FACTORS AFFECTING THE RELATIVE BENEFIT OF DEEP-BANDING VERSUS BROADCAST APPLICATION OF PHOSPHORUS AND POTASSIUM FOR CORN AND SOYBEAN

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Abstract

Scientifically based recommendations concerning the choice of deep banding versus traditional broadcast application of phosphorus (P) and potassium (K) for corn and soybean production in conservation tillage systems have been hampered by insufficient research and inconsistent results. Even when the decision is made (e.g. by strip-tillage corn farmers) to go with deep-banding of P and K, numerous questions remain about fertilizer rates, optimum deep-banding depth and frequency, whether to have a constant or changing band position over time, accompanying starter fertilizer and nitrogen (N) fertilizer delivery programs, and optimum soil sampling methods. Although Dr. Tony Vyn's oral presentation for this conference will address what recent research has found for the example of deep-banding of K, this paper will review some of the general factors that influence the possible advantage of deep banding versus broadcast application. Potential advantages for deep banding of P and K, as well as optimum management of deep banding itself for a particular field situation, are very dependent on (a) soil-test P and K, (b) extent of P and K stratification, (c) inherent soil properties that affect available-P and exchangeable-K availability, (d) soil temperature and moisture regime during periods of high plant demand for P and K, (e) crop species and cultivar, (f) the associated starter fertilizer (if any) and, (g) fixed or random fertilizer band positions over time. Deep banding of P and K is particularly well suited to strip-till production systems but, even for that tillage system, field-specific circumstances will influence the potential advantage to be gained from deep banding.

Introduction

Across the Corn Belt, growers have traditionally met crop demand for P and K through broadcast fertilization. Broadcast application is a relatively low-cost and popular method that is ideal for high-speed operations and high application rates. If P and K are spread evenly on the soil surface and incorporated by a conventional tillage implement (e.g., plow, disk, or cultivator), broadcast application often uniformly enhances available P and exchangeable K in much of the tilled soil zone that plant roots are likely to explore. However, this application method has a number of drawbacks that are particularly evident for conservation tillage systems (e.g., no-till, strip-till, and ridge-till). These limitations potentially include reduced nutrient use efficiency, greater P and K fixation, enhanced vertical soil nutrient stratification, and greater risk of P contamination of surface runoff water.

Crop producers using conservation tillage systems have therefore sought alternative methods of P and K placement in order to improve nutrient use efficiency, prevent or lessen detrimental environmental impacts, and increase productivity and profitability (Randall and Hoeft, 1988). One alternative is the deep-banding of P and K, which, for the purposes of this publication, refers to the placement of these nutrients in a concentrated band (usually in a pre-plant application) at least 4 inches below the soil surface. The deep-banding depth with most strip-tillage units is normally 6 to 7 inches, but may be as deep as 12 inches. Deep-banding is normally conducted before planting of the ensuing crop.

The use of this method in conservation tillage systems has a number of potential advantages including (a) reduced fixation and stratification of available P and exchangeable K in soil, (b) increased P and K soil-test levels in a consistent zone of nutrient enrichment, (c) potentially higher plant P and K uptake from deeper soil horizons during dry years, and (d) more timely planting when used in conjunction with strip-tillage systems. Until recently, deep-banding of P and K has not become a widely-adopted alternative to broadcast application. Slow grower adoption during the past two decades is likely partially the result of research in Illinois, Indiana, Iowa, Missouri, Nebraska, and Wisconsin that has shown an inconsistent yield benefit from deep-banding of P and K in corn and soybean (e.g., Jamison and Thornton, 1960; Cihacek et al., 1974; Touchton, 1984; Mengel et al., 1988; Randall and Hoeft, 1988; Mallarino et al., 1999; Mallarino and Borges, 2006; Canepa, 2007; Wolkowski, 2007). Slow grower adoption may also result from greater initial equipment costs, higher operating expenses, and the additional complexity (application and soil-test determination) in deep-banding versus broadcast fertilization programs. Although deep-banding of P and K can increase crop productivity and grower profitability, it is not likely to do so consistently. We therefore discuss factors that affect the level of benefit likely to be realized by growers considering the adoption of a deep-banded P and K fertility program.

