



# Nutrient Management in Conservation Tillage Systems

To understand soil fertility and nutrient management in conservation tillage systems, we need to recognize the unique conditions in these systems that influence nutrient behavior and management. One of the most important functions of conservation tillage systems is the maintenance of crop residues on the soil surface to protect the soil from erosion. To achieve proper residue maintenance, there must be limited soil mixing. If crop residues are not incorporated or mixed with the soil, then fertilizer, manure, and limestone also will not be mixed with the soil. Lack of incorporation can have a major impact on the behavior and management of nutrients. Producers traditionally have depended on tillage to mix immobile nutrients such as phosphorus with the soil, thus moving them into the primary rooting zone of crops. With conservation tillage systems this movement does not occur. For nitrogen sources that contain urea, lack of incorporation can result in substantial nitrogen losses from volatilization. Potassium dynamics, on the other hand, are largely unaffected by variation in tillage systems.

One of the main objectives of conservation tillage systems is to maintain crop residue on the soil, which ensures that organic matter accumulates near the soil surface. The accumulation of organic matter increases soil microbial activity by providing the microbes with a source of energy in the form of carbon compounds. However, microbial activity tends to be slower in conservation tillage systems than it is when the organic material is incorporated into the soil by conventional tillage. The surface mulch in conservation tillage systems tends to remain in larger particle sizes that take longer for microbes to break down. Also,

surface mulch reduces the soil temperature, which slows microbial activity. Nitrogen behavior, in particular, is determined largely by microbial activity. Thus, the accumulation of organic matter will have an important effect on nitrogen dynamics and how N must be managed in conservation tillage systems.

Water infiltration, runoff, and erosion are among the main reasons for adopting conservation tillage systems. Generally, conservation tillage increases water infiltration, thereby increasing the moisture level in the soil. Increased moisture levels influence crop growth, drought tolerance, and microbial behavior. An example of this effect is nitrogen lost through microbial denitrification in wet soil conditions. Increased infiltration also can increase leaching of mobile nutrients in the soil, which is an important environmental concern with nitrate-nitrogen. Phosphorous, on the other hand, is largely lost when soil erodes, so the reduced erosion in conservation tillage systems can reduce phosphorus losses.

Changes in soil temperature and moisture that influence microbial activity also will affect plants' rooting patterns, usually resulting in higher concentrations of roots near the soil surface than in conventional tillage systems. Nutrient dynamics in conservation tillage systems often reinforce this tendency.

Nutrients usually are stratified in conservation tillage systems because of the lack of substantial mechanical soil mixing. Nutrient levels tend to be higher near the soil surface where the nutrients are applied and where crop residues decay. Thus, roots will not detect a uniform level of nutrients all through the primary rooting zone and may concentrate near the soil surface to find mois-

ture and nutrients. Soil pH often is stratified in conservation tillage systems because of the surface application of limestone and acid-forming nitrogen fertilizers and manures. This stratification can further influence rooting patterns, the availability of nutrients, and the effectiveness of herbicides.

Conservation tillage systems often increase surface residue and limit incorporation and mixing of organic matter and nutrients, resulting in reduced soil erosion, accumulation of organic matter near the soil surface, lower soil temperatures, increased water infiltration, decreased water runoff, higher soil moisture, stratification of nutrients and soil pH, and changes in the rooting pattern of crops. In the following sections, the effects of these unique conditions will be discussed specifically for soil acidity, N, P, K, and manure management in conservation tillage systems.

## SOIL ACIDITY

Soil acidity is caused by hydrogen ( $H^+$ ) and aluminum ( $Al^{+++}$ ) ions in the soil solution. The activity of this acidity is expressed by the familiar measurement of "soil pH" in soil tests. A pH measurement of 7 is neutral, pH less than 7 is acid, and pH greater than 7 is basic. Most soils in Pennsylvania are acidic with pH between 5 and 7. The optimum pH range for agronomic crop production is 6 to 7.

Soil pH is critical for many reasons. It has a major influence on the availability of elements, including essential nutrients like nitrogen, phosphorus, and potassium, as well as secondary nutrients, micronutrients, and potentially toxic elements like aluminum. One of the main reasons for managing soil pH by

liming is to reduce the toxic effects of aluminum on plant roots. At low pH, high aluminum availability can severely restrict root growth and thus uptake of water and nutrients. Most soil microbes are sensitive to soil pH, which has an influence on nutrient availability (especially nitrogen), soil organic matter, and general soil health. Also, many pesticides are sensitive to soil pH. Extremes in soil pH can reduce the efficacy or increase the activity of pesticides, which can result in crop injury.

