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Editor's note: This is the last article in a five-part series from the International Plant Nutrition Institute titled "Know Your Fertilizer Rights," sponsored by The Fertilizer Institute and the Canadian Fertilizer Institute. The series is based on fertilizer best management practices structured around the "4R" nutrient stewardship concept. For more information, visit www.ipni.net.

Know your fertilizer rights: right place

By T.S. Murrell, U.S. Northcentral Director, International Plant Nutrition Institute, West Lafayette, IN; ***G.P. Lafond***, Scientist, Production System Agronomy, Indian Head Research Farm, Indian Head, SK, Canada; and ***T.J. Vyn***, Professor of Agronomy, Department of Agronomy, Purdue University, West Lafayette, IN

The 4R nutrient stewardship concept defines the right source, rate, time, and place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem. This concept was introduced by Bruulsema et al. (2009) in an earlier article in *Crops & Soils* magazine. Following that article, subsequent authors discussed concepts of using the right source (Mikkelsen et al., 2009), the right rate (Phillips et al., 2009), and the right time (Stewart et al., 2009). This article completes the series by discussing agronomic concepts of the right place. Right place involves all nutrients and all application methods, such as broadcasting with or without incorporation, banding at various depths, and foliar applications at various growth stages. It also considers the correct location in the field and landscape.

The focus of this article is on soil applications of P and K, and examples of right place concepts are drawn from studies conducted on corn, soybean, and wheat. For soil-applied nutrients, right place involves matching the location of a nutrient supply to the zone within the soil that is accessible to the plant. As such, it is about managing fertilized soil volume—its concentration and location relative to the plant root system. This is particularly important for P and K since they have limited mobility.

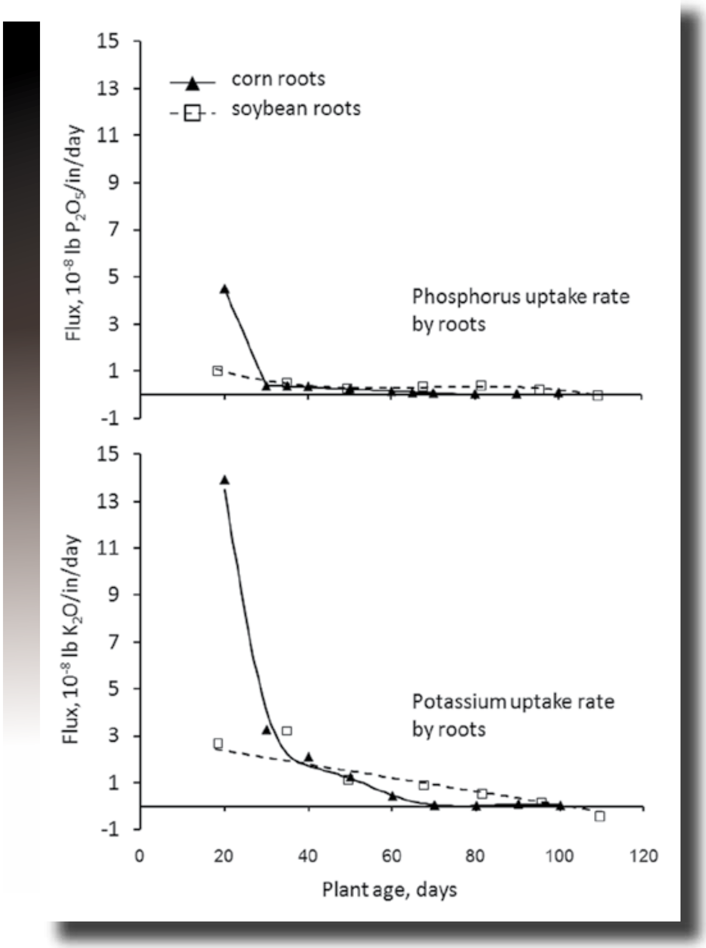
Uptake of nutrients by plant roots

Both P and K move to plant roots primarily through diffusion (Barber, 1984). When a root depletes the supply of nutrients in its immediate vicinity, P and K will move limited distances to replenish this supply, but only if a more concentrated zone exists nearby. Higher concentrations supply nutrients more quickly and for a longer period of time to the depleted zone around the root.

There is a limit, however, to how quickly a root can take up nutrients (Barber, 1984). Once this limit is reached, increasing the nutrient supply does not result in any faster or greater uptake. For this reason, more than just a few plant roots must have access to a nutrient supply in order to meet total uptake requirements, particularly during rapid vegetative growth stages.