P and K Soil-Test Levels

Soil-test levels for P and K have a major effect on crop response to deep-banding. A recent synopsis of the 3.4 million soil samples submitted to commercial laboratories across North America in 2005 indicated that approximately 41% of the samples needed P addition and 39% required K application to avoid profit loss. For example, of the samples collected in Indiana in 2005, 24% and 19% were below the critical levels for P and K, respectively (Fixen et al., 2006). When levels of available P and K are low to medium starter-banded P application typically produces a greater yield than broadcast fertilization. However, on soils testing medium to high for available P and K, yield benefits conferred by banding (e.g. starter fertilizer, although it is less certain with deep bands) generally disappear (Randall and Hoeft, 1988; Randall et al., 2001). The percentages of soil samples with below critical-level P and K concentrations suggest that deep-banding of P and K may be beneficial in numerous crop fields across the Corn Belt.

Although crop responses to deep-banding of P and K are not typically evident when soil-test levels of P and K are above the critical level, research in Iowa found that corn yields increased with deep-banding of K 6 to 8 inches below the soil surface even in soils testing between optimum and very high for exchangeable K. However, corn yields did not increase in response to deep-banded P in soils that were high in available P (Bordoli and Mallarino, 1998; Mallarino, 2000). Growers should therefore realize that responses to deep-banding of P and K can vary by nutrient at different soil-test levels, since each nutrient is affected differently by soil properties and weather phenomena.

Soil Properties and P and K Availability

Benefits from deep-banding of P and K depend upon inherent soil properties such as pH, texture, and cation exchange capacity (CEC), with each nutrient being affected differently by these properties. Phosphorus is a relatively immobile nutrient that becomes less soluble over time. It is adsorbed by elements in the soil such as calcium (Ca), magnesium (Mg), aluminum (Al), and iron (Fe), with the type of adsorption varying with soil pH. Soil reactions gradually occur in which adsorbed P forms more insoluble compounds. This leads to greater P fixation and reduced availability (Busman et al., 2002). This trend results in a decrease in soil-test P, and necessitates P application when soil-test P concentrations are below recommended levels.

Benefits from deep-banding of P are therefore likely to be greatest in soils with a high P-fixation capacity. Such soils are often characterized by an excessively low (<5.5) or high (>7.3) pH and a high clay content (particularly Fe and Al oxides). In such soils, deep-banding in the effective rooting zone can result in greater efficiency of P use since (a) less applied P comes into contact with P-fixing soil particles and (b) applied P is likely to be closer to plant roots. To ensure proper rates of deep-banded P application, growers should know the relative clay content, pH, and available P in their fields. Proper soil testing and analysis is therefore recommended.

Potassium, like P, is a relatively immobile nutrient whose availability is affected by a number of soil properties. Despite its relative immobility, K can diffuse a greater distance in soils than P. Plant roots can therefore take advantage of more distant K sources compared with P. Although most soils contain vast quantities of K, 90 to 98% is in a relatively unavailable form. The 1 to 2% of total soil K that is available to plants is either in the soil solution or adsorbed on the surface of soil particles. In the presence of 2:1 clays such as vermiculite and smectite, K may not only become adsorbed, but also fixed, with this fixation being more prevalent at higher soil pH levels. Plants cannot use much of this fixed K during a single growing season, so it is not measured during routine soil testing procedures (Rehm and Schmitt, 2002). The availability of K is also affected by the cation exchange capacity (CEC) of a soil. Soils higher in clay and organic matter generally have a higher CEC and thus a greater K-supplying power.

Similar to P, growers should be aware of the relative clay content, type of clay, pH, and available K in their fields. Producers should also occasionally test for available K levels below the standard 7 to 8 inch sampling depth. Soils formed under native grasses in the central Corn Belt have relatively low subsoil K availability. Deep-banding of K in such soils may be beneficial.

