could be placed a specified distance from the fertilizer bands. There are some important agronomic considerations with this practice.

While fall is a popular time to apply P and K, it may not be the best time to apply bands that are expected to replace starter fertilizer applications. Commonly, starter fertilizers are composed of N-P or N-P-K combinations. The research presented previously indicates that banded P remains in a concentrated zone for a period of months and years; however it appears that much of the effectiveness of P in bands results from the accompanying N in the ammonium form. Fertilizer materials commonly used for starters have N in this form along with the P. While most commonly-used P fertilizers contain ammonium, fall-applied ammonium N may not be present in sufficient quantities to significantly impact rhizosphere pH and make the P in the band more plant available. Consequently, fall-banded P may need to be accompanied by ammonium-containing N fertilizers in the spring if they are to be most effective in providing P to the plant early in the season. Spring, rather than fall, applications provide another alternative that could improve the amount of ammonium present during early corn growth. However, this application time carries logistical risks, since in the Midwest, spring conditions are generally wetter than fall conditions, resulting in fewer days when field work can be accomplished. Use of nitrification inhibitors with spring applications might also provide benefits when warmer and wetter conditions are encountered.

Can Automatic Guidance Eliminate Broadcast Fertilizer Applications?
Long-term research from the Great Plains indicates that over time, repeated band applications of fertilizer slowly build average soil test levels (Zentner et al., 1993). Traditionally, the placement of bands has been subject to lack of precision, but with the advent of currently available technology, a systematic spacing of fertilizer bands over time could fertilize desired soil volumes.

In reduced tillage systems, substantial amounts of K can be moved from positions deeper in the soil profile to the soil surface through plant uptake and leaching of K from residue. The greater diffusion rates of K also imply that over time, bands of K will become more diffuse than those of P. Consequently, it may be that K banded lower in the profile would, over time, effectively fertilize a much larger volume, both at the surface and subsurface, than its original placement. Therefore, at a given application rate, it seems plausible that in reduced tillage systems, soil test K levels could be built over time more completely through the soil profile by banding than by broadcasting. Band spacings of K would need to be matched with row spacings of both corn and soybean. This is not an issue if both corn and soybean are grown in 30 in. rows, but this does not take advantage of the benefits of closer row spacing observed for soybeans. A possible approach would be to band K on 30 in. centers before growing corn. Before growing soybean, K could be banded on 30 in. centers again, but the bands would be shifted 15 in. to one direction, placing the fresh bands between the previously applied ones. Soybean could then be grown in 15 in. rows with each row over either a fresh or residual K band. The third year, before growing corn, K could be banded in the same place as the first year, directly under corn rows and then the cycle continued.

In reduced tillage systems, deep bands of P have not had consistent advantages over broadcast applications. Consequently, advantages of an additional, more highly concentrated supply of P deeper in the profile does not appear necessary. This may due in large part to the higher mycorrhizal inoculation rates in undisturbed soil. Mycorrhizal associations would effectively create an increased P supply to host corn and soybean plants lower in the profile, perhaps eliminating the need for a fertilizer application beyond what is necessary, based on soil test interpretations.

References

Allan, D.L., G.W. Rehm, and J.L. Oldham. 1997. Root system interactions with potassium management in corn. p. 111-116. *In* D.M. Oosterhuis and G.A. Berkowitz (ed.) Frontiers in potassium nutrition: New perspectives on the effects of potassium physiology of plants. Potash & Phosphate Institute/Potash & Phosphate Institute of Canada, Norcross, GA.

Anderson, E.L. 1987. Corn root growth and distribution as influenced by tillage and nitrogen fertilization. Agron. J. 79:544-549.

Anghinoni, I. and S.A. Barber. 1980a. Phosphorus application rate and distribution in the soil and phosphorus uptake by corn. Soil Sci. Soc. Am. J. 44:1041-1044.

Anghinoni, I. and S.A. Barber. 1980b. Predicting the most efficient phosphorus placement for corn. Soil Sci. Soc. Am. J. 44:1016-1020.

Barber, S.A. 1984. Soil nutrient bioavailability: A mechanistic approach. Wily Interscience, New York, NY.

