Tillage

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SECTION CONTENTS:

DEFINING TILLAGE SYSTEMS

The way in which tillage systems change fertilization practices is a complex issue. Tillage systems are sequences of operations that manipulate the soil in order to produce a crop. Operations include tilling, planting, fertilization, pesticide application, harvesting, and residue chopping or shredding. The ways in which these operations are implemented affect the physical and chemical properties of the soil, which in turn affect plant growth. The first step in making fertilizer management decisions is to understand the practices associated with each tillage system.

Conservation tillage practices focus upon managing crop residues. Crop residue management is defined by the Conservation Tillage Information Center (CTIC) as a year-round system beginning with the selection of crops that produce sufficient quantities of residue and may include the use of cover crops after low residue producing crops. Crop residue management includes all field operations that affect residue amounts, orientation, and distribution throughout the period requiring protection. Site-specific residue cover amounts needed are usually expressed in percentage but may also be in kilograms. Tillage systems included under crop residue management are no-till, ridge-till, mulch-till, and reduced-till.

Conservation Tillage (30 percent or more crop residue left after planting)

The category of conservation tillage is defined by the CTIC as any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, conservation tillage is defined as any system that maintains at least 1,120 kilograms per hectare of flat, small grain residue equivalent on the surface throughout the critical wind erosion period. The tillage systems classified as conservation tillage are no-till, ridge-till, and mulch-till.

No-till

The CTIC defines no-till as a system in which the soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created

by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

Ridge-till

In ridge-till, the soil is also left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

Mulch-till

The soil is disturbed before planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with herbicides and/or cultivation. Mulch-till is a category that includes all conservation tillage practices other than no-till and ridge-till.

Two tillage practices that fall into this category are zone-till and strip-till. Both of these tillage practices involve tilling a strip into which seed and fertilizer are placed. Although these are popular terms in some areas, they are not official survey categories because they are considered modifications of no-till, mulch-till or "other tillage types." Less than 25% row width disturbance is considered no-till. More than 25% row width disturbance would be considered mulch-till or "other tillage type," depending on the amount of residue left after planting.

Other Tillage Systems (less than 30 percent crop residue left after planting)

Tillage systems that leave less than 30 percent crop residue after planting are not classified as conservation tillage. However, these systems may meet erosion control goals with or without other supporting conservation practices, such as strip cropping, contouring, terracing, etc.

Reduced-till

Reduced-till systems leave 15-30 percent residue cover after planting or 560 to 1,120 kilograms per hectare of small grain residue equivalent throughout the critical wind erosion period.

Conventional-till

Conventional-till systems leave less than 15 percent residue cover after planting, or less than 560 kilograms per hectare of small grain residue equivalent throughout the critical wind erosion period. These systems generally involve plowing or some other form of intensive tillage.

EFFECTS OF TILLAGE ON PLANTS AND SOILS

Conservation tillage practices change many soil properties when implemented for a long term. Changes in soil properties change the way in which crops respond to fertilizer management practices. Tillage systems affect soil properties such as temperature, moisture, bulk density, aggregation, organic matter content, and plant properties such as root density.

Temperature

Table 16.1: Effects of Tillage on Soil Temperature

Tillage System	Average daily maximum soil temperature (°C) at 10 cm, 8 weeks after planting
Plow, disk twice	21.9
Chisel, field cultivate	19.8
Ridge-till	21.0
No-till	18.4

Data cited in: Griffith, D.R., J.F. Moncrief, D.J. Eckert, J.B. Swan, and D.D. Breitbach. 1992. Crop response to tillage systems. p. 25-33. In MidWest Plan Service Committee (Ed) Conservation tillage systems and management: Crop residue management with no-till, ridge-till, mulch-till. Iowa State University, Ames, IA.

Spring soil temperatures are usually lower in conservation tillage systems than in other tillage systems. This results from the insulating effect of residue cover. Residues reflect a portion of the solar energy that would otherwise reach the soil surface. In addition, residues delay soil drying. Higher soil moisture results in cooler Spring soil temperatures because wetter soils require more energy to warm than do drier soils.