The rate at which a plant root takes up nutrients, termed flux or inflow, changes with plant age. Figure 1 (next page) shows that for both corn and soybean, flux is higher earlier in the season than it is later in the season. Uptake rates of corn roots exceed those of soybean in initial crop developmental stages; however, as plants age, soybean fluxes exceed those of corn. Additionally, throughout much of the season, root uptake of K is several times more rapid than that of P for both crops. Similar trends have also been observed for winter wheat (Gregory et al., 1979); however, for this crop, fluxes reach a second, though more diminished peak, at the start of rapid shoot growth following winter. In general, more rapid fluxes tend to occur when root growth rates are slower, allowing the plant's uptake demand to be met.

Plant roots also respond to localized, concentrated supplies of N and P. When corn, soybean, and wheat roots encounter bands of these nutrients in the soil, they initiate more branching, developing more of their root system in ▶



▶ **Fig 1. Changes in nutrient flux by corn and soybean roots at different plant ages (Barber, 1978; Mengel and Barber, 1974).**

them (McClure, 1972; Passioura and Wetselaar, 1972; Strong and Soper, 1973; Anghinoni and Barber, 1980a; Borkert and Barber, 1985). Such effects have not been observed for K. Additionally, plants benefit from having an ammonium form of N applied in combination with P in these bands. When N is taken up in the ammonium form, the plant root exudes an acid cation to maintain charge balance. As these acid cations accumulate, the soil around the root becomes more acid, increasing the solubility of P and increasing P uptake (Soon and Miller, 1977). Such effects are greatly reduced when ammonium forms of N are applied in a band separated from P (Miller and Ohlrogge, 1958).

The implications of these findings are that a concentrated nutrient supply should be near plant roots early in the season, when root systems are not extensive but root uptake rates are at their highest. High inflow rates rapidly deplete soil nutrient levels around the root and a concentrated supply in close proximity is better able to resupply P and K. If P and K are banded, K should be placed with either P or N to ensure roots proliferate in the K band, since K alone does not promote root branching.

Managing fertilized soil volume

Creating a concentrated supply can be done through banding or increasing the overall fertility throughout the rooting zone. The fundamental dependence of placement upon nutrient rate is demonstrated in a corn study in Fig. 2. When lower rates of P were applied to a soil low in P, maximum uptake and biomass yield were achieved by limiting the fertilized soil fraction to create a concentrated supply that could better keep up with the higher flux rates of the young corn root system. However, because not enough roots could access the supply, overall uptake and biomass yield were lower than those at higher nutrient rates where a greater proportion of the root system was exposed to higher soil P concentrations. This greenhouse study demonstrates the importance of providing a volume of fertilized soil that is adequate for plant nutrient demands.

Extending these concepts to the field is not straightforward because the distribution of nutrients in the soil changes over time and with different management practices. Additionally, the volume and distribution of soil being explored by roots changes during the season as the crop responds to the soil's physical and chemical properties as well as to above-ground environmental conditions.

Increases in fertilized soil volume can be achieved through higher rates of P and K broadcast and then incorporated through tillage. This approach has been followed in much of the eastern Corn Belt. Using this approach generally results in an initial spike in soil fertility that decreases exponentially with time if no further additions are made (Mallarino et al., 1991). Another approach to increasing fertilized soil volume is to make repeated applications of banded nutrients, as is done in much of the western Corn Belt, the Great Plains, and the Canadian Prairies. Such an approach results in soil fertility levels that slowly increase over many years (Zentner and Campbell, 1988; Zentner et al., 1993). The effect of a banded application on fertility levels over time depends greatly on the rate applied and the frequency of the application. Stecker et al. (2001) investigated how P concentrations in a band change over time in a no-till system (Fig. 3). They predicted that increases in fertilized soil volume could only be achieved when a higher rate of P was banded annually in a corn–soybean rotation. The lower rate banded annually or both rates banded biannually kept fertilized soil volume essentially unchanged or decreased it.

In reduced-tillage systems, lack of soil mixing results in higher concentrations of nutrients near the soil surface compared to those deeper in the soil profile—a more limited fertilized soil volume. While the higher concentrations promote greater root proliferation near the surface (Bauder et al., 1985), nutrient distribution may not be adequate, particularly under drier conditions. For instance, positive corn yield responses have been observed under drier situations when K is applied in deep bands that create a higher volume of fertilized soil deeper in the profile (Bordoli and Mallarino, 1998).