Several factors can cause soil acidity, including decay of crop residues, acid precipitation, leaching of basic ions (leaving behind the more tightly bound aluminum), and the acidifying effect of ammonium sources of nitrogen. Ammonium nitrogen usually is the largest single source of acidity in farmed soils. Any source of ammonium nitrogen will increase soil acidity. For example, the most commonly used N fertilizer materials, including manure N, urea, urea-ammonium nitrate solution (UAN), ammonium nitrate, anhydrous ammonia, and ammonium sulfate, all will increase soil acidity. About 3 pounds of pure calcium carbonate limestone are required per acre to neutralize the acidity from 1 pound of N from any of these nitrogen sources except ammonium sulfate, which will require 6 pounds of limestone per acre for each pound of N. Thus, balancing the acidity created by an application of 150 pounds per acre of urea N to corn would require 450 pounds per acre of limestone.

Soil acidity is managed in agricultural soils by applying liming materials, primarily ground limestone. The carbonates in these materials react to neutralize the acidity in the soil. The quality of a liming material is determined by its neutralizing ability and how finely it is ground. The neutralizing ability, or the amount of soil acidity the material will neutralize, is given as the calcium carbonate equivalent (CCE) of the material. This equivalent is simply a comparison between any liming material and pure calcium carbonate as a stan-

dard. Because most soil test recommendations are based on 100 percent CCE, actual application rates must be adjusted for the CCE of the liming material being used. The fineness of a liming material determines how fast it will react. The finer a material is ground, the faster it will react to neutralize the soil acidity. Standards are set by state law for limestone fineness. If a material meets the minimum standards for “finely ground” limestone, it will react rapidly enough to be adequate for most agricultural liming purposes.

A major characteristic of conservation tillage systems is the layering of the effect of soil acidity primarily due to surface application of nitrogen fertilizer or manure. Since there is little vertical mixing of the nitrogen in conservation tillage systems, the acidity formed when these materials react with the soil will stay near the soil surface, resulting in a lower soil pH near the surface. Table 1 shows the effect of surface acidification when no-till corn was fertilized with liquid nitrogen for several years. This effect is called the “acid roof” in reduced tillage systems.

Table 1. Acid roof in no-till corn.

Sampling depth	Soil pH
0 – 6"	6.2
0 – 1"	5.8

Greater acidity in the surface of no-till soils can have a major impact on weed control. The triazine herbicides are very sensitive to soil pH. Their effectiveness is greatly decreased when the pH drops below 6.2. Also, these herbicides work primarily in the surface layer of soil. If the pH in this surface layer is below 6.2, serious weed problems can develop. Another concern with low soil pH near the surface is that in conservation tillage systems with good amounts of residue on the surface, more of the roots of the crop are concentrated near the soil surface. Thus, if the surface layer

is acidic, aluminum toxicity can occur. This toxicity can limit root growth and thus the ability of the crop to get nutrients and water. Also, at lower pH, the availability of some nutrients may be lower than at optimum pH. Finally, beneficial activity of the soil organic component in these systems may be reduced due to inhibition of microbial activity concentrated near the surface.

In the data shown above, a normal rooting-depth soil sample would indicate that the pH is adequate for good weed control. In reality, the surface soil where the herbicide is trying to work has a pH well below 6.2. Therefore, producers should periodically check the surface pH in reduced tillage systems. If the surface pH is below 6.2, limestone should be applied regardless of the pH indicated in the normal depth sample. Surface soil pH can easily be checked with a reliable field pH test kit. Simple colorimetric pH kits normally are the most satisfactory for this purpose, but a separate sample from the surface soil could be submitted to the soil testing lab for analysis. In either case, a normal rooting-depth sample should also be submitted to determine the limestone and fertilizer recommendation for the crop.

A pH layering effect also may result from limestone applications, as illustrated in the following table. Limestone was applied at 2 tons per acre the previous year.

Table 2. Layering of soil pH due to surface lime application in no-till corn.