For both P and K, proper soil sampling procedures should be followed (see Mengel and Hawkins, 1994) with the realization that they may need to be slightly modified for a deep-banding fertilization program or strip-tillage system. Indiana, Michigan, and Ohio growers should also consult the Tri-State Fertilizer Recommendations (see Vitosh et al., 1995) for further information on soil sampling, handling, and testing plus recommended P and K application rates.

P and K Stratification, Soil Moisture Content, and Soil Temperature

Continued broadcast application of P and K can result in the accumulation of these nutrients near the soil surface. This accumulation is known as stratification, and can result from (a) the minimal mixing of surface fertilizer applications and (b) the cycling of nutrients (particularly K) from deep to shallow soil depths through above-ground plant nutrient accumulation and subsequent decomposition of crop residues (Bruulsema and Murrell, 2006). Stratification of P and K is problematic in conservation (i.e., reduced) tillage systems in general and in no-till systems in particular (Vyn et al., 2002b). Reduced tillage systems are characterized by higher nutrient and moisture levels and lower temperatures near the soil surface. These conditions can result in a concentration of root growth in this zone. Crops in such systems therefore acquire a higher percentage of their P, K, and water from this region than in conventional tillage systems (Mackay et al., 1987).

Concentrated root growth and P and K stratification near the soil surface in conservation tillage systems are not necessarily problematic when (a) soil-test levels are medium to high in upper soil layers, (b) water availability in nutrient-rich surface soils is adequate during periods of rapid nutrient uptake, and (c) soil temperatures near the soil surface are comparable to conventional tillage systems during periods of rapid root growth and nutrient uptake. However, limited root growth and pronounced nutrient stratification in reduced tillage environments are detrimental to crop productivity when (a) surface and subsoil P and K levels are low to very low, (b) surface soil layers become dry due to drought, and (c) early root growth and nutrient uptake in the upper soil layers are restricted due to low soil temperatures or compaction. It is in these latter conditions that deep-banding of P and K in conservation tillage systems is particularly justified. Deep-banding potentially can (i) enrich nutrient concentrations at greater soil depths marked by P and K deficiencies as a result of pronounced stratification, (ii) provide adequate P and K to deeper-growing roots during dry conditions near the soil surface, and (iii) provide P and K in a concentrated band in zones of limited root growth resulting from compaction. However, it is also fair to acknowledge that in rain-fed corn production systems in the Eastern Corn Belt, soil from 6 to 12 inches deep may be drier than soil in the upper 6 inches during periods of high P or K uptake by corn plants (Canepa, 2007). In this situation, broadcast fertilizer application may result in higher uptake than deep-banded application.

Crop Species and Cultivar

Yield responses to deep-banding of P and K vary by both crop species and cultivar. Corn responses to deep-banding of P and K are highly dependent upon soil fertility level and weather conditions during periods of rapid nutrient uptake. At low soil-test levels and in dry conditions near the soil surface, deep-banding of P and K has shown a yield advantage over broadcast application. However, at medium and high soil-test levels and with average to above-average precipitation, this yield advantage typically disappears (Jamison and Thornton, 1960; Cihacek et al., 1974; Randall and Hoeft, 1988; Mallarino et al., 1999; Mallarino and Borges, 2006).

Unlike corn, soybean usually responds more to broadcast than deep-banding application of P and K when soil-test levels are low (Touchton, 1984; Randall and Hoeft, 1988). However, deep-banding of K has periodically resulted in greater yields than broadcast fertilization on both low (Hairston et al., 1990) and high (Borges and Mallarino, 2000) K soils. Despite potential yield benefits from the deep-banding of P and K in soybean, producers currently using narrow-row, no-till, soybean production systems involving surface broadcasting of P and K should not switch to wide-row, no-till, soybean production systems involving the deep-banding of P and K (Yin and Vyn, 2002) because of the yield reduction common to wide row widths (particularly in short-season maturity soybeans and for varieties with limited stem branching).

