The Role of Starter Fertilizers in No-till Corn and Wheat Production

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Introduction

Fertilizer use can not be considered alone in crop production programs. Crop yields for any given field and year result from the combination of yield-building and yield protection factors (Fig. 1). Yield building factors include genetics, plant nutrition and precision planting. Hybrid or variety selection is a management decision that determines potential yield capacity, disease and insect resistance, maturity date, resistance to lodging and, to some extent, grain quality. Precision planting involves planting at the proper rate, date, and depth to achieve a uniform population of vigorously growing plants that can maximize the utilization of available sunlight, moisture and nutrients. Adequate plant nutrition enables the plant to express its genetic potential for the specific site and year. While available moisture is also a yield building factor, in non-irrigated fields, growers must manage with natural rainfall.

Yield protection factors include weed, insect, disease, and lodging control, as well as harvest management. Proper management of the yield protection factors enables harvest of the yield that has been "built" through implementation of the yield building factors.

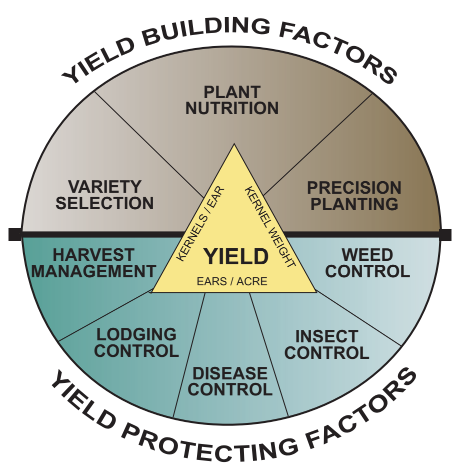

Figure 1. Yield building and yield protection factors in crop production.

Fertilizer use is the part of the plant nutrition program that provides nutrients to develop yield potential and to sustain productivity of the land for future crops. Fertilizer is of special interest for the 2008 crop year, not only because of its importance in producing economic yields and sustaining soil productivity capacity, but because of the dramatic price increases that have occurred in the past year. Starter fertilizers can be an important part of the total plant nutrition program through improving early season vigor in no-till systems, and increasing nutrient use efficiency in the overall crop production program.

The objective of this paper is to describe the reactions of nutrients in no-till environments and discuss the use of starter fertilizer in no-till production systems.

Nutrients in No-till Soil Environments

Nitrogen fertilizer availability in high-residue, no-till farming systems is influenced by volatilization (if surface applied), immobilization, and denitrification. No-till systems often exhibit decreased yields because of lesser N availability (Rao and Dao, 1996). This occurs because of slower N mineralization, greater N immobilization and denitrification (Rice and Smith, 1982), and NH_3 volatilization (Terman, 1979). Also, cooler soil temperatures under crop residues in no-till systems can cause lower nutrient availability, especially in the early part of the growing season.

Several studies (Bandel et al., 1980; Eckert, 1987; Fox et al., 1986; Kelly and Sweeney, 2007; Maddux et al., 198; Mengel et al., 1982) have examined placement methods for no-tillage corn production in the mid-Atlantic region, the Corn Belt and the Great Plains. In general, similar application rates of broadcast UAN produced lower yields than either injected or surface-banded UAN. Possible loss mechanisms with broadcast UAN include volatilization and immobilization (Kelley and Sweeney, 2007).

Phosphorus in soil solution moves to plant roots mainly by diffusion (Barber, 1984). Diffusion rates are directly proportional to differences in P concentrations in soil solution relative to the concentration at the root surface. Soil moisture also directly affects P diffusion in soil solution with higher levels of soil moisture increasing diffusion rates (Mahtab et al., 1971). No-till crop production systems maintain higher levels of soil moisture and thus can be expected to enhance P diffusion rates in soil. In addition, band application of P near the seed creates a zone of high P concentration relative the concentration at the root surface where uptake is occurring. Higher P diffusion rates result from the band placement as compared to broadcast applications of similar rates, especially at low plant available P levels and cool temperatures.