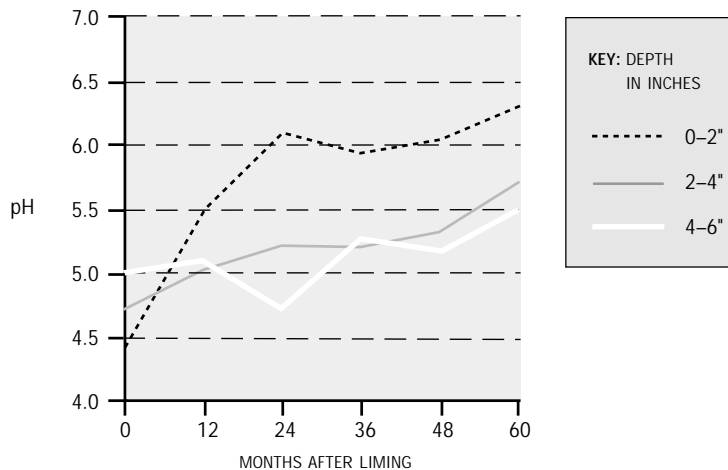
Depth	Soil pH	
	Conventional till	No-till
0 – 1"	6.8	6.6
1 – 2"	6.8	6.4
2 – 4"	7.0	6.3
4 – 6"	6.8	6.5

In conventional tillage systems, the effects of liming are uniformly distributed throughout the plow layer. However, in a no-till system, the beneficial effect of the limestone is greatest near the surface and decreases with increasing depth. Because reduced tillage systems mix little or no limestone into the soil and a chisel plow or disk only mixes to about one-third of the actual tillage depth, a pattern similar to no-till is found. This physical layering effect also is chemically reinforced because limestone moves very little in the soil, which is the reason for the standard recommendation to thoroughly mix limestone with the soil. If soil pH is adequate to begin with, limestone movement will be rapid enough for surface applications of limestone to effectively maintain the soil pH in the rooting zone. However, if the initial soil pH is very low, building the soil pH of the entire rooting zone up to an adequate level can be a very slow process in a conservation tillage system. Research with liming an acid no-till soil has shown that four or five years may be required before the effect of a surface application of limestone becomes apparent below the top 2 inches of soil (Figure 1).

Producers considering reduced tillage should build the pH and all nutrient levels up to the optimum range before eliminating tillage. When it is not possible to mix the limestone before going into a conservation tillage system, applications should be made to allow maximum time for natural mixing. Therefore, as with conventional tillage systems, fall is the best time to lime. Also, producers should be aware of soil moisture conditions when applying lime to no-till fields because there is no opportunity to correct compaction problems or level ruts created by driving a lime spreader on wet soil.

Because of the unique conditions in conservation tillage, soils should be tested for pH at the surface and to plow depth and limed accordingly. For optimum nutrient availability, root growth, and herbicide activity, the soil pH throughout the plow layer should be

Figure 1. pH change over time and depth after application of 6,000 pounds of limestone per acre in 1985.



close to 6.5 and at least above 6.0. Optimum pH levels should be established by mixing recommended amounts of high-quality limestone throughout the plow layer before starting a conservation tillage system. Regular liming based on soil testing should maintain an already established optimum soil pH at an adequate level once a conservation tillage system has been implemented.

### NITROGEN

Nitrogen makes up almost 80 percent of air, but this N is accessible to plants only after it has been extracted from the air and converted to liquid or solid form. Nitrogen can be converted industrially, as in the creation of commercial N fertilizers, or it can be converted by certain soil bacteria in association with the roots of legumes.

Only 2 percent of the N present in the soil is in the mineral forms of N, ammonium, and nitrate, which are readily available to plants. Commercial fertilizers provide additional N in various mineral forms that are available for quick uptake by plants. The other 98 percent of the N present in soil is bound up in organic matter. Soil organic N, because of its chemical composition, is very resistant to change and is unavailable for uptake by plants. Organic forms of N become available for plant uptake only when converted to mineral ammonium-N ( $\text{NH}_4^+$ ) by soil microbes in a

process called mineralization. A subsequent microbial activity called nitrification converts the ammonium-N to nitrate-N ( $\text{NO}_3^-$ ), which is the main form of N used by plants. Regardless of the source of soil ammonium, a by-product of the soil nitrification reactions that convert ammonium to nitrate is increased soil acidity. In fact, this reaction is the major source of acidity in agricultural soils. Effects of the reaction on soil pH and the creation of an acid roof was discussed earlier under the section on soil acidity.