Moisture

Table 16.2: Moisture Conservation between Tillage Systems

		No-till		Moldboard Plow	
Month	Rainfall	Transpiration	Evaporation	Transpiration	Evaporation
		(mm)			
May	179	0	21	0	63
June	97	76	10	64	66
July	101	124	3	95	21
August	41	92	2	72	14
September	91	15	5	11	23
Total	509	307	41	242	187

Data cited in: Griffith, D.R., J.F. Moncrief, D.J. Eckert, J.B. Swan, and D.D. Breitbach. 1992.Crop response to tillage systems. p. 25-33. In MidWest Plan Service Committee (Ed) Conservation tillage systems and management: Crop residue management with no-till, ridge-till, mulch-till. Iowa State University, Ames, IA.

Conservation tillage systems increase the amount of water stored in the soil profile. Surface residues reduce evaporation and increase water infiltration. The conservation of soil moisture can be very important in regions of reduced rainfall, on soils low in water-holding capacity, and in years with below-average rainfall.

Soil Bulk Density

Soils in conservation tillage systems generally have higher bulk densities than tilled soils. Bulk density is the weight of soil within a given volume. Soils with higher bulk densities usually have less pore space. This condition can lead to a decreased amount of root growth. In an intensively tilled system, higher bulk densities would result in decreased root growth. However, in conservation tillage systems, higher bulk densities do not necessarily result in reduced root growth. Soils in conservation tillage systems exhibit increased aggregation and higher numbers of root and worm channels than other tillage systems. These channels provide paths for root growth. If the channels are open to the soil surface, water infiltration increases. The differences in bulk density between conservation tillage systems and other tillage systems usually disappears at the end of the growing season, because tilled soils become more dense throughout the season from compaction by rainfall.

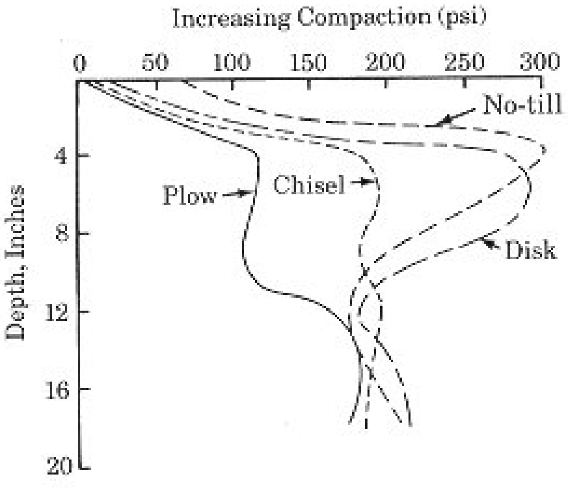


Figure 16.1 Soil compaction (measured by cone penetrometer) was higher for no-till than for other systems in an Illinois study. Data: Illinois, USA. Cited in PPI. Fertilizer mangement for today's tillage systems.

Organic Matter Accumulation

Long-term implementation of conservation tillage practices also increases organic matter levels in the soil. Lower soil temperatures and increased soil moisture contribute to slower rates of organic matter oxidation. Increases in organic matter are normally observed within the surface 10 cm of soil. Higher organic matter levels stabilize soil aggregates, which increases soil tilth. Such benefits do not persist, however, if plowing is occasionally implemented in the conservation tillage system.

Table 16.3: Percent Organic Matter in Various Tillage Systems

Depth (cm)	Moldboard Plow	No-till
0-10	4.1	4.8
10-20	4.1	4.2
20-30	3.7	3.8

Data: Indiana, USA, Chalmers silty clay loam soil after growing continuous maize for 7 years. Cited in: Griffith, D.R., J.F. Moncrief, D.J. Eckert, J.B. Swan, and D.D. Breitbach. 1992.Crop response to tillage systems. p. 25-33. In MidWest Plan Service Committee (Ed) Conservation tillage systems and management: Crop residue management with no-till, ridge-till, mulch-till. Iowa State University, Ames, IA.