Fertilization research with continuous no-tillage systems prior to 1984 was reviewed by Thomas and Frye (1984) who concluded that surface broadcast applications of P and K provided adequate nutrition of grain crops, especially maize. Reasons for this conclusion were: (1) higher moisture levels are generally maintained under surface mulches in no-tillage which facilitates P diffusion to plant roots; (2) reduced interaction of soil with P increases P concentration in soil solution, root proliferation, and P uptake in the surface soil layer in no-tillage systems; and (3) K uptake is adequate from surface soil layers as P and N enhance root development, and high concentrations of K in this layer maintain high K concentrations in soil solution. Thomas and Frye (1984) did indicate that lower soil temperatures early in the growing season due to surface mulch usually decreased P and K uptake until soil temperatures increased. Most of the early work in no-tillage in the USA was done in the Virginia-Kentucky-Tennessee (USA) region which has a generally warmer climate and more well-drained soils than the Corn Belt.

The desire to increase no-tillage in the more northern areas of the USA has resulted in a number of studies to determine optimum methods of P and K application for reduced tillage grain crop production in colder soils. Eckert and Johnson (1985) showed that shallow subsurface banding (2 x 2) at planting increased P and K fertilizer use efficiency compared to broadcast fertilization. Bordoli and Mallarino (1998) and Mallarino et al. (1999) reported on 26 site-years of P and K fertilizer experiments for no-tillage corn in Iowa Mollisols. Phosphorus increased corn yields on soils testing low as defined by the Bray-1 method, but placement (banded beside the row, deep banded (6-10 in. below the soil surface), or surface broadcast) had no effect on yield. Early season P uptake and growth were increased by side band (2 x 2) placement at planting, but grain yields were not affected. Grain yields were increased slightly with K applications in soils that tested in the optimum range (ammonium acetate method), and responses were slightly greater for deep-band K placement than for side-band and broadcast placement. Deep banded K did increase K uptake by corn. The authors indicated that the observed average yield response of 4.0 bu/acre appeared to be most related to low rainfall in late spring and early summer. Also, the small yield increase would probably not cover the increased application costs of deep band placement of K fertilizer. The overall conclusion of this work is that side-band placement of P and K does increase early season nutrient uptake in cool soils, but that yield responses do not result unless soil test P and K levels are low. Similar results for corn were reported by Vetsch and Randall (2000) but in their work in Minnesota, they found more consistent yields corn yields with the use of starter fertilizers due to cooler soils, even on high P testing soils.

Nutrient availability in no-tillage wheat production in semi-arid environments is not only influenced by immobilization and volatilization of N by surface residues, but the lack of moisture in the surface soil layers may also reduce all nutrient availability. Asghar et al. (1996) observed significant stratification of P and K after 8 years of no-tillage wheat production in the semi-arid environment of Central Queensland Australia, and postulated that nutrients in the 0-2.5 in layer were unavailable during wheat grain fill due to dry surface soil conditions. Mixing the surface 0-4 in. layer resulted in uniform amounts of P and K in the 0-1 and 1-2 in. depths. Soil mixing had no effect on wheat plant contents of P, K, and Zn 30 days after planting. However, soil mixing increased P, K, and Zn levels in grain plus straw at harvest by 29%, 29% and 26%, respectively, indicating greater plant uptake. Grain yields were increased by 28% with the soil mixing treatment. However, such mixing destroys the benefits of long-term no-till. Finally, Kelley and Sweeny (2007) working in Kansas found that wheat grain yields and N and P use efficiency were increased by pre-plant subsurface band applications. Differences were primarily associated with reduced immobilization of surface applied N, and increased crop utilization during the growing season of subsurface placed nutrients.