Barber, S.A. 1978. Growth and nutrient uptake of soybean roots under field conditions. Agron. J. 70:457-461.

Barber, S.A. 1971. Effect of tillage practice on corn (*Zea mays* L.) root distribution and morphology. Agron. J. 63:724-726.

Bauder, J.W., G.W. Randall, and R.T. Schuler. 1985. Effects of tillage with controlled wheel traffic on soil properties and root growth of corn. J. Soil Water Conserv. 40:382-385.

Blevins, R.L., G.W. Thomas, M.S. Smith, W.W. Frye, and P.L. Cornelius. 1983. Changes in soil properties after 10 years of continuous non-tilled and conventionally tilled corn. Soil Tillage Res. 3:135-146.

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

Borges, R. and A.P. Mallarino. 2003. Broadcast and deep-band placement pf phosphorus and potassium for soybean managed with ridge tillage. Soil Sci. Soc. Am. J. 67:1920-1927.

Borges, R. and A.P. Mallarino. 2001. Deep banding phosphorus and potassium fertilizers for corn managed with ridge tillage. Soil Sci. Soc. Am. J. 65:376-384.

Borkert, C.M and S.A. Barber. 1985a. Soybean shoot and root growth and phosphorus concentration as affected by phosphorus placement. Soil Sci. Soc. Am. J. 49:152-155.

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

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

Chaudhary, M.R. and S.S. Prihar. 1974. Root development and growth response of corn following mulching, cultivation, or interrow compaction. Agron J. 66:350-355.

Coale, F.J. and J.H. Grove. 1990. Root distribution and shoot development in no-till full-season and double-crop soybean. Agron. J. 82:606-612.

Dana, P.H. 1994. Global positioning system overview [Online]. Available at http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html (verified 13 Oct. 2005).

Dick, W.A., E.L. McCoy, W.M. Edwards, and R. Lal. 1991. Continuous application of no-tillage to Ohio soils. Agron. J. 83:65-73.

Duiker, S.W. and D.B. Beegle. 2005. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. Soil Tillage Res. (in press).

Edwards, J.H. and S.A. Barber. 1976. Phosphorus uptake rate of soybean roots as influenced by plant age, root trimming, and solution P concentration. Agron. J. 68:973-975.

Eghball, B., D.H. Sander, and J. Skopp. 1990. Diffusion, adsorption, and predicted longevity of banded phosphorus fertilizer in three soils. Soil Sci. Soc. Am. J. 54:1161-1165.

Foth, H.D. 1962. Root and top growth of corn. Agron. J. 54:49-52.

Hallmark, W.B. and S.A. Barber. 1981. Root growth and morphology, nutrient uptake, and nutrient status of soybeans as affected by soil K and bulk density. Agron. J. 73:779-782.

Holanda, R.S.R., D.B. Mengel, M.B. Paula, J.G. Carvaho, and J.C. Bertoni. 1998. Influence of crop rotations and tillage systems on phosphorus and potassium stratification and root distribution in the soil profile. Comm. Soil Sci. Plant Anal. 29:2383-2394.

Karlen, D.L., E.C. Berry, T.S. Colvin, and R.S. Kanwar. 1991. Twelve-year tillage and crop rotation effects on yields and soil chemical properties in northeast Iowa. Comm. Soil Sci. Plant Anal. 22:1985-2003.

Kaspar, T.C., S.D. Logsdon, and M.A. Prieksat. 1995. Traffic pattern and tillage system effects on corn root and shoot growth. Agron. J. 87:1046-1051.

Kaspar, T.C., H.J. Brown, and E.M. Kassmeyer. 1991. Corn root distribution as affected by tillage, wheel traffic, and fertilizer placement. Soil Sci. Soc. Am. J. 55:1390-1394.

Kaspar, T.C., C.D. Stanley, and H.M. Taylor. 1978. Soybean root growth during the reproductive stages of development. Agron. J. 70:1105-1107.

Kitchen, N.R., J.L. Havlin, and D.G. Westfall. 1990. Soil sampling under no-till banded phosphorus. Soil Sci. Soc. Am. J. 54:1661-1666.