In the soil, mineral N is vulnerable to a complex variety of processes brought about by the interactive effects of weather and soil microbes. Some of these processes may cause the loss of available N. Therefore, the quantity of mineral N in soil and the changes in its availability to plants generally are unpredictable. Potential routes of N loss are described below.

### Immobilization

Available N may be used by soil bacteria when there is abundant high-carbon, low-N organic matter, such as corn stover. The bacteria breaking down carbon materials need additional N for their protein and therefore tie up all the available N. This process, which is most likely to occur in no-till corn production where N fertilizer is surface applied and corn stover is left from previous seasons,

temporarily prevents N availability to plants or its loss by other means. Since immobilization is temporary, there is no difference in the optimum N rate among different tillage or no-tillage methods of production.

### Denitrification

Soil may become water saturated because of poor drainage, excessive rainfall, or a field depression where water tends to stand. As water fills the spaces between soil particles, air is pushed out. Because aerobic bacteria need oxygen and lack air in saturated soil, they will take the oxygen from nitrate ( $\text{NO}_3$ ). As a result, the nitrate is converted into various gaseous forms, such as nitrous oxide ( $\text{N}_2\text{O}$ ), elemental nitrogen ( $\text{N}_2$ ), and nitric oxide ( $\text{NO}$ ). These forms are unavailable to plants and easily lost by volatilization into the atmosphere. The extent of N loss by denitrification is difficult to estimate, but significant losses can occur in less than a week of saturated conditions. Two conditions necessary for denitrification are saturated soil conditions and a source of energy for the microbes in the form of organic matter. Both of these conditions are enhanced in reduced tillage systems, where there is usually a higher concentration of organic matter and higher soil water content. Thus, denitrification is potentially greater in reduced tillage systems.

### Leaching

Rain water, in excess of what can be held by well-drained soils, leaches down through the soil profile and carries nitrate with it. Nitrate leaches easily because it is very water soluble and is negatively charged, so it is not held by the negatively charged soil particles. Because ammonium has a positive charge, it is held by these soil particles, keeping it from being leached. The potential loss of N by leaching is greatest in wet winter and spring months in well-drained soils. In conservation tillage systems, runoff usually is reduced and consequently infiltration is increased. Thus, because more water enters the soil in reduced tillage systems, there is

potential for increased leaching. However, in no-till soils, there often is an increase in large pore spaces because they are not broken up by annual tillage. These large, continuous pores may help this additional water drain through the soil without interacting with most of the soil chemistry described above, thus bypassing the nitrate. In this situation, pores that increase water infiltration may not increase nitrate leaching unless there is a heavy rain immediately after fertilizer application, in which case the nitrogen may be washed directly down through large pores in no-till soils. Nitrogen that is leached is lost to the plants and can contribute to groundwater contamination.

### Volatilization

In addition to being lost to the atmosphere through microbial denitrification, N also is lost as a result of other types of chemical reactions in the soil. The urea form of N, found in urea-containing fertilizers and in animal manure, chemically converts to gaseous ammonia,  $\text{NH}_3$ . A significant amount of the N left at the soil surface may be lost to the atmosphere in this way. If the urea is incorporated, however, this loss is eliminated because the ammonia gas in the soil is further converted to ammonium N and is absorbed by the soil particles. Urea-containing materials can be incorporated into the soil through some form of tillage or by rainfall. Table 3 lists estimates of ammonia volatilization and loss that can occur if incorporation is dependent on rainfall, as would be the case in a no-till system.

**Table 3. Urea-N loss by volatilization versus time until incorporation by rainfall.**

Rainfall (in)	Days after application	N loss (%)
1/2	2	0
1/2	3	<10
1/4	5	10–30
0	6	>30

SOURCE: Adapted from R.H. Fox and L.D. Hoffman, *Agron. J.* 73:891-895.