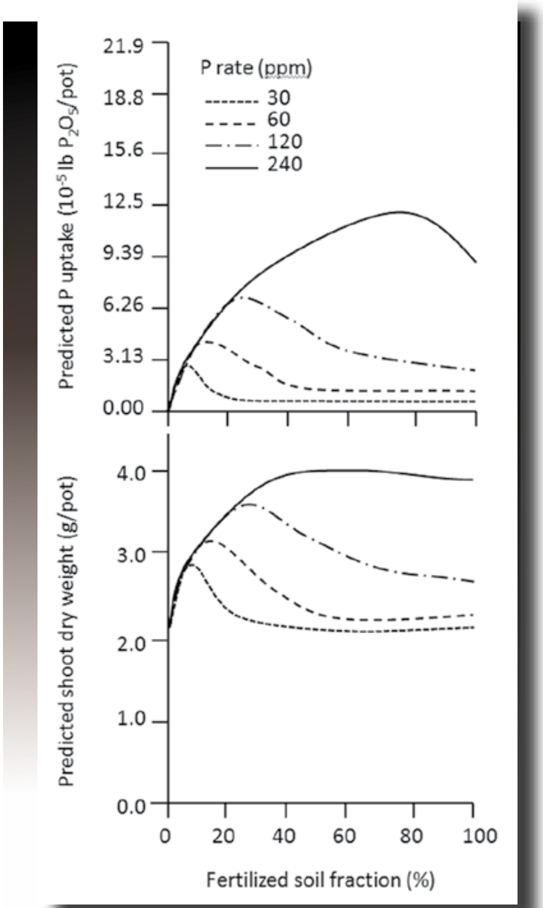


Fig. 2. The influence of P rate on the volume of fertilized soil required to maximize P uptake and dry matter yield of 18-day-old corn grown in greenhouse conditions (Anghinoni and Barber, 1980).

In crops like corn and wheat, many studies have shown the importance of including a band of concentrated nutrients near the seed at planting (termed starter fertilizer). For instance, such a fertilization strategy is common practice for P applied to spring wheat grown in the Canadian Prairies. Placement of P near the seed is important to meet the higher flux rates of wheat roots early in the season. Additionally, proper early-season P nutrition is important for tiller initiation—an important component of final grain yield. Positive wheat responses to starter applications of P have occurred in this area even on soils with a history of broadcast or banded P applications (Wagar et al., 1986).

The need for a starter fertilizer may diminish as nutrient levels in the soil increase. Bundy and Andraski (2001) surveyed 100 farms in Wisconsin, most of which had soils testing high in P. They found no relation between probability of corn response to N-P-K starters and soil test P but did find that when K fertility level was lower, probability of response increased, particularly when longer-season hybrids were planted later. Vyn and Janovicek (2001) also noted that response to starter K was more likely at lower soil test K levels in no-till systems. Such observations demonstrate that

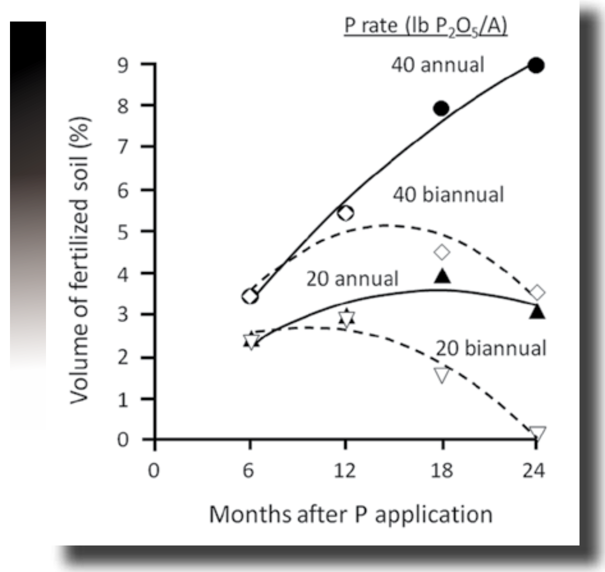


Fig. 3. Predicted volume of P-enriched soil after applications of various P rates banded 2 inches to the side and 2 inches below no-till corn seed planted in 30 in rows (Stecker et al., 2001).

in higher-fertility soils, further increases in fertilized volume through the application of a starter fertilizer may be unnecessary.

Managing limited root access to nutrient supplies

Management practices, both for P and K nutrients as well as others, can affect the plant's ability to access the volume of soil fertilized. As demonstrated above, reduced tillage and the resulting stratification of nutrients is one example. However, there are others.