Root Density

The distribution of roots in the soil profile is often dependent upon the tillage system implemented. Roots of plants growing in conservation tillage systems are more concentrated at shallower depths than plant roots grown in other tillage systems. This difference in distribution is attributable in part to the higher soil moisture levels near the surface in conservation tillage. Important also is that without soil mixing, nutrients become more concentrated near the soil surface. Such a nutrient distribution contributes to the concentration of roots nearer the soil surface.

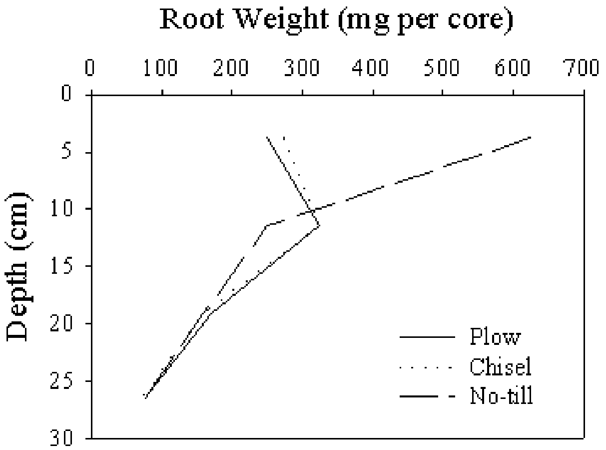


Figure 16.2 Data: Hoeft, R.G. and G.W. Randall. 1985. Tillage affects fertility: How to alter one when you change the other.

Summary

This discussion has demonstrated that tillage systems change many soil properties. Plant roots respond to these changes, shifting their root distributions to areas in the soil that are more conducive to growth. The shift in root distributions has a tremendous impact upon appropriate fertilizer placement. To understand how fertilizer applications should change under different tillage systems, it is first necessary to understand how tillage affects the distribution of fertilizer applied in different ways.

FERTILIZER APPLICATION METHODS

Broadcast

Figure 16.3 Broadcast application

Broadcast fertilizer applications apply nutrients to the soil surface. Proper practices result in fairly uniform fertilizer applications. Applications usually precede any tillage that is used. Both fluid and dry fertilizer may be broadcast. This application method usually provides the most uniform distribution of nutrients within a given soil volume. This method is suited particularly well to high rates of applied fertilizer.

Banding

Band applications of fertilizer concentrate nutrients within a specific soil volume. The goal of band applications is to limit the contact of the applied fertilizer with the soil. This application method is desirable when fertilizer reacts with soil to produce compounds that reduce its availability to the crop.

Surface

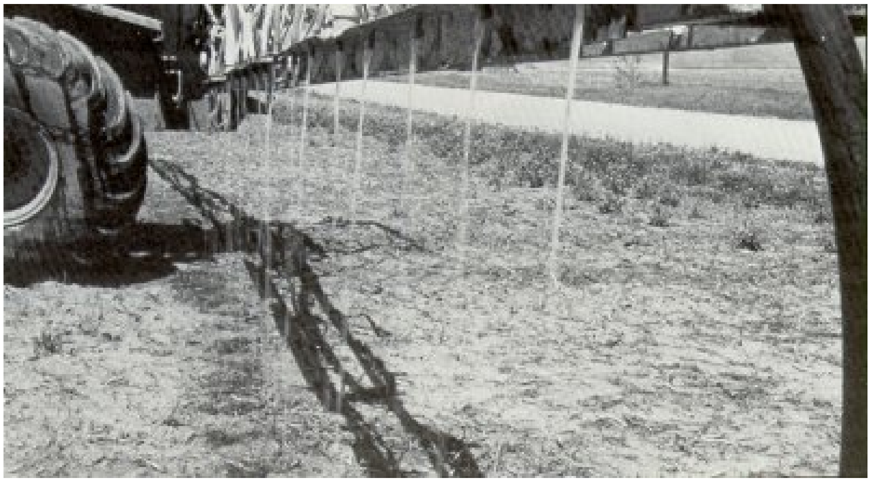


Figure 16.4 Surface Banding

Surface band applications concentrate solid or liquid forms of nutrients within a band at the soil surface. Band widths vary, but the strips normally cover from 25-30% of the soil surface.