Mackay, A.D., E.J. Kladivko, S.A. Barber, and D.R. Griffith. 1987. Phosphorus and potassium uptake by corn in conservation tillage systems. Soil Sci. Soc. Am. J. 51:970-974.

Marschner, H. 2002. Mineral nutrition of higher plants. 2nd ed. Academic Press, New York, NY.

Mayaki, W.C., I.D. Teare, and L.R. Stone. 1976. Top and root growth of irrigated and non-irrigated soybeans. Crop Sci. 16:92-94.

McGonigle, T.P. and M.H. Miller. 1996. Mycorrhizae, phosphorus absorption, and yield of maize in response to tillage. Soil Sci. Soc. Am. J. 60:1856-1861.

Mengel, D.B. and S.A. Barber. 1974a. Development and distribution of the corn root system under field conditions. Agron. J. 66:341-344.

Mengel, D.B. and S.A. Barber. 1974b. Rate of nutrient uptake per unit of corn root under field conditions. Agron. J. 66:399-402.

Mitchell, R.L. and W.J. Russell. 1971. Root development and rooting patterns of soybean (*Glycine max* (L.) Merrill) evaluated under field conditions. Agron. J. 63:313-316.

Miller, H.H. and A.J. Ohlrogge. 1958. Principles of nutrient uptake from fertilizer bands. I. Effect of placement of nitrogen fertilizer on the uptake of band-placed phosphorus at different soil phosphorus levels. Agron. J. 50:95-97.

Raper, C.D. Jr. and S.A. Barber. 1970. Rooting systems of soybeans. 1. Differences in root morphology among varieties. Agron. J. 62:581-584.

Rehm, G.W. 1995. Impact of banded potassium for corn and soybean production in a ridge-till planting system. Comm. Soil Sci. Plant Anal. 26:2725-22738.

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

Rehm, G.W. and J.A. Lamb. 2004. Impact of banded potassium on crop yield and soil potassium in ridge-till planting. Soil Sci. Soc. Am. J. 68:629-636.

Riley, D. and S.A. Barber. 1971. Effect of ammonium and nitrate fertilization on phosphorus uptake as related to root-induced pH changes at the root-soil interface. Soil Sci. Soc. Am. Proc. 35:301-306.

Robbins, S.G. and R.D. Voss. 1991. Phosphorus and potassium stratification in conservation tillage systems. J. Soil Water Conserv. 46:298-300.

Soon, Y.K. and M.H. Miller. 1977. Changes in the rhizosphere due to NH_4^+ and NO_3^- fertilization and phosphorus uptake by corn seedlings (*Zea mays* L.). Soil Sci. Soc. Am. J. 41:77-80.

Silberbush, M and S.A. Barber. 1983. Prediction of phosphorus and potassium uptake by soybeans with a mechanistic mathematical model. Soil Sci. Soc. Am. J. 47:263-265.

Stecker, J.A., J.R. Brown, and N.R. Kitchen. 2001. Residual phosphorus distribution and sorption in starter fertilizer bands applied in no-till culture. Soil Sci. Soc. Am. J. 65:1173-1183.

Vivekananden, M. and P.E. Fixen. 1991. Cropping system effects on mycorrhizal colonization, early growth, and phosphorus uptake of corn. Soil Sci. Soc. Am. J. 55:136-140.

Yin, X. and T.J. Vyn. 2003. Potassium placement effects on yield and seed composition of no-till soybean seeded in alternate row widths. Agron. J. 95:126-132.

Zentner, R.P., C.A. Campbell, and F. Selles. 1993. Build-up in soil available P and yield response of spring wheat to seed-placed P in a 24-year study in the Brown Soil zone. Can. J. Soil Sci. 73:173-181