Maximizing Nutrient Uptake and Minimizing Nutrient Losses During Early Season Plant Growth

Placing nutrients, especially N and P, below the surface residue in no-till systems, eliminates potential volatilization losses of N, minimizes potential immobilization of N in the residue layer, and reduces run-off losses of soluble N and P fertilizers. In addition to minimizing fertilizer nutrient losses, subsurface band application near the row provides a concentrated zone of nutrients for the young seedling.

Plant root growth responses to enriched zones of nutrients are shown in Fig. 2. In the classic experiment by Drew (1975), three zones of soil were prepared with either high (H) levels of N, P and K (the control), or low (L) and high levels of phosphate, nitrate, ammonium, and potassium. The barley plants in this experiment responded to the high levels of phosphate, nitrate, and ammonium by increasing the root density in these regions. Increased root growth was not observed for the enriched zone of soil with just K. Plant roots proliferate in soil zones with high levels of nutrients in order to absorb as much of the available nutrients in these soil zones as possible.

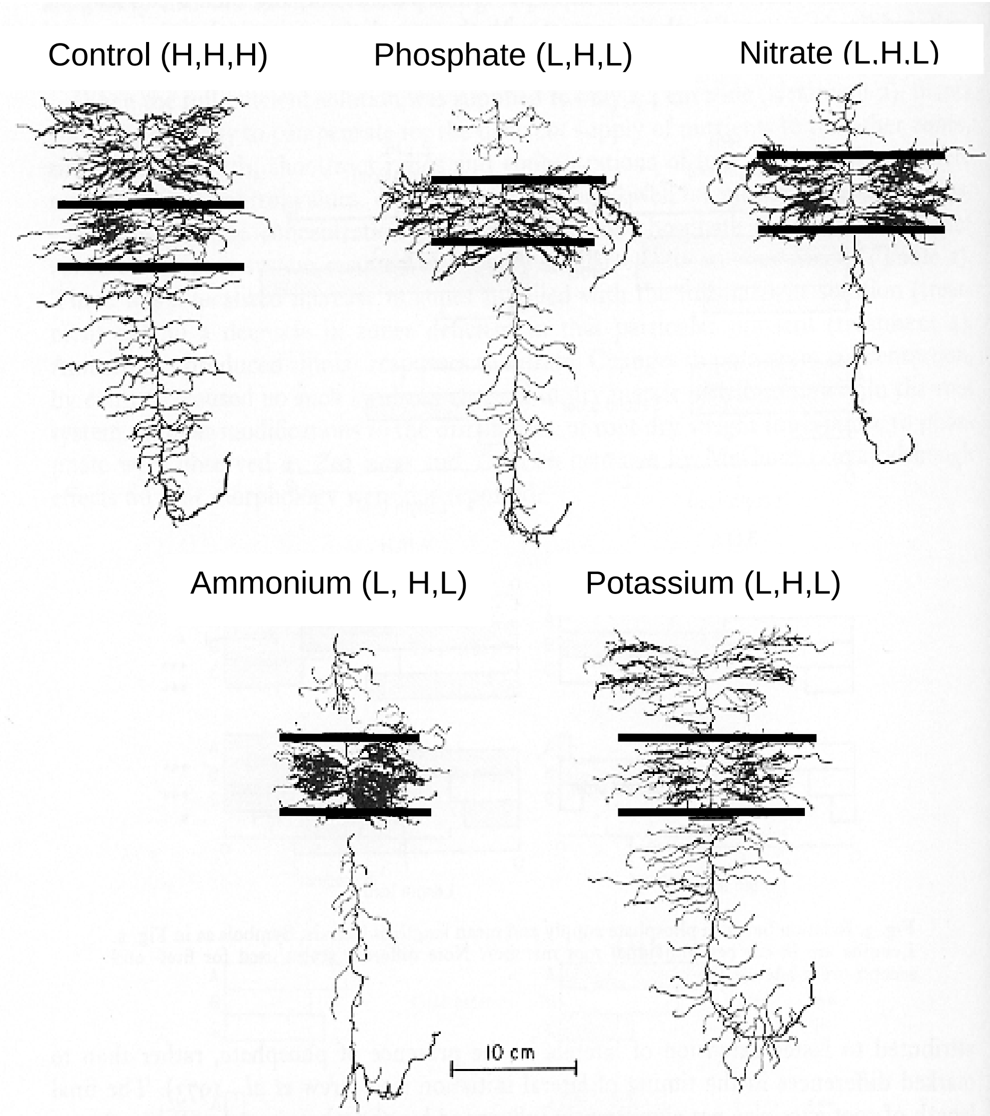

Figure 2. Barley plant root growth responses to zones of nutrient enrichment for N, P, and K. Zones are designed as L or H from the surface downward. (Drew, H. C., 1975).

Band placement of N and P near the seed not only reduces potential for N and P losses as described in the preceding section, this type of placement creates soil zones of enriched nutrient levels in which roots will proliferate, increasing the probability of nutrient uptake, as well as enhancing P diffusion rates to plant roots.

Corn Response to Early Season N Fertilization