Deep

Figure 16.5 Deep Banding

Deep banding concentrates solid or liquid fertilizer within rows below the soil surface. Depth of placement ranges from 5-38 cm. Nutrients are placed below the soil surface by implements such as knives, chisels, and cultivators.

High Pressure Injection

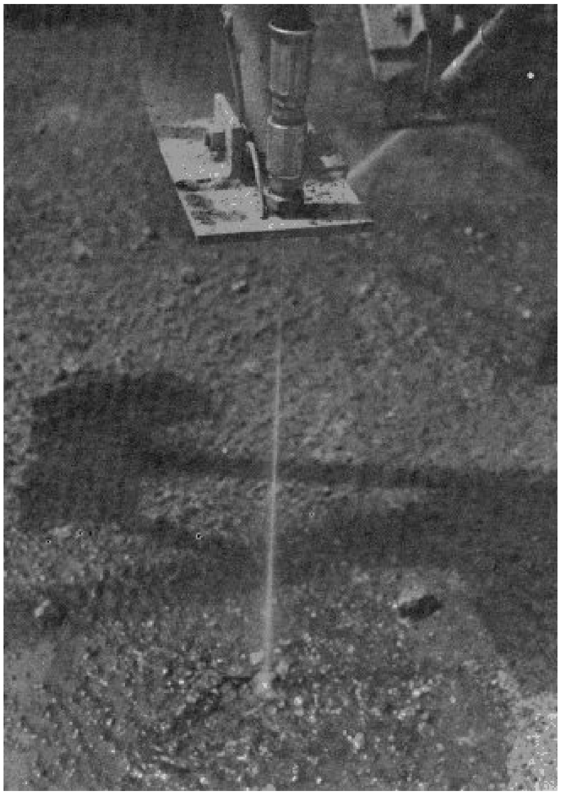


Figure 16.6 High Pressure Injection

This method uses pressures from 140-420 kg cm-2 to inject liquid fertilizer into the soil. Streams can be continuous or pulsed. Under this system, the zone of fertilizer concentration extends from the soil surface down to the depth of penetration.

Point Injector

Figure 16.7 Point Injector System

In this method, spokes from a central hub comprise a wheel that injects fertilizer at points 10-12 cm deep and spaced about 20 cm apart. A rotary valve in the wheel hub dispenses fertilizer only to the spokes that penetrate the soil. This application method provides minimal soil disturbance and has lower power requirements than many of the other banding options.

Starters

Starter fertilizer applications are bands of fertilizer applied at planting. The exact position of the bands varies. Fertilizer can be applied approximately 5 cm below and 5 beside the seed row, or simply to the side, below, or directly with the seed. Fertilizer applications applied in direct contact with the seed are frequently termed "pop-up." Seedling damage from salt effects reduces the application of "pop-up" fertilizer to low rates.

NITROGEN

Appropriate fertilizer nitrogen management seeks to maximize the quantity of plant-available nitrogen while minimizing its losses to the environment. Nitrogen may be lost in a number of ways. Some loss mechanisms have a greater chance of occurring in conservation tillage systems. Therefore, knowing the loss mechanisms and how to minimize their impact on applied nitrogen is critical for economic and environmentally responsible applications.

Minimizing Immobilization

Immobilization is a process in which inorganic nitrogen is converted to organic nitrogen forms. Immobilization occurs when plant and animal residues, low in nitrogen, are added to soils.

