Fertilizer Band Location
For Cereal Root Access
Seminal roots supply all the nutrient needs of cereals until the 4-leaf stage, when tillers begin to emerge and crown roots begin to develop. Early seminal root access to fertilizer can increase yield potential.

Tillage System Definitions

No-Till: Placement of the seed and, in most cases, some or all of the crop's fertilizer requirement through the previous crop stubble without prior tillage. Soil disturbance is usually slight but varies with drill selection and operation.

Minimum (or Reduced) Tillage: A reduction in the number of tillage operations compared to conventional tillage, and/or the selection and use of tillage implements which leave 30 percent or more of the crop residue on the soil surface after seeding.

The Authors — The authors are Roger Veseth, Robert McDole, Carl Engle and James Vomocil. Veseth is a STEEP Extension Conservation Tillage Specialist with the University of Idaho and Washington State University, located in the UI Department of Plant, Soil and Entomological Sciences, Moscow. McDole is Extension Soil Scientist, University of Idaho, Moscow. Engle is Extension Soil Scientist, Washington State University, Pullman. Vomocil is Extension Soil Scientist, Oregon State University, Corvallis.

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Fertilizer Band Location for Cereal Root Access in No-Till and Minimum Tillage Systems

Introduction

The use of no-till and minimum tillage systems in cereal production is growing rapidly in the Pacific Northwest. These production systems effectively control soil erosion and can reduce production costs. Yield potentials with no-till and minimum tillage have increased significantly in recent years. Among reasons for the increased success and popularity of these conservation tillage systems are the advances made in fertilizer placement technology and equipment design. For the intermediate and lower precipitation zones, surface broadcasting of fertilizer has largely been replaced by deep banding, either in one operation with seeding or in a separate application. Placing fertilizer in deep bands below the seeding depth and near the seed row has many potential advantages over surface broadcasting for cereal production in the Pacific Northwest. These advantages include:

- Higher yield potential from increased early plant vigor and growth rate;
- Lower grass weed populations and improved ability of the crop to compete with weeds;
- Less nutrient tie-up from microbial decomposition of residue; and
- Higher fertilizer use efficiency by the cereal crop.

The effects of soil nutrient test levels, fertilizer-soil interactions, precipitation levels, soil temperature and other factors must be considered in determining optimum fertilizer placement, however.

One important factor in crop response to deep-banded fertilizer can be the location of the fertilizer band for early access by the cereal root system. Consequently, a basic understanding of cereal root growth patterns is essential for development of an effective fertilizer placement system. Fig. 1 shows the typical pattern of early root development of a wheat seedling shortly after germination.

Fig. 1. Root development of a wheat seedling shortly after germination. The primary root or radicle extends straight down while the first seminal pair develops at about a 30 degree angle from horizontal (Betty Klepper, USDA-ARS, Pendleton, OR).
One objective of researchers in the STEEP program has been to design fertilizer placement systems for conservation tillage. At the USDA-ARS Columbia Plateau Conservation Research Center at Pendleton, OR, an important step in that research has been to develop an understanding of cereal root growth patterns and of the importance of early root access to fertilizer. Betty Klepper, Paul Rasmussen, Ron Rickman, Dale Wilkins and other STEEP researchers have been instrumental in this effort. Portions of research results from Klepper, Rasmussen and Rickman (1983) and from other STEEP research are summarized in this publication.

Cereal Root Development

Cereals such as wheat have two types of roots: seminal roots and crown or nodal roots. Seminal roots are produced from the base of the main stem at the seed shortly after germination. Later, the crown roots grow from the base of the crown beginning about the 4-leaf stage when tillers begin to form. Figs. 2 and 3 illustrate seminal root development at two early plant growth stages.

Wheat commonly has three to six individual seminal roots. These roots develop in an orderly, predictable sequence. The primary root or radicle, which is the first visible sign of germination, generally grows straight down. About the same time that the coleoptile or main shoot begins to emerge from the seed, a pair of seminal roots form at either side of the primary root. This is the lower of two pairs of seminal roots that occur in wheat. These two roots grow downward at an angle roughly 30 degrees from horizontal. When their tips reach an average distance of 2.5 inches to the side of the seed, they turn and grow straight down.