Early season nutrient availability is influenced by fertilizer placement. Germination and emergence of the corn seedling usually occurs in six to ten days with reasonable temperatures and moisture. The corn seedling can be expected to develop two fully-expanded leaves and a primary root system that obtains needed nutrients from soil within seven days after emergence.

The supply of nutrients in the seed will be exhausted by this time (seven days after emergence). The corn plant roots generally do not reach the middle of the rows until the corn plant has eight fully emerged leaves, which is about the time the corn is knee-high. Therefore, during approximately the first six weeks after planting, nutrients that are band-placed close to the corn row are more likely to be available for corn-plant uptake than if the same amount of nutrients were broadcast over the entire soil surface.

We conducted 9 field experiments to determine the optimum starter-band N rate in conjunction with the optimum side-dress N rate. Our research used blends of urea-ammonium nitrate (30% N) solution as the N source and 10-34-0 as the P source. We varied N rates from 10 to 70 lbs N/acre placed in a 2 x 2 band. Soil test P levels in these studies were all high and the banded P rate of 34 lbs P_2O_5 would be expected to provide for any P fertilizer needs. In addition, we conducted starter band P application rate studies of 0, 20, 40 and 60 lbs P_2O_5 at each site to measure corn responses to varying P application rates.

An example of enhanced N availability from starter-band placement is shown in Fig. 3. The percent N in whole corn plant tissue samples collected six weeks after planting (knee-high) was approximately the same with either a starter-band application of 30 lbs N/acre, or a surface broadcast application of 60 lbs N/acre plus 10 lbs N/acre in a starter-band. The starter-band N was more efficient in supplying N to the young corn plants.