Microorganisms that decompose organic residues require nitrogen. If the residue to be decomposed has nitrogen concentrations between 1.5-1.7%, sufficient nitrogen usually exists to supply most of the nitrogen that the microorganisms need. However, if nitrogen concentrations in the residue drop below this range, microorganisms begin to use not only the nitrogen in the residue but also the inorganic nitrogen in the soil. This immobilizes the inorganic soil nitrogen into organic forms, reducing the amount of soil nitrogen that is readily plant-available. Besides nitrogen concentration, the ratio of carbon to nitrogen in the residue is also important for trying to predict when nitrogen may be immobilized. Generally, when the carbon to nitrogen (C/N) ratio is 30:1 or higher, some soil nitrogen will be immobilized. When the ratio is between 30:1 and 20:1, little if any nitrogen may be immobilized. Below a C/N ratio of 20:1, nitrogen is likely to be released from the decomposition of the residue. When this release occurs, nitrogen is converted from organic forms to plant-available inorganic forms in a process termed mineralization. These ranges of C/N ratios are given as very general guidelines. They will change according to soil moisture, temperature, quantity of residue present, residue composition, and the quantity of readily available nitrogen. To minimize loss of applied nitrogen through immobilization, it is recommended that nitrogen be applied below the residue-covered soil surface in conservation tillage systems.

Table 16.4: C/N Ratio of Organic Substances

Organic Substances	C/N Ratio
Sweet clover (young)	12:1
Bean stems	17:1
Clover residues	23:1
Corn stover	60:1

Data cited in Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil fertility and fertilizers. Macmillian Publishing Co., New York, NY.

Minimizing Denitrification

Fertilizer nitrogen in the nitrate form may be lost through a process termed denitrification. When denitrification occurs, nitrate is converted by anaerobic organisms, or denitrifiers, into gaseous forms of nitrogen. The nitrogen-containing gases can then escape from the soil into the atmosphere. This process occurs when the soil is warm and wet. The distribution within the soil profile of denitrifiers differs under different tillage systems. The table below shows the ratio of denitrifiers in no-till compared to conventional-till.

Table 16.5: Ratio of Denitrifiers in Various Tillage Systems

Soil Depth (cm)	Ratio of denitrifiers (no-till vs. conventional-till)
0-7.5	7.31 to 1
7.5-15	1.77 to 1
Total (0-15)	2.83 to 1

Data: Nebraska data cited in Hoeft, R.G. and G.W. Randall. Tillage affects fertility: How to change one when you change the other.

The higher population of denitrifiers in conservation-till creates an increased probability of nitrogen loss. When fertilizers containing the ammonium form of nitrogen are applied, adding a nitrification inhibitor has been shown to slow the conversion of ammonium to nitrate. Slowing this process results in lower soil nitrate levels, which reduces the probability of nitrogen loss from denitrification. An additional management practice that can help reduce nitrogen losses is to inject nitrogen 10 cm deep or deeper. This places nitrogen below the zone of highest denitrifier populations.

Minimizing Volatilization

Urea-containing fertilizers may be lost through a process called volatilization. In this pathway, urea is broken down by the enzyme urease. Urease converts urea to ammonium. During this process, ammonium begins to convert to ammonia gas. If this reaction takes place at the soil surface, ammonia will be lost to the atmosphere. However, if this reaction occurs below the soil surface, the ammonia produced will react with soil water and convert to ammonium. Once in the ammonium form, nitrogen can be held by the soil until it converts to nitrate.

Tillage systems influence the placement of urea-containing fertilizers because of their effect upon the quantity of residue cover. Surface applications of urea may be more subject to loss in conservation tillage systems. Urea, when surface-applied, will have less contact with the soil and more contact with surface residues that contain urease. The increased contact with urease can translate to increased losses. Therefore, to minimize losses, urea must be incorporated below the soil surface. This may be accomplished by injecting it below the surface or by broadcasting it and then incorporating it with tillage operations. Because urea is soluble in water, rainfall will also solubilize urea and move it below the soil surface. Rainfall events of a quarter to a half an inch are usually sufficient for moving urea below the soil surface. If rainfall will be used as the method of incorporation, urea should be broadcast no more than two days before an appropriate rainfall event.