The dynamic behavior of N has several important management implications in conservation tillage systems. Probably the biggest concern is volatilization losses from urea-containing materials applied to no-till fields. As the data in Table 3 indicate, these losses can be very large. There are several ways to deal with this problem. Other forms of fertilizer N can be used, such as ammonium nitrate and ammonium sulfate, which do not volatilize. However, these sources are usually more expensive and are not always available. Use of minimum tillage systems can retain most of the soil conservation properties of no-till while allowing adequate mixing of the fertilizer with the soil to reduce volatilization losses. The best way to deal with volatilization in strictly no-till systems is to time the applications of urea-containing materials so that they are followed by 0.5 inch of soaking rain. Volatilization can also be reduced by banding rather than broadcasting urea sources. Banding liquid UAN is a common practice in no-till for reducing N loss. A compromise system might include injection of the urea-containing material. Many injectors cause little disturbance to the soil surface and leave all of the important residue on the surface while incorporating the nitrogen to the point that it will reduce volatilization losses. Injecting the nitrogen below the surface residue also can reduce any immobilization of the applied nitrogen due to the higher organic-matter levels near the surface in conservation tillage systems. Immobilization usually is not a serious concern because it only temporarily ties up the N. However, in cases where nitrogen is marginal, immobilization can result in early season N deficiency.

The use of conservation tillage can potentially increase N losses by denitrification because of the higher organic-matter levels and generally higher soil water content used in these systems. Also, because of the greater water infiltration and percolation in conservation tillage systems, there is a greater potential for leaching losses. Very little can be done to directly stop either of

these processes. However, producers can reduce the potential for their occurrence by waiting to apply N until the crop is ready to take it up, thereby reducing the amount of time the N sits in the soil and is vulnerable to loss. For example, in corn production the conditions for denitrification and leaching are greatest in the early spring, but corn uptake of N is minimal until approximately 35 days after emergence. Delaying the application of most of the N (50 to 90 percent) until the corn is 10 to 20 inches tall will allow producers to avoid the early spring wet period when the losses are greatest and still be in time to meet the major needs of the crop. It also is recommended that producers apply N to winter grains in the spring just before the rapid growth period of the crop. Wet weather in the fall can contribute to N losses, especially in wetter reduced-tillage soils. The best way to minimize these losses is to carefully manage the rate of N application so that there is little extra N in the soil at the end of the growing season, when crop uptake has ceased. If the application rates were correct and soil N levels are low in the fall, there will not be much N left for the fall rains to leach away.

Colder soil temperatures in conservation tillage systems resulting from high-residue cover also can affect N management. This effect is especially apparent when producers are working with organic sources of N like manure and legumes. Colder soil temperatures generally will slow the mineralization of the organic N, thus slowing the production of N forms available to the crop. This process often is observed when corn is planted into a legume sod. Corn planted no-till into the sod usually will not be as dark green in the early part of the season as corn planted into a field where the sod has been tilled prior to corn planting. In most cases, this early season effect will not result in a yield difference regardless of the tillage system used. Extended cold periods during the growing season could result in a yield reduction in the reduced tillage system, but such reductions are very rare.

Fertilizer N placement may be more critical in no-till than in conventional tillage systems. Normally, if N is placed where the roots can get at it, the overall placement is not very important. For example, corn can utilize N from a band placed in the middle between two rows. Because the roots are concentrated closer to the soil surface in reduced tillage fields, a surface band of N may be more available to roots than a band placed in a conventionally tilled field. However, there is a greater chance of mid-row compaction in no-tilled fields because no tillage is used to break up tire tracks. If mid-row compaction does occur, root growth may be limited in the middle of the row. Consequently, N fertilizer placed in the middle of a compacted row may not be available to the crop.

#### PHOSPHORUS

The behavior of soil phosphorus (P) is characterized by the chemical's lack of mobility in the soil. Unlike N, which can be lost in a variety of ways, P usually is lost only by runoff or erosion. Although soil contains very little soluble phosphate ( $\text{PO}_4$ ) at any time, a large amount of phosphorus is always present. Some of this phosphorus is part of the soil organic matter. Organic-P availability is seasonal because microbial activity in warm, moist soil is required to break down the organic material. Most of the phosphorus in soil is inorganic. Instead of dissolving in the soil solution, most of it binds with varying degrees of adhesiveness to iron and aluminum compounds in the soil. Replenishment of the soil solution with phosphate comes from those compounds whose hold on phosphate is weakest. Soluble phosphorus in the soil solution must be replenished over 500 times during a growing season to meet the nutritional needs of the crop.