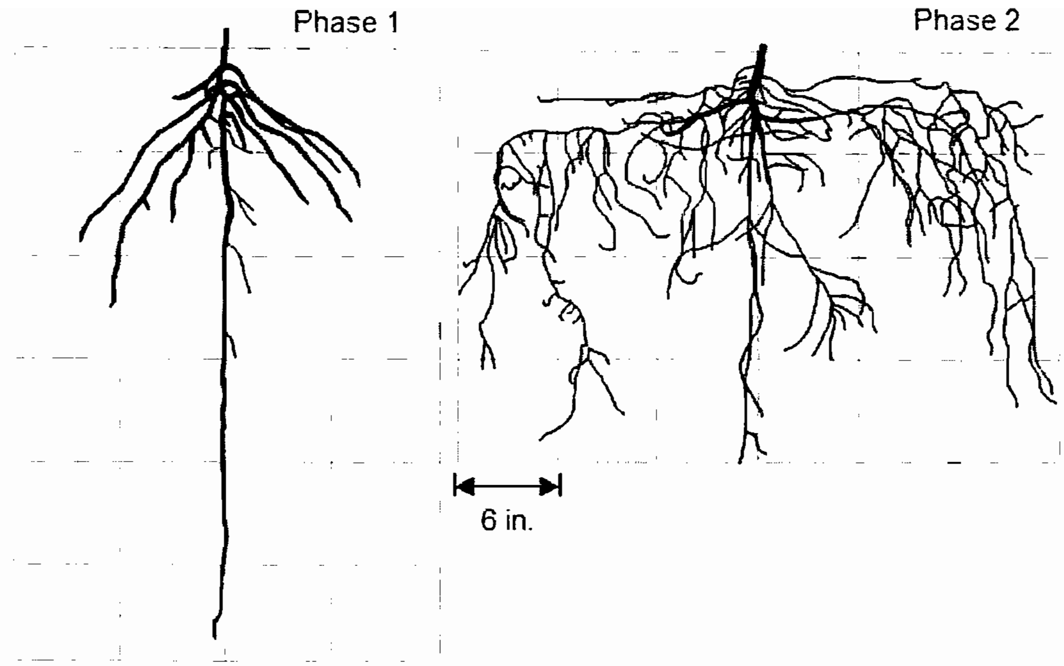

Figure 1. Phases 1 and 2 of the 3-phase root growth classification system developed by Mitchell and Russell, 1971.

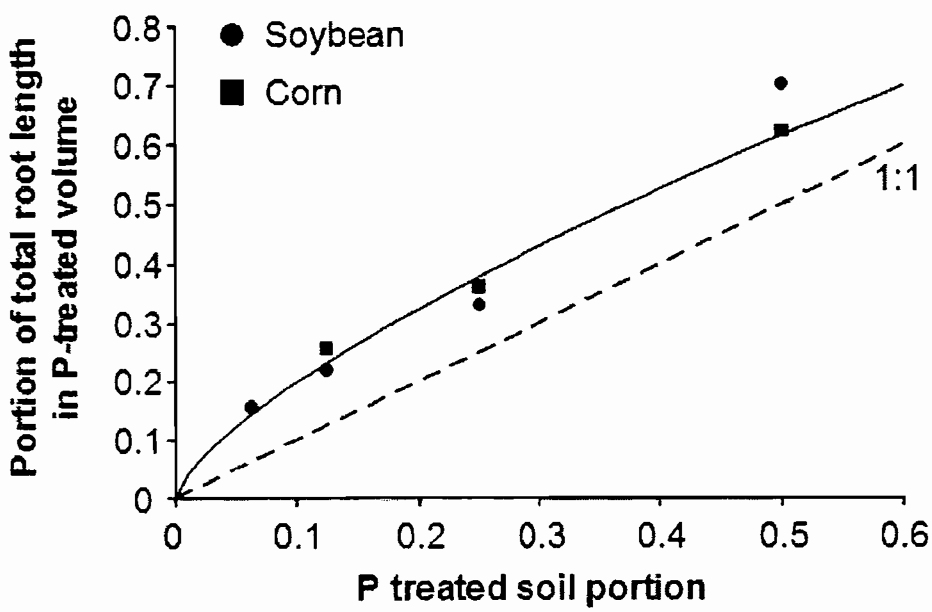

Figure 2. Proliferation of corn and soybean roots in zones of higher P concentration (Anghinoni and Barber, 1980a; Borkert and Barber, 1985a).