LIME

Repeated surface applications of nitrogen in conservation-till systems can lead to pH stratification. As ammonium and urea forms of nitrogen convert to nitrate, acidity is produced. With reduced tillage, this acidity may become concentrated in the upper 5-8 cm of the soil profile. If the soil is

sampled to 15 cm, surface acidity may not be detected. For this reason, the upper half of soil samples taken to 15 cm should be separated from the lower half. The upper half (down to 5-8 cm) should be analyzed separately and compared to the lower half to monitor the degree of soil pH stratification.

Most lime recommendations assume that lime will be thoroughly mixed down to approximately 15-20 cm. However, in conservation-till systems, lime may be left unincorporated or tilled to only a shallow depth. If the recommended rate of lime is used in such systems, lime may be over-applied. If the pH becomes too basic at the surface, phosphate and other nutrients can become less available to plants. In addition, some adverse pesticide interactions may occur. The key to appropriate lime applications is to match the rate of lime with the volume of soil with which lime will react. Generally, in conservation tillage systems, lime will react with only half of the soil volume of that in conventional-till systems. Consequently, lime recommendations should be reduced by approximately one half. If deeper or shallower incorporation is used, lime rates will need to be increased or decreased, respectively. With reduced lime applications, more frequent soil testing and lime applications may be necessary.

PHOSPHORUS AND POTASSIUM

Nutrient Distribution and Tillage

Fertilizer distribution is extremely important for plant availability. Plant roots can take up nutrients by three pathways. First, as they explore the soil volume, roots may directly contact a nutrient supply. This is known as root interception. Second, as plant roots take up water, nutrients dissolved in the water will be transported to the surface of the root where they can be taken up. This uptake mechanism is termed mass flow. Third, as a plant root takes up nutrients, it depletes nutrient levels in the soil volume in which it is growing. Nutrients will move into this depleted soil volume from adjacent areas where nutrient concentrations are not depleted. This process is called diffusion. The table below shows the importance of each pathway in nutrient uptake.

Table 16.6: Amount of Nutrients Supplied by the Three Pathways

Nutrient	Amount needed for 9500 kg maize grain ha-1	Approximate amount supplied by		
		Root interception	Mass flow	Diffusion
Nitrogen	190	2	150	38
Phosphorus	40	1	2	37
Potassium	195	4	35	156
Calcium	40	60	150	0
Magnesium	45	15	100	0
Sulfur	22	1	65	0

Data: Barber, S.A. 1984. Soil nutrient bio-availability: A mechanistic approach. John Wiley and Sons, Inc., New York, NY.

This table shows that diffusion is an important mechanism for plant uptake of phosphate and potassium. For diffusion to take place, the plant root must get fairly close to the zone of fertilizer application. Neither phosphate nor potassium moves very far in soils. For instance, in a silt loam soil, phosphate may diffuse over distances less than 0.3 cm while potassium may move less than 0.8 cm. Knowledge of root and fertilizer distributions under various tillage systems is critical for understanding how tillage and fertilizer applications should be combined to ensure that nutrients are available during the entire growing season.

In conservation tillage systems, reduced tillage leads to nutrient distributions that differ from those in other tillage systems. Where tillage is reduced, less mixing of the soil leads to soil distributions of phosphorus and potassium that reflect the method in which they are applied. Broadcast applications tend to concentrate phosphate and potassium near the soil surface. An example of this is shown on the next page.