Between the 1- and 2-leaf stage, the second or upper pair of seminal roots develops above the lower pair in the same vertical plane. These roots grow nearly horizontally, then turn downward when they reach about 4 inches from the primary root axis. A third single root may develop at the level of the upper pair of seminal roots, positioned 90 degrees from this pair. Thus, as many as six seminal roots may develop.

Both genetic and environmental factors influence the actual number of seminal roots. Plants developing from poor seed or in poor seedbeds often are missing some seminal roots, generally the upper pair and the single root located 90 degrees from that pair.

Seminal roots and their lateral branches are the structures that absorb fertilizer nutrients if the seedling is to make use of the nutrients before tillering. Seminal roots branch before tillering, and the length of branches depends upon soil conditions. Longer branches occur in moist, friable soil. When the plant has four leaves and one tiller, the longest lateral that develops from the primary root averages about 2 inches. If the plant is stressed by low nutrient levels, root diseases or other environmental factors when it begins tillering, some of the earliest, most productive tillers may not develop or may be aborted.

The crown root system (Fig. 3) does not begin to develop until the main stem has four leaves and one tiller becomes visible from the axil of the first leaf. Crown roots develop in a pattern similar to that of the upper pair of seminal roots. They grow almost horizontally for the first few inches, then turn downward. Additional crown roots develop on the main stem as each tiller emerges. Each tiller produces crown roots after it has about three leaves. These crown roots eventually comprise the bulk of the plant roots, extending to depths of 3 to 5 feet or more.

Crown roots allow exploration of soil between rows above the seed depth, but only after tillering begins. This may leave a large volume of soil between the rows that is void of crop roots early in the growing season. This area becomes a favorable site for weeds to grow without competition, particularly with surface or shallow fertilizer placement.
Fertilizer Use Efficiency

One factor that enhances use of deep-banded fertilizer is the unusual amount of root branching that occurs in areas of high nutrient content. Uptake of nutrients from the concentrated fertilizer band is increased both by the larger root surface area in contact with the fertilizer and by the natural movement of nutrients from the high concentration band to low concentration areas in and near the roots.

A fertilizer placement-use efficiency study was conducted in 1983 by STEEP researchers Bobette Parsons and Fred Koehler, Washington State University soil scientists at Pullman (Parsons and Koehler 1984). Spring wheat was planted after spring wheat under conventional and no-till systems in a 15-inch annual precipitation area near Davenport, WA. Where nitrogen was banded 2 inches below the seed, a fertilizer use efficiency of about 75 percent was measured under both tillage systems, compared to a fertilizer efficiency of 40 percent for surface broadcast applications. In the no-till treatment, about 16 percent of the broadcast nitrogen was held in the surface crop residue early in the growing season. This decreased to 6 percent by harvest.

Fertilizer Placement Options

Understanding the cereal root distribution patterns at early plant stages helps a farm operator select more efficient fertilizer placement systems in conservation tillage. Figs. 4 and 5 schematically illustrate examples of five different fertilizer band positions in a 12-inch row spacing at two early crop growth stages. The fertilizer band positions include placement with the seed (starter or pop-up); 2 inches below the seed; 2 to 3 inches to the side of the seed at seed depth; 2 inches below and 2 to 3 inches to the side of the seed; and 2 inches below and 6 inches to the side of the seed.

Not all of the band positions are equally available to the seminal root system at these early crop stages.

With the Seed

Banding starter fertilizer with the seed is one method of applying the crop phosphorus requirement. Applying the crop's entire nitrogen and sulfur needs with the seed would cause excessive seedling damage, however. A separate fertilizer band would be needed. Placing phosphorus with higher rates of nitrogen in a deep band below, or below and to the side of the seed, has generally resulted in higher yields than placing phosphorus with the seed and applying nitrogen separately. Crop response still depends on the potential for phosphorus tie-up in the soil and other factors. Deeper placement is particularly important in areas where the surface soil dries out early in the growing season. Under cold, wet soil conditions, cereals seeded in late fall or early spring may still benefit from starter fertilizer placed with the seed in addition to the deep band.