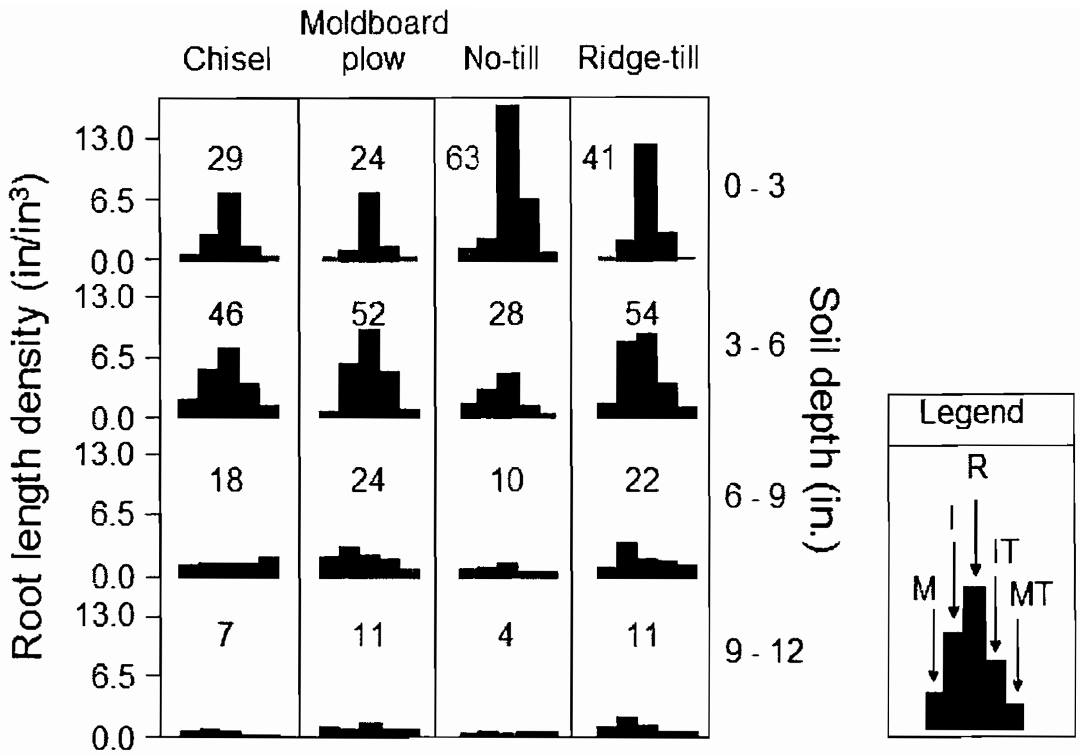

Figure 3. Root length density for various tillage systems and positions perpendicular to the rows. Numbers in the graph are total root length (in.). MT = mid-row (15 in. from row), trafficked; IT = intermediate distance (7.5 in.) from row, trafficked; R = in-row; I = intermediate distance (7.5 in.) from the row, untrafficked; M = mid-row (15 in. from the row), untrafficked (Bauder et al., 1985).