The level of soybean yield response to deep-banding of K may depend upon the relative proximity of soybean rows to previous corn rows. If no-till soybeans are planted over previous corn rows, soybean yield response to banded K application may be minimized while yield response to residual soil K may be maximized (Yin and Vyn, 2003b). Soybean yield response to deep-banding of K (and potentially P) may also depend upon the location of fertilizer placement. When soybean rows are grown in close proximity to K fertilizer bands, deep-banding of K can be more effective than surface broadcasting (Yin and Vyn, 2003a).

Growth and yield responses to P and K application have been shown to vary by cultivar (Rehm, 1995; Gordon and Pierzynski, 2006). Such factors as root morphology and physiology, nutrient use efficiency, cold tolerance, and drought tolerance all affect how a particular cultivar responds to deep-banding of P and K. For example, a corn hybrid with good early-season cold tolerance can sustain sufficient root growth in a no-till environment despite cool early-season soil temperatures. This enhanced root development can permit rooting to deeper soil layers (below the zone of stratification) where band placement of P and K has occurred. In an environment with marked P and K stratification, such a hybrid would likely exhibit a greater response to deep-banding than a hybrid with poor cold tolerance and restricted root growth. This would be particularly evident when dry conditions exist later in the growing season. Growers who are considering the deep-banding of P and K should therefore consider both the historical responsiveness of a crop to deep placement and the growth, development, and stress tolerance of the specific cultivar to be planted.

Strip-Tillage and Fertilizer Application Method

No-till systems typically have high moisture levels and low temperatures near the soil surface in early spring that can delay planting and reduce seedling vigor. Strip-tillage reduces surface residue levels in created strips, allowing for quicker drying and warming of the planting zone and thus earlier planting and improved seedling growth (McVay and Olson, 2004). Strip-tillage also provides an effective method for the deep-banding of P and K. Both P and K can be deep-banded into the strips in either the fall or spring. Performing some P and K application in the fall can reduce the number of spring field operations and improve the timeliness of planting. Equipment designed to carry and deliver dry and liquid fertilizers while simultaneously performing strip-tillage is available from several manufacturers. Although such equipment may provide an economical and an agronomically-efficient means of meeting a crop’s P and K requirements, it has yet to show a distinct yield advantage over planter-applied P and K in a strip-tillage environment.

Starter Fertilizer

Starter fertilizer application typically involves the placement of nutrients in a concentrated zone in close proximity to the location of seed placement. Application often occurs in a band in the furrow, over the row, below the seed, to the side of the seed, or below and to the side of the seed (Hergert and Wortmann, 2006). Traditionally, starter fertilizer for corn is placed 2 inches to the side and 2 inches below the zone of seed placement (2 x 2 placement). Starter application is primarily recommended in no-till and strip-tillage systems, especially when early planting occurs (Brouder, 1996). Cool, spring soil temperatures in no-till and strip-tillage systems slow root growth, decrease nutrient uptake, and restrict the release of nutrients from organic matter. Placing fertilizer near the seed improves early plant growth and uniformity by improving nutrient availability to developing plants. As with deep-banding, starter application improves nutrient use efficiency through reduced P and K fixation.

Similar to the deep-banding of P and K, crop responses (early growth and yield) to starter P and K are generally expected at lower soil-test levels (Brouder, 1996). However, increased corn yields in response to starter P and K have also been observed on soils testing high for each nutrient (Gordon, 1999). Positive responses might also be observed on sandy soils with low organic matter or on some high pH soils (Hergert and Wortmann, 2006).

When starter P and K are applied, crop responses to the deep-banding of P and K are likely to be reduced. For example, a 2 x 2 placement of starter P fertilizer encourages root proliferation in this zone of nutrient enrichment and potentially limits root growth deeper in the soil profile in the zone of deep-banded soil nutrients. When root growth is concentrated near the soil surface, deep-banded P and K are likely to remain underutilized by the crop unless drought conditions near the soil surface encourage more prolific root growth at deeper depths. Research has shown that deep-banded P and K do not provide the same early-season growth response as a 2 x 2 starter placement; however, deeper-placed P and K are still utilized at a later date by a crop such as corn (Wolkowski, 2007). In low soil-exchangeable K situations, corn yields have responded more to starter K than to higher rates of deep-banded K fertilizer (Vyn and Janovicek, 2001; Vyn et al., 2002a,b).