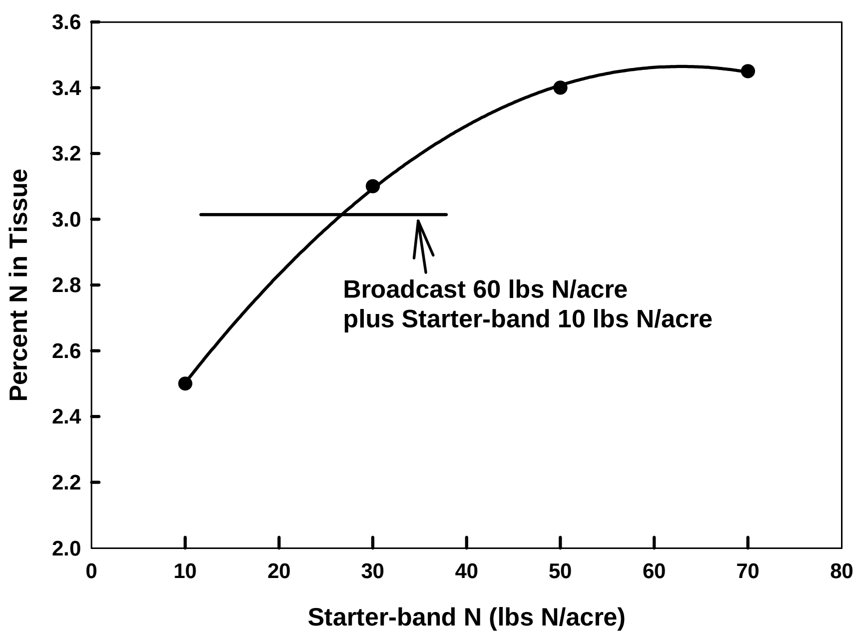

Figure 3. Percent N in whole corn plant (12-15 in. height) related to starter-band and broadcast N applications on a Slagle silt loam soil (Alley et al., 2007).

The response observed in Fig. 3 is reasonable in that the broadcast fertilizer N was subject to losses and immobilization as well as much of the applied N not being near the corn seedling small root system. The band applied N minimized losses and immobilization while maximizing positional availability to the small seedling root system.

Data in Table 1 show that optimum starter-band (2x2) N rates ranged from 27 to 70 lbs N/acre for the 9 experimental sites, all of which were no-till planted into wheat-double crop soybean residue. Optimum side-dress N rates ranged from 0 to 125 lbs N/acre as yield potential varied due to varying weather conditions for these mid-Atlantic Coastal Plain region sites. Detailed statistical analysis of the starter-band placement data demonstrated that essentially all the yield advantage for the higher starter-band N treatments could be obtained with a 50 lb N/acre starter-band application. The 50 lbs N/acre starter-band application also reduces the potential for salt injury compared to a 60 or 70 lb N/acre application, and provides room in the starter fertilizer for addition of K or other nutrients. The most important aspect of these data is that higher rates of starter band N are the most efficient way to apply early season N.

Table 1. Starter band and side-dress N rates for achieving highest yields in 9 no-till corn field experiments in the Virginia Coastal Plain.

Soil Series	Optimum Starter-band N Rate*	Optimum Side-dress N Rate*	Yield**
	Lbs N/acre	Lbs N/acre	Bu/acre
Pamunkey sil	66	0	89
Slagle sil	70	93	168
Pamunkey fsl	70	80	154
Slagle sl	49	125	128
Turbeville	27	107	111
Cullen l	44	58	126
Eubanks sil	70	0	122
Ross l	40	93	105
Pamunkey sil	70	93	148

*Optimum starter band and side-dress N rates were the combination of starter-band and side-dress rates that resulted in the highest yield for the site. Starter-band N rates were 10, 30, 50 and 70 lbs N/acre. These were applied in combination with side-dress N rates of 0, 60, 120, and 180 lbs N/acre.
**Multiple regression analyses were used to determine the combination of starter-band and side-dress N that produced the highest yield at each site.

Corn Yield Response to Starter Band Phosphorus Applications

Phosphorus fertilizer needs and grain yield responses to starter band P rates determined in nine field experiments associated with the starter N experiments discussed in the previous section (Alley et al. 2007). Our data showed no grain yield responses were found on soils testing high to very high in plant available P and that one grain yield response of 12 bu/acre was obtained on a medium testing soil. These results are similar to the 26 site years of corn and soybean response to P and K in Iowa reported by Bordoli and Mallarino (1998) and Mallarino et al. (1999); and are to be expected as calibrations for soil test levels of high mean a low probability of yield response to applied fertilizer is expected. However, working with poorly drained, cooler soils in continuous no-till, Vetsch and Randall (2000) reported that corn yields can be improved most consistently (8 bu/acre average) by placing a small amount (10 gals/acre) of starter fertilizer (10-15-0) over the seed zone. The more consistent corn yield increases were obtained in conjunction with the use of row cleaners and injecting additional N below the surface residues.