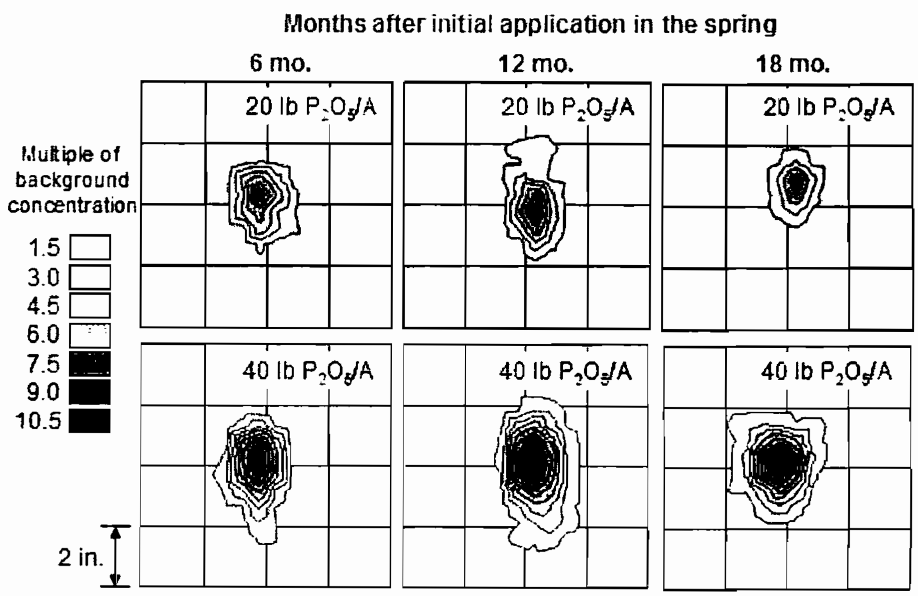

Figure 4. Time series of residual P distributions for 2 P rates after an initial application in the spring on a Mexico silty clay loam soil (Stecker et al., 2001).

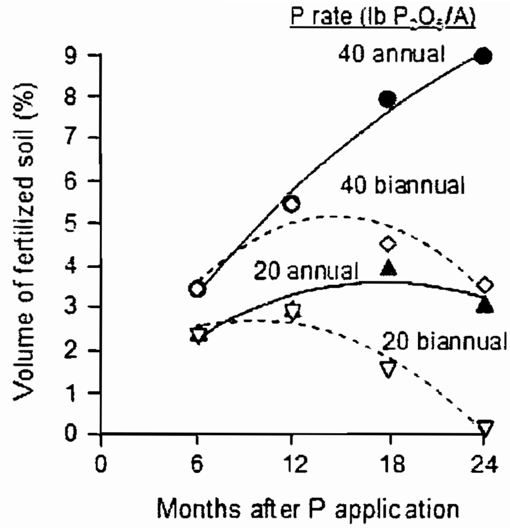

Figure 5. Predicted volume of P-enriched soil after multiple applications of various P rates on a Mexico silty clay loam soil (Stecker et al., 2001).

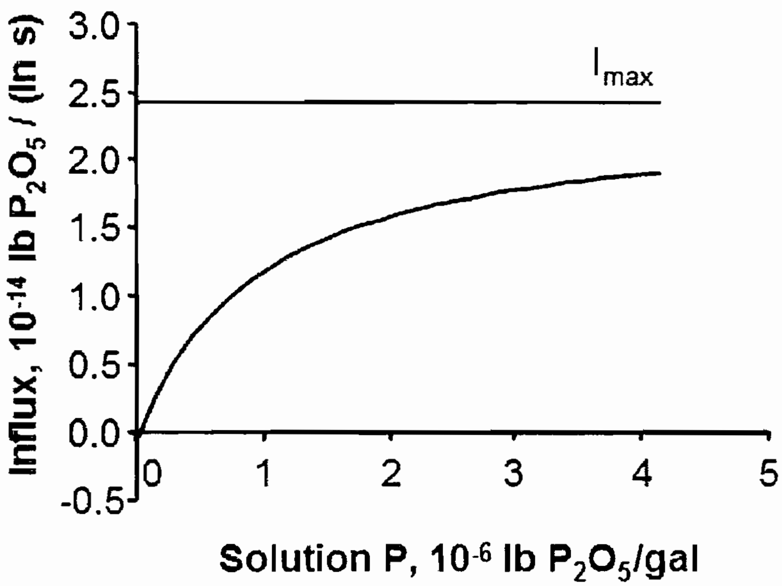

Figure 6. Nutrient influx by 22-23 day old soybean roots showing a pattern of active uptake characteristic of P and K (Edwards and Barber, 1976).