Below the Seed

Fertilizer banded directly below the seed is immediately available through the primary seminal root, often even before seedling emergence. However, banding high rates of nitrogen and sulfur fertilizer too close to the seed can delay emergence and cause root or seedling injury, primarily through burning of the seminal root tip. STEEP researchers have found a minimum separation of about 2 inches is needed between the seed and the fertilizer band in a silt loam soil (Wilkins et al. 1982; Babowicz, Hyde and Simpson 1983). A wider separation may be needed in coarser textured soil when ammonium-type fertilizers are used. This position has the advantage of allowing placement of seed and fertilizer with one opener, instead of two separate openers.
Beside the Seed at Seeding Depth

Banding fertilizer to the side of the seed row, at seed depth, does not provide sufficient seminal root access because of the downward growth angle of the roots. Placed in this position, the fertilizer — particularly an immobile nutrient like phosphorus — would not be available until secondary branching begins on the second seminal root pair, or until crown roots are initiated as the tillers begin to emerge after the 4-leaf stage. This shallow fertilizer band may also be unavailable because of early drying of surface soils. Roots do not actively grow and absorb nutrients in dry soil.

Below and to the Side of the Seed

A fertilizer band located about 2 inches below and 2 to 3 inches to the side of the seed provides excellent access for the first seminal root pair with little potential for root damage. This fertilizer band position may also be incorporated into a paired-row planting system where one fertilizer band supplies two closely spaced seed rows. A 6:14 inch paired-row spacing at the 1-leaf stage of wheat is schematically illustrated in Fig. 6. An increasing number of no-till drills, reduced tillage drills and modified air seeders use this paired seed row/deep fertilizer band combination.

Increasing the distance of the deep fertilizer band from the seed row would reduce its availability to the crop early in the season. For example, placing a fertilizer band between 12-inch rows would significantly delay its availability. The fertilizer band 6 inches to the side of the row (Fig. 5) is still not available to the plant at the 4-leaf stage as the plant begins to tiller. The fertilizer band would be used by the crown roots later as the crop developed, but nutrient stress may already have limited yield potential by that time through loss of early tillers and generally reduced plant vigor.

An example of the impact of early seminal root access to the fertilizer band is illustrated in Table 1. Two fertilizer band locations were used in no-till spring wheat-winter wheat rotation studies by STEEP researchers Gary Hyde and John Simpson, Washington State University agricultural engineers (Hyde and Simpson 1983). The studies were conducted in a 16-inch precipitation area near St. John, WA, and a 20-inch precipitation area near Pullman, WA. Fertilizer was either banded 2 inches below the seed or between the 16-inch rows 2 inches below seed depth. Placing the fertilizer 2 inches below the seed, where it was immediately available to the seminal roots, resulted in the highest yield. Yields with this treatment were 13 bushels per acre higher in winter wheat and 11 bushels per acre higher in spring wheat, compared to yields from the same rate of fertilizer deep-banded between the 16-inch rows.

Separate Fertilizer Operation

Fertilizer can be deep-banded in a separate operation before seeding in minimum or reduced tillage. However, most fertilizer injector equipment has spacings of 12 inches or wider. Depending on drill row spacing, the lateral spread of seminal roots from the seed
60 PERCENT OF THE PLANTS HAVE ACCESS TO THE FERTILIZER BANDS

7 INCH ROW SPACING

12 INCH FERTILIZER INJECTOR SPACING

80 PERCENT OF THE PLANTS HAVE ACCESS TO THE FERTILIZER BANDS

7 INCH ROW SPACING

9 INCH FERTILIZER INJECTOR SPACING

Fig. 7. Schematic illustration of the effect of fertilizer injector spacing on fertilizer availability to the seminal roots of wheat at the early 1-leaf stage when seed rows and fertilizer bands are parallel.

row may not be wide enough at the early crop stages to allow efficient use of all the fertilizer bands. An example is the deep fertilizer band centered 6 inches between rows (Figs. 4 and 5). This illustrates one possible band location with a 12-inch fertilizer injector spacing and 12-inch drill row spacing.

Combinations of fertilizer injector and drill row spacings could be selected to improve seminal root access to the deep fertilizer bands in minimum tillage. Fig. 7 illustrates the impact of two fertilizer injector spacings when seed rows and fertilizer bands are parallel. With a 7-inch row spacing and a 12-inch fertilizer injector spacing, about 60 percent of the plants are within 3 inches of a fertilizer band, making the fertilizer available to the seminal roots by about the 1-leaf stage. When the fertilizer injector spacing is reduced to 9 inches, the percentage of plants within 3 inches of a fertilizer band is increased to about 80 percent.