Although more research is necessary on these effects, deep-banding of P and K is less likely to prove beneficial when starter application of these nutrients also occurs. Growers should therefore evaluate which application method most effectively suits their needs. The choice between starter or deep-banded P and K application (or the option of using both) will be contingent upon cropping system, soil conditions, equipment availability, and cost (Wolkowski, 2007).

Consistent Nutrient Enrichment and Automatic Guidance Systems

With deep-banding of P and K, fertilizer is applied in a relatively restricted zone. This reduces the amount of P and K fixed by soil and can result in improved nutrient use efficiency. Due to the limited mobility of P and K, consistent deep-banding of these nutrients in the same zone over multiple years builds soil-test levels in the region of application. This continued build-up of P and K fertility in the rooting zone may optimize yields when compared to random banding or intentional displacement of subsequent deep-banded nutrient applications. Yet for a minimal amount of fixation to occur, accurate, uniform, repeated placement of P and K in the zone of soil physically disturbed is clearly necessary.

Automatic guidance systems that provide sub-inch accuracy (e.g., RTK (real-time kinematic) GPS) can enhance both the accuracy and repeatability of deep-banding. When such devices are used, deep-banding of P and K can be easily integrated into strip-tillage operations. When strip-tillage is completed in the fall, locating the strips in the subsequent spring for fertilizer application and planting is challenging but also critical for realizing the benefits of crop response to strip-tillage. The use of automatic guidance systems for strip-tillage operations combined with deep-banding of P and K as well as subsequent planting can make this process much easier. Such systems enable planting at any distance from previously applied fertilizer bands (Bruulsema and Murrell, 2006; Vyn and West, 2006) and can additionally facilitate the implementation of controlled traffic programs.

Application of N in the ammonium form (e.g., anhydrous ammonia or urea ammonium nitrate (UAN)) can improve P fertilizer efficiency by lowering the soil pH in the zone of N and P application. Lower soil pH values result in greater $H_2PO_4^-$ (the form of P preferentially absorbed by plant roots) concentrations in the soil solution, enhanced root proliferation in the fertilizer zone, and, incidentally, improved P uptake by the plant. Accurately placing N in or near the zone of deep-banded P with automatic guidance devices has the potential to improve the efficiency of deep-banded P.

Conclusions

Deep-banding of P and K will not improve corn and soybean productivity or grower profitability in all situations. Growers therefore need to evaluate their individual circumstances. Deep-banding fertilization will likely be most beneficial when a number of the following conditions are met:

a) soil-test P and K levels are low to medium,
b) the soil has a high P- and/or K-fixation capacity,
c) subsoil P and K levels are low due to nutrient stratification,
d) surface soil layers are dry due to below-normal rainfall but the soil zone of deep-banding stays sufficiently moist for root growth and high nutrient uptake rates,
e) low surface soil temperatures restrict early root growth and nutrient uptake,
f) the row crop being grown has been planted more than 10 inches away from previous corn rows or fertilizer bands,
g) the cultivar planted exhibits good early-season cold tolerance and extensive root growth in dry conditions,
h) strip-tillage is integrated into the cropping system,
i) starter P and K fertilizers are not applied, and
j) automatic guidance is used for tillage, fertilization, and planting operations.

Not all of the above conditions need to be present for a deep-banding system to improve crop productivity and farm profitability, but a positive response is more likely when a greater number of these conditions are met. Public research on the short-term and long-term benefits of continued deep-banding in consistent or inconsistent soil zones (vertical and horizontal displacement from previous zones of deep-banding) for modern cropping programs is still in its infancy. Corn and soybean producers therefore need to evaluate not only the potential agronomic benefits of deep-banding fertilization for their operations, but also the economics of such a program.

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