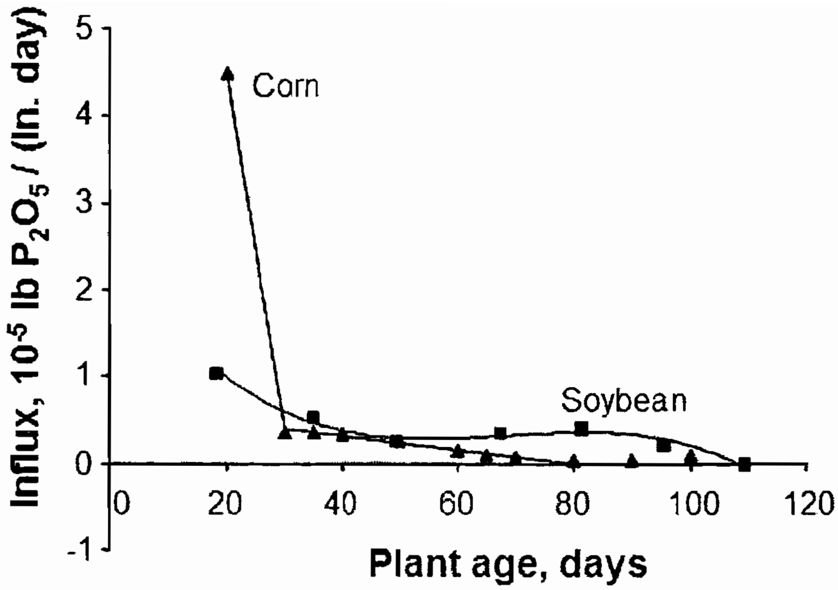

Figure 7. Changes in P influx with plant age for corn and soybean (Barber, 1978; Mengel and Barber, 1974b).

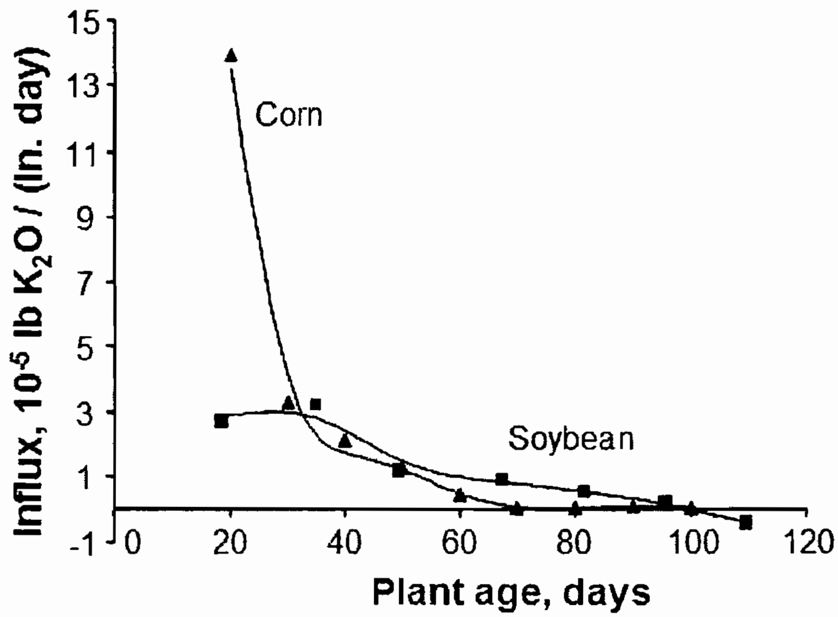

Figure 8. Changes in K influx with plant age for corn and soybean (Barber, 1978; Mengel and Barber, 1974b).

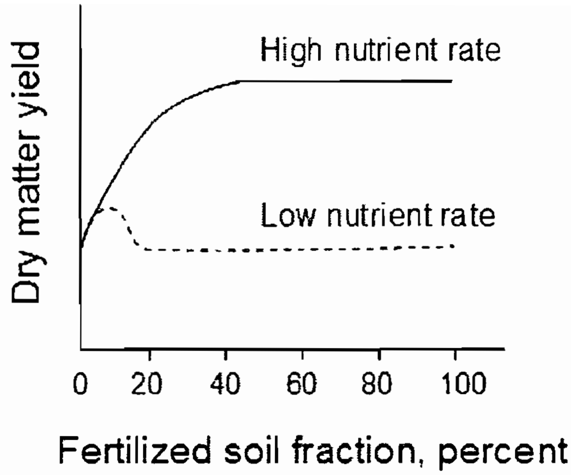

Figure 9. Conceptual model of the influence of fertilized soil volume and associated concentration affect crop dry matter yield (Anghinoni and Barber, 1980b; Borkert and Barber, 1985b).