Besides fertilizer injector spacing, depth of the fertilizer band is also important. The fertilizer band must be placed at least 2 inches below seed depth because of the 30 to 45 degree downward angle of the seminal root pairs.

Additional Placement Considerations

Fertilizer band placement for early access to the seminal root system of cereals is an important part of optimizing production potential and fertilizer use efficiency. Other interacting factors may enhance or overshadow the effect of fertilizer placement, however. These factors include nutrient availability in the soil, nutrient mobility in the soil, precipitation and soil temperature.

Soil Test of Nutrient Availability

A good fertility management program must begin with soil tests to determine fertilizer needs. For example, the highest crop response to deep-banded phosphorus is generally found in soils with a low phosphorus soil test. As soil test levels increase, phosphorus fertilizer use and placement become less critical. A general overview of plant nutrient levels is available in PNW publication 276, Current Nutrient Status of Soils in Idaho, Oregon and Washington.
Soil tests can also indicate the potential availability of fertilizer nutrients. If the soil pH is 7.5 or higher, for example, increasing amounts of phosphorus fertilizer can become immobilized by the free lime (calcium carbonate) in the soil. At pH levels below 6.0, immobilization by iron and aluminum can increase. Concentrating the phosphorus in a band, particularly in combination with nitrogen, helps reduce soil tie-up and maintain availability of the phosphorus to the crop.

**Nutrient Mobility and Precipitation Level**

Fertilizer nutrients differ greatly in their level of mobility in the soil. Nitrate nitrogen and sulfur are highly mobile and move readily with the soil water. If precipitation and movement of water into the soil are sufficient, surface broadcast or shallowly placed nitrogen and sulfur will be moved into the crop root zone. In intermediate and lower precipitation areas, fertilizer availability may be reduced because movement of water into the soil profile is not sufficient to move the fertilizer into the root zone, particularly for spring crops. In contrast, deep-banding or broadcasting all of a winter wheat crop’s nitrogen fertilizer needs in the fall in a high precipitation area could result in considerable loss through denitrification or leaching if the nitrogen was in the mobile nitrate form. In these areas, ammonium nitrogen, nitrogen stabilizers or split fall-spring or predominately spring applications of nitrogen could be considered.

Phosphorus fertilizer is immobile in the soil and must be placed in the cereal root zone for early access by the plant. In areas where the surface soils dry out early in the season, shallow-placed phosphorus would be less available than phosphorus banded deeper in the root zone since roots do not grow or absorb nutrients in dry soil. Under irrigated conditions, increased root activity near the surface allows for increased use of shallow-placed phosphorus. Potassium is only slightly mobile in the soil and has placement considerations that are similar to those for phosphorus.

**Soil Temperature**

Soil temperature indirectly affects nutrient availability by restricting root growth and activity. A common difference in responses to fertilizer placement between fall-planted and spring-planted cereal can be attributed to soil temperature differences. In the fall, soil temperatures are lower near the soil surface than deeper in the soil profile. The opposite is true in the spring where spring cereal roots encounter cooler, wetter soils with depth. Roots of spring cereals do not penetrate as deeply in the profile as do roots of fall-planted cereals. Compared at the same stage of growth when the number of roots are the same, the spring cereal root system is usually shorter, due in part to soil temperature differences.

A larger, faster-growing root system means more root-soil contact for nutrient absorption. This is especially true for immobile nutrients such as phosphorus and potassium. Consequently, spring cereals may respond to phosphorus banded near the seminal roots, while winter cereals may not show a consistent response.

**Summary**

Recent advances in fertilizer placement technology and equipment design have greatly increased the yield potential for cereal production under no-till and minimum tillage systems. An important part has been the development of an understanding of cereal root development patterns. Banding fertilizer below the seeding depth near the seed row for early access by the seminal root systems generally provides the greatest cereal yield response and fertilizer use efficiency. Other factors such as soil nutrient test levels, nutrient mobility in the soil, seasonal precipitation level, soil moisture and soil temperature can enhance or reduce the benefits of fertilizer placement.

**Literature Cited**