Row position on fields with a history of banded P and K applications is an important consideration for nutrient access, particularly when the nutrient needs of all crops in a rotation are considered. As an example, Yin and Vyn (2003) compared yields of soybean grown directly over bands of K applied the previous corn season to those growing between the bands. Bands of K were spaced 30 inches apart for the previous corn crop. Soybeans were grown in 15-inch rows or 7.5-inch rows, depending on study location. In the 15-inch row configuration, half of the soybean rows were directly over residual K bands while half were not. In the 7.5-inch row arrangement, one out of every four rows was directly over a residual band. Soybeans grown between fertilizer bands were not as well supplied with K as those growing directly over them, resulting in yield losses. Because soybean roots turn downward when they encounter root systems of other soybeans grown in adjacent rows (presumably to avoid competition for water and nutrients; Raper and Barber, 1970), it is likely that root systems of narrow-row soybeans are oriented more directly under the plant and extend more deeply, rather than outward. Such a change in root distribution may explain why soybean grown between residual fertilizer K bands in the study by Yin and Vyn (2003) had reduced K levels and lower yields.

A final example of management impacts on access to fertilized soil volume comes from a study examining the response by corn to starter K applications on a compacted soil (Wolkowski, 1989). In that study, corn response to starter K increased as compaction increased. Such an observation is consistent with the more limited root volume explored by a plant growing under compacted soil conditions. With less rooting volume, the concentration of K would need to be higher to meet plant uptake requirements throughout the life cycle of the corn plant.

Summary

Right place is an important part of proper nutrient management and must be combined with considerations of right source, rate, and time. It has been shown that right place is a moving target that changes depending on the crop grown, the stage of its development, the overall fertility of the soil, and the accompanying management practices implemented. The overall concept with right place is managing the extent and concentration of fertilized soil volume. To be successful, this must be planned by considering all crops grown in a particular cropping system to ensure each crop can access the nutrients it needs when it needs them. ■

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1. Which of the following is NOT a consideration for the right place?
- ❑ a. Landscape position.
- ❑ b. Quantity of nutrients removed in crop harvest.
- ❑ c. Root system extent.
- ❑ d. How far nutrients move in the soil.

2. Phosphorus and potassium move through the soil to the plant root primarily through
- ❑ a. osmosis.
- ❑ b. mass action.
- ❑ c. diffusion.
- ❑ d. cation exchange.

3. The rate at which a plant root takes up nutrients is termed
- ❑ a. flux.
- ❑ b. diffusion.
- ❑ c. adsorption.
- ❑ d. desorption.

4. For corn, inflow rates are highest
- ❑ a. during early vegetative growth stages.
- ❑ b. during late vegetative growth stages.
- ❑ c. during early reproductive growth stages.
- ❑ d. during late reproductive growth stages.

5. When present in a concentrated supply, this macronutrient is known to cause plant root systems to initiate more branching:
- ❑ a. manganese.
- ❑ b. potassium.
- ❑ c. phosphorus.
- ❑ d. zinc.

6. When placed together in a band, ammonium forms of nitrogen enhance phosphorus uptake because
- ❑ a. roots take up acid cations and exude ammonium cations.
- ❑ b. roots branch when they encounter zones of concentrated acid cations.
- ❑ c. ammonium nutrition increases the pH of the soil around the root.
- ❑ d. ammonium nutrition acidifies the soil around the root.

7. On a soil deficient in phosphorus, if only a low rate of phosphorus will be applied to either corn or wheat, it should be
- ❑ a. foliar applied.
- ❑ b. banded near the seed at planting.
- ❑ c. broadcast and left unincorporated.
- ❑ d. broadcast and incorporated with tillage.

Quiz continues next page

8. Which of the following is NOT a way to increase fertilized soil volume over time?

- ❑ a. Apply a lower rate in a band every few years.
- ❑ b. Apply a higher rate in a band every year.
- ❑ c. Broadcast a higher rate every year and incorporate with tillage.
- ❑ d. Each year, combine a higher rate that is broadcast and incorporated with a lower rate that is banded.

9. When potassium has been applied in subsurface bands that are 30 inches apart, and soybeans are planted in 7.5-inch rows with one row directly over the band, what percentage of the crop is likely to have adequate access to the banded K?

- ❑ a. 25%. ❑ c. 75%.
- ❑ b. 50%. ❑ d. 100%.

10. Which of the following is NOT a characteristic of starter fertilizer?

- ❑ a. It provides a supply of nutrients near young, limited root systems.
- ❑ b. It provides a more concentrated supply that helps keep up with higher inflow rates.
- ❑ c. It promotes root branching if N, P, or both are in the fertilizer formulation.
- ❑ d. It is well distributed in the soil and provides nutrients to the entire root system later in the season.

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