The greatest amount of phosphorus is available to plants at a pH range of 6.5 to 7.0. At a lower pH, when the soil is very acidic, more iron and aluminum are available to form insoluble phosphate compounds; therefore, less phosphate is available. Even when the soil pH is well within the optimum range, fertilizer

phosphorus can be so strongly tied up by the soil that it cannot be used to replenish the soil solution and is unavailable to the crop. The ability to fix phosphorus into unavailable forms varies among soils and is related to the amounts of iron, aluminum, and some clay types. Forms of phosphorus do not act independently in soil; rather there is an equilibrium between forms. When soluble phosphorus is added to the soil, the equilibrium is disturbed. Soil solution phosphorus levels are high initially, but within a day or two, most of the added phosphorus reacts with aluminum, iron, and clay surfaces. During a period of several weeks or longer, a gradual conversion to less soluble forms takes place. When phosphorus is removed from the soil solution by crop uptake, some of the less soluble forms of phosphorus dissolve, thus replenishing the soil solution P.

Because of phosphorus immobility and soil fixation, placement of fertilizer phosphorus can affect its availability to plants. Fertilizer that is broadcast and plowed down is mixed uniformly with a large amount of soil. Thus, the probability of root contact with the fertilizer is maximized. However, fertilizer also is absorbed by the soil surfaces that it comes into contact with and is fixed in less-available forms. When the fertilizer is applied as a concentrated band, contact with the soil, and thus fixation, is minimized. However, lack of phosphorus movement from point of placement means that the number of roots in contact with the fertilizer also may be minimized. The greater the ability of the soil to fix phosphorus, the greater the importance in overriding that fixation capacity with a concentrated band. Crop response to fertilizer phosphorus placement is further complicated by crop root characteristics, soil phosphorus levels, and soil temperature. Placement limitations imposed by no-till often result in an accumulation of nutrients near the soil surface. When proper residue management is practiced, corn root distribution appears to respond to differences in soil moisture and nutrient

location in no-till culture with greater root density near the surface. Therefore, nutrient uptake of surface-applied fertilizer usually equals or exceeds uptake under conventional-tillage management.

Whether producers should band or broadcast phosphorus depends mostly on the soil phosphorus status. On soils with optimum to high levels of phosphorus, banding is less advantageous, and broadcast applications are generally adequate and sometimes superior to banding. Row crops in general, particularly corn, appear to have greater yields when soils contain relatively high levels of phosphorus throughout the rooting profile. In lower-testing soils, research has indicated that a combination of band and broadcast phosphorus applications produces much greater yields than applications using one method alone. The advantage of building up the general soil level of phosphorus probably is due to the need of all roots to take up some phosphorus. In comparison, small grains have limited rooting systems that reduce their capacity to explore soil. In addition, they are short-season crops that often are grown in cooler temperatures. Therefore, phosphorus placement is more critical for small grains than for row crops and perennials. Greater yield response to banded-P is common, especially on low phosphorus soils or soils with a greater ability to fix phosphorus. Recommendations for incorporated broadcast phosphorus for small grains frequently have been twice as high as for banded phosphorus, because higher soil phosphorus levels compensate for the crop's reduced phosphorus uptake ability. Where soils are built up to optimum or high phosphorus levels, however, banded or broadcast-P can be equally effective. For successful no-till, it is very important to build the soil up to the optimum range throughout the plow layer before tillage is discontinued. If the soil starts out with an optimum P level, it is possible to maintain this level with broadcast and starter applications of P.

Starter fertilizer is a specific band application at a specific time. Even if

you are planning to broadcast the majority of the required phosphorus, a banded starter application is important for spring-planted crops, particularly corn. In conservation tillage fields in particular, limited root growth in combination with cold and wet soils early in the season can reduce the availability of phosphorus and plants' uptake ability. Early plant vigor and final yield often are improved by starter-P applied close to seedling roots, even when soil phosphorus levels are high or when manure has been applied. Phosphate applied in combination with ammonium-N results in greater phosphorus uptake. Phosphorus itself has a low-salt effect and may be placed close to the seed. However, if P is applied with nitrogen and potassium and placed 2 inches from the seed, the rate should be limited so as to supply no more than 70 pounds total of N plus  $K_2O$ . High water solubility of the starter phosphorus source is important. Ammonium phosphates meet that criteria and supply some N as well. However, diammonium phosphate (DAP) reacts with soil water to produce ammonia that is potentially toxic to seedling roots. Therefore, the rate of DAP used as a starter source of N and P should be kept low, and DAP should be placed at least 2 inches from the seed.