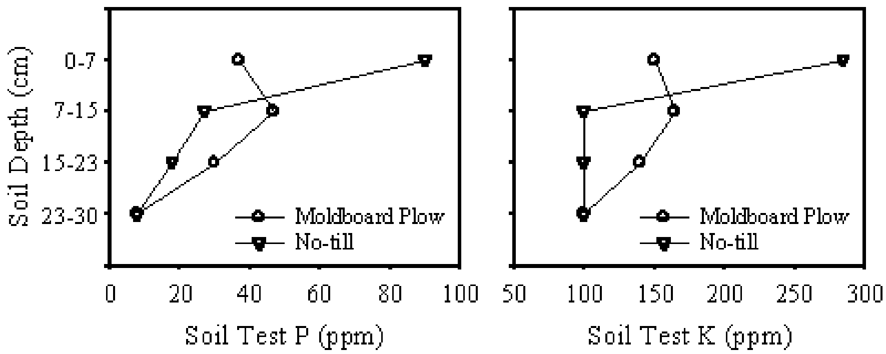


Figure 16.8 Broadcast applications tend to concentrate phosphate and potassium near the soil surface. Cruz, 1982. Cited in: Mengel, D.B., J.F. Moncrief, and E.E. Schulte. 1992. Fertilizer management. p. 83-87. In MidWest Plan Service Committee (Ed) Conservation tillage systems and management: Crop residue management with no-till, ridge-till, mulch-till. Iowa State University, Ames, IA.

Band applications have produced zones of higher fertilizer concentrations that can persist for several years. The shape of these regions depends upon the type of tillage system, depth of fertilizer placement, rate of fertilizer applied, and the ability of the soil to adsorb phosphate. The graph below shows soil-phosphate concentrations (mg kg-1) around a sub-surface band applied midway between 76 cm rows. In this example, large differences in phosphate distribution exist between chisel and ridge-till systems. Chisel tillage disturbed the phosphate band only slightly, while ridge-till exhibited a much more diffuse distribution of phosphate.

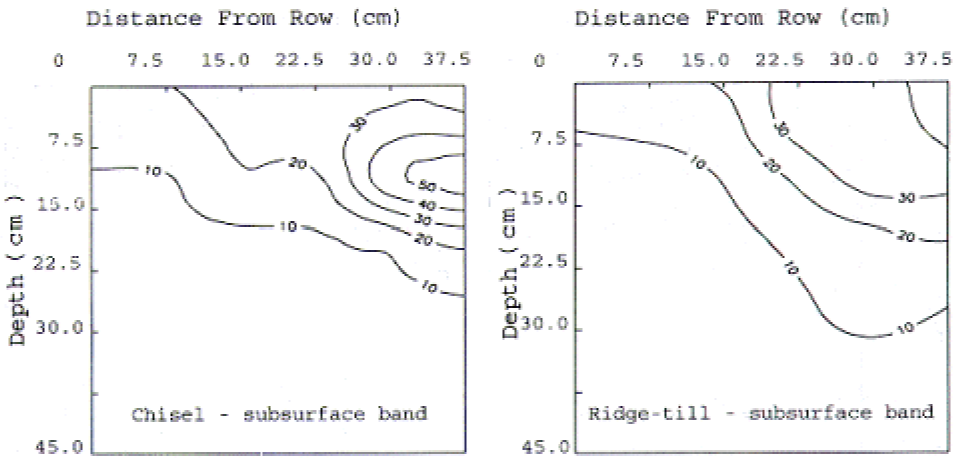
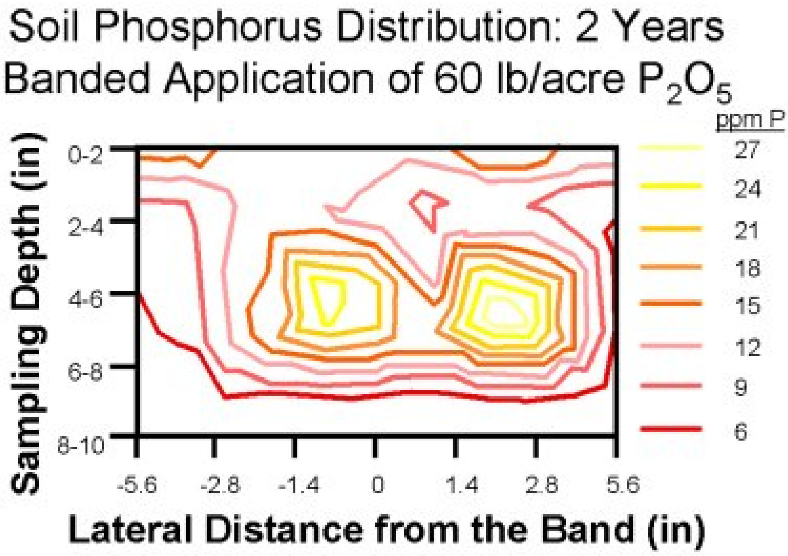


Figure 16.9 Soil phosphate concentrations around a sub-surface band applied midway between 76cm rows. Rehm, G.W., G.W. Randall, A.J. Scobbie, and J.A. Vetsch. 1995. Impact of fertilizer placement and tillage system on phosphorus distribution in soil. Soil Sci. Soc. Am. J. 59:1661-1665.