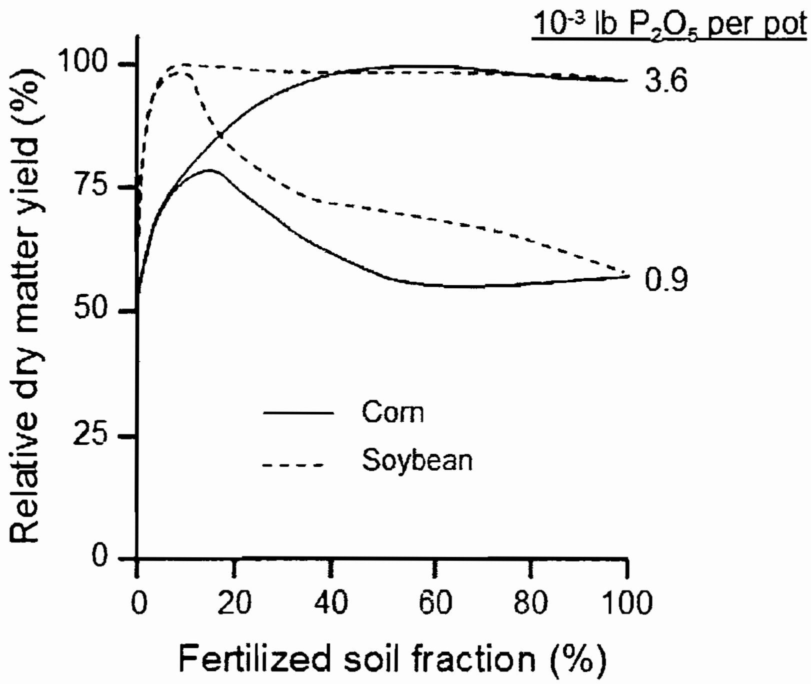

Figure 10. Differences in impact of fertilized soil volume on corn and soybean dry matter yield (Anghinoni and Barber, 1980b; Borkert and Barber, 1985b).

OPPORTUNITIES AND LIMITATIONS OF AUTOMATIC STEERING TECHNOLOGIES

N.C. Wollenhaupt
AGCO Global Technologies, Minnetonka, MN

Introduction

In the short span of 10 years we have gone from using the Global Positioning System (GPS) to locate ourselves in a farm field, to automatically steering a machine working in the field. This application requires about 15 components with each component evolving at a rapid pace. A number of companies have formed to provide automatic steering packages as aftermarket retrofits. At a slightly slower pace, the main equipment manufactures are engineering machines that will be factor ready or factory equipped with automatic steering.

With the rapid advance in these technologies has come a variety of products with names including the terms "guide", "trak", "steer", "pilot" and other related terms. The product names may be a source of confusion because they do not always distinguish between guidance applications and automatic steering applications.

For many custom applicators and farmers, the path through all the vendors and options they offer is simplified by determining how much precision and accuracy is required, tempered by the cost to attain the desired accuracy.

Technology Components Required for Automatic Steering

Following is a breakdown of some of the components required for automatic steering applications. The Global Positioning System (GPS) is assumed to be available. Some of the components are commonly bundled together as a single product. For example it is not uncommon for a GPS receiver to be enabled to also receive a WASS or Coast Guard Beacon DGPS signal, and have a self-contained antenna. This bundling makes for a simpler installation, but may also limit upgradeability.

- GPS Receiver
- GPS Antenna
- Source for a Differential Correction Signal
- Receiver for DGPS
- DGPS Antenna
- RTK Base Station (optional)
- RTK Base Station antenna
- DMU (optional)
- Steering Control (Integrated or Mechanical)
- Wheel Angle Sensor (wheeled machines)
- Display Console
- Application Software (electronic control unit processor, ECU)

PROCEEDINGS OF THE

THIRTY-FIFTH NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 21

November 16-17, 2005
Holiday Inn Airport
Des Moines, IA

Program Chair:

Brad Joern
Purdue University
West Lafayette, IN
(765) 494-9767

Published by:

Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
(605) 692-6280
Web page: www.ppi-ppic.org

Our cover: To world food security and agricultural production, the Haber-Bosch process has been the most economical means for fixation of nitrogen for fertilizer. Fritz Haber won the Nobel Prize for Chemistry in 1918 and Carl Bosch shared the prize in 1931.