Because most P is lost through runoff and erosion, conservation tillage practices that reduce both runoff and erosion are important for reducing P loss and potential pollution. Recent research on conservation tillage has indicated that there is an unfortunate tradeoff between these two factors. Loss of sediment-bound P is greatly reduced with conservation tillage. However, immobile nutrients like P tend to become concentrated at the soil surface because of the lack of mixing by tillage. If runoff is not also reduced, the water flowing over the soil surface can pick up significant amounts of soluble P, carry it off the field, and potentially pollute surface water. In one study using conservation tillage and other conservation practices, sediment P loss by erosion was reduced

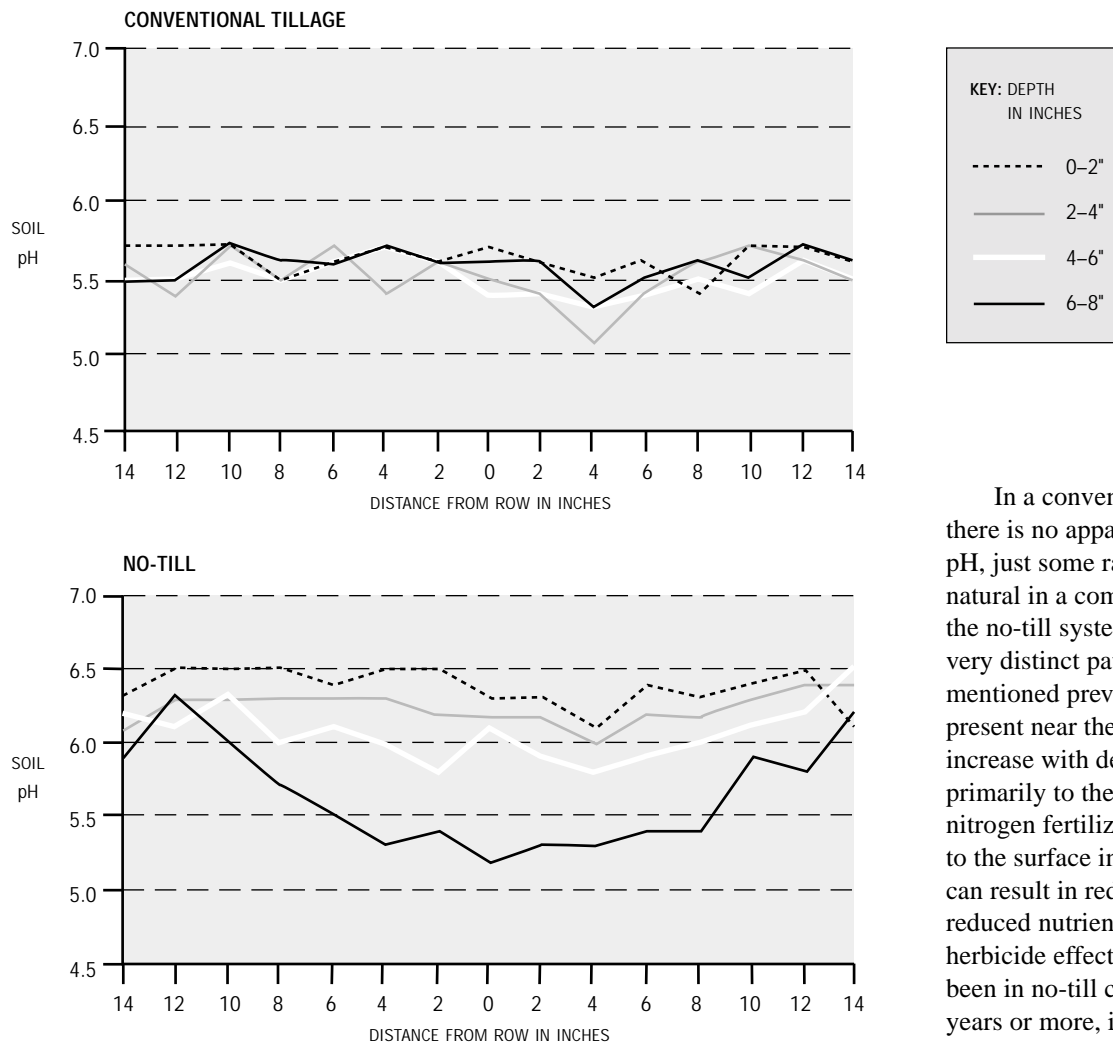
by 88 percent, while total P loss was reduced by only 9 percent because of the increase in soluble P leaving the field via runoff.