Increasing the rate of applied fertilizer in the band increases the volume of soil the band occupies. The extent of this increase in volume depends upon the phosphate fixation capacity of the soil. Soils that fix more phosphate lower the volume of soil the fertilizer occupies. If left undisturbed, residual fertilizer bands can remain intact for several years. Repeated band applications in the same row often increase the volume of soil fertilized. This happens because it is difficult to apply fertilizer precisely into previous bands. New bands created next to old bands spread out the distribution of nutrients. The figure below shows how phosphate is distributed after two band applications.



Zerkoune et al., Nebraska

Figure 16.10 How phosphate is distributed after two band applications.

Placement

To attain maximum yields, fertilizer should be placed where plant roots are likely to find it. The application method that produces higher yields depends upon many factors, some of which are crop

type, soil properties, and fertility levels. A review of research has shown that broadcasting and banding produce different results under different situations.

Broadcast applications and banded applications equally effective

This is more likely to happen when fertility levels are fairly uniform and high throughout the rooting zone. Uniform fertility levels in the upper 6-8 inches is achieved only when applied fertilizer is mixed well with the soil, as in conventional tillage systems. In this case, there is a good chance that the fertilizer will be placed in moist soil. In drier parts of the season, as the roots explore deeper portions of the soil profile in search of water, roots will still be able to encounter applied fertilizer. The temperature of the growing season is also important. Warm season crops such as sunflowers, soybeans, and sorghum are more likely to respond equally well to broadcast and banded fertilizer applications.

Band applications more efficient than broadcast applications

This is the case that most agronomists expect and is the basis of recommendations that reduce application rates for banding. This relationship is most likely when soils are cool and wet, fertility levels are low, and soils fix a large quantity of applied fertilizer. Fixation is defined here as transforming applied fertilizer from plant-available compounds to compounds not readily plant-available. For example, soils that fix phosphorus typically have higher levels of aluminum and iron oxides or higher levels of free calcium carbonate. In soils that fix applied fertilizer, banding reduces the amount of soil that the fertilizer contacts. This results in more of the fertilizer remaining plant-available in the season of application.

Band applications more effective than broadcast applications

This may be observed in cool, wet soils when banded fertilizer stimulates early growth and the early growth is critical for attaining maximum yields. This relationship may also be observed with relatively low soil test levels, minimal incorporation of broadcast fertilizer, and dry soil surface conditions. In this latter case, dry periods in the season cause roots to explore deeper portions of the soil profile. When roots explore soil that is deeper than the nutrient-enriched surface layer, the growing crop can become undernourished. In such cases, deep banding places fertilizer in the portion of the soil that the roots explore. Low soil test levels may not always be necessary to see this response. For instance, data from Minnesota and Iowa have shown maize yield increases from banded potassium in ridge-till and no-till systems, respectively, even at high soil test levels of potassium.

Broadcast applications are more efficient than band applications

This is likely to occur on soils that do not fix much of the applied fertilizer, have heavy residue cover, and are warm and moist. Examples of this are no-till systems in humid regions and under irrigation. In these cases, roots proliferate near the soil surface, where broadcast fertilizer is most concentrated. Fertilizer banded deeper below the surface may not contact the roots as much as the broadcast fertilizer.

Links to other sections of the EFFICIENT FERTILIZER USE MANUAL
History • MEY • Soil • pH • Nitrogen • Phosphorus • Potassium • Secondary • Micronutrients • Fluid-Dry • Sampling • Testing • Site-Specific • Tillage • Environment • Appendices • Authors