Winter Yield Response to Starter Band Fertilizer Applications

For no-till winter wheat, supplying fertilizer nutrients in close proximity to the seed at planting, and below the surface residue may increase fall tiller and root system development and lead to higher yields. While not directly measuring grain forming tillers, Boman et al. (1992) found increased total season wheat forage yield due to seed-banded phosphorus (P) fertilizer on acid soils with high soil test P levels. Wheat forage yields were increased due to banding P in Texas, especially in dry years (Miller, 1998). Goos and Johnson (2001) found increased tillering, early growth, and P uptake when P fertilizer was placed in-furrow at planting. Nitrogen placed in furrow has also been shown to increase growth, tiller production, and grain yield in studies conducted in Arizona (Clark and Carpenter, 2002).

Recent work by Kelly and Sweeney (2007) showed that wheat grain yield responses were related to increased N and P uptake where N and P fertilizers were placed below previous crop residues for wheat planted no-tillage into corn or soybean residues. In addition to the grain yield increases, fertilizer N requirement was approximately 35 lbs lower for knifed-in (coulter-knife) applied N than for broadcast surface applications. In one year of research in Virginia with N and P application methods for winter wheat, early-season growth responses were found for band-placed at seeding applications of N and P, but no grain yield responses were observed. This work is continuing.

Starter Fertilizer N:P Ratios for Corn

The data from our Virginia trials clearly indicate that relatively high rates of N are needed in starter band fertilizers, and that P applications can be determined by soil testing. Our recommendations for corn are to apply 50 lbs N/acre in a 2 x 2 starter band in conjunction with needed P up to a rate of 50 lbs P_2O_5/acre in the starter band. This rate of P covers the vast majority of soils used for corn production in the mid-Atlantic region. In most cases either a 1:1 N:P ratio starter fertilizer such as a 15-15-0 material can be used, but on high available P soils, starter fertilizers with ratios of 2:1 N:P such as a 20-10-0, are being used utilized to maximize corn response to N, assure adequate early season P, and optimize both N and P efficiency. For very high levels of soil test available P, starter applications (2x2) of N only using either UAN solution or urea, provide the benefits of increased early season N availability and early season vigor. The data from regions with cooler early season temperatures indicate that in no-tillage systems, starter fertilizers may be needed in small amounts to enhance early season growth and maintain consistently high yields, even on high P testing soils (Vetsch and Randall, 2007).

Summary

Efficient plant nutrition programs are a yield building component of a profitable and environmentally sound crop production system. Early season nutrient availability is essential for establishment of a vigorously growing crop that is positioned for maximizing yield potential for the specific site. No-till systems with large amounts of surface residues and cool soil temperatures present a challenge to providing corn seedlings with the nutrition for vigorous growth. Starter band application (2x2) application of N and needed P, as determined by soil testing, is a way to reduce volatilization, immobilization, and runoff losses of N fertilizers as well as optimize positional availability of applied N and P. Starter band application of P also minimizes potential runoff losses and soil fixation of P fertilizers while optimizing availability to the developing root system. Our research in Virginia has shown that starter fertilizers should contain up to 50 lbs N/acre applied in a 2x2 band as well as needed P as shown by soil testing. We found no danger to stand establishment with these rates of N even on sandy loam soils as long as the fertilizer band is at least 2 inches from the row. These applications insure early season nutrient availability with minimal losses and provide the grower with a longer window for side-dressing the remainder of the N fertilizer need, as compared to starter fertilizers that supply only minimal amounts of N. Starter fertilizers with N:P ratios of 1:1 or 2:1 provide the opportunity to optimize early season corn N and P needs; and to reduce the need for preplant broadcast applications of N, as well as P for soils testing medium to high in plant-available P. Nitrogen alone can be used in the starter band on soils testing very high to excessively high in plant-available P. Research in Kansas has shown grain yield and nutrient use benefits to applying N and P below the surface residues for no-till winter wheat production systems.

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