## POTASSIUM

Approximately 24,000 pounds of K per acre are in most agricultural soils; so this nutrient certainly is not in short supply. However, K exists in at least three main forms: soil solution, exchangeable, and mineral. Like other nutrients, K is taken up by plant roots only from the soil solution; yet, K in solution represents a very small fraction of the total K in soil. The K in soil solution removed by plants must be replenished with K from other sources in the soil to meet the need of a growing crop. This replenishment comes primarily from readily available, "exchangeable" K.

Exchangeable K, like other positively charged ions, such as magnesium (Mg), calcium (Ca), and aluminum (Al), is held loosely in soil by an attraction to the negative-charged surfaces of soil particles, somewhat like magnets on a refrigerator. The amount of negative charge in a soil is characteristic of that soil and is called the soil's cation exchange capacity (CEC). When K is added to soil, it occupies negative-charged sites on soil particles by exchanging with other positive-charged ions. The CEC holds K in ready reserve to supply the needs of crops. As plant uptake occurs, K is released from these sites to the soil solution in quantities dependent on the amount of K present and the proportion of the CEC sites that it occupies. Therefore, the amount of exchangeable K is related to the amount of K available to the crop. This exchangeable K is the K measured by soil tests. Most of the K in soil is mineral K, which is held more tightly or is entrapped as part of the structure of soil minerals. These forms, also called nonexchangeable K, generally are either unavailable or only slowly available to plants. Therefore, mineral K is not measured as part of the soil test procedure. Decomposing organic matter in soil contributes little K because K is a

Figure 2. Soil pH by depth across a corn row in conventional and no-tillage systems.



In a conventional tillage system, there is no apparent spatial pattern in soil pH, just some random variation that is natural in a complex material like soil. In the no-till system, however, there is a very distinct pattern in soil pH. As mentioned previously, the lowest pH is present near the surface, and pH tends to increase with depth. This pattern is due primarily to the acidifying effects of the nitrogen fertilizer that has been applied to the surface in the no-till system and can result in reduced root growth, reduced nutrient availability, and reduced herbicide effectiveness. If the area has been in no-till corn management for two years or more, it is advisable to use a reliable field kit to measure the pH of the surface soil. Collect several cores less than 2 inches deep from the no-till area and mix them thoroughly in a clean bucket. Remove a sample for pH measurement. An accurate, reliable, and durable field pH test can be used for valid pH measurements. Simple colorimetric pH kits normally are the most satisfactory for field use. If the pH of the surface soil is less than 6.2, take a standard soil sample for laboratory analysis. Apply the recommended lime as early as possible before planting. If this standard sample does not indicate a need for limestone and the surface pH is below 6.2, apply 2,000 pounds of calcium carbonate equivalent every other year. This amount should be adequate to neutralize the acidity created by the surface-applied nitrogen fertilizer.

soluble nutrient that leaches quickly from fresh crop residue and manure. On the other hand, organic matter is important to K fertility because it provides many negative-charged sites for holding exchangeable soil K.

Potassium is intermediate in mobility between N and P. The behavior of K is not as dynamic as N. Because there are no volatile forms to worry about, incorporation is not necessary to reduce losses, and in most soils K does not convert to permanently unavailable forms. However, K is more mobile than P, and exact placement is not as critical as with P. Even so, on some soils, especially on those with low K levels, there may be a benefit to banding the K. On optimum or higher-testing soils, there

is little difference between broadcast and banded K. Likewise, K generally is not as important in a starter fertilizer as P. However, studies have shown that K in the starter often is more important in no-till than in conventional tillage systems. Thus, complete N-P-K fertilizers should be used as starters in conservation tillage systems.

#### SOIL TESTING

Sampling soil to test for pH, P, and K requires some special considerations in conservation tillage systems because of the stratification that occurs. Figure 2 illustrates the different distribution of pH in conventional and no-till systems across a corn row.

Figure 3. Distribution of P across the corn row in conventional no-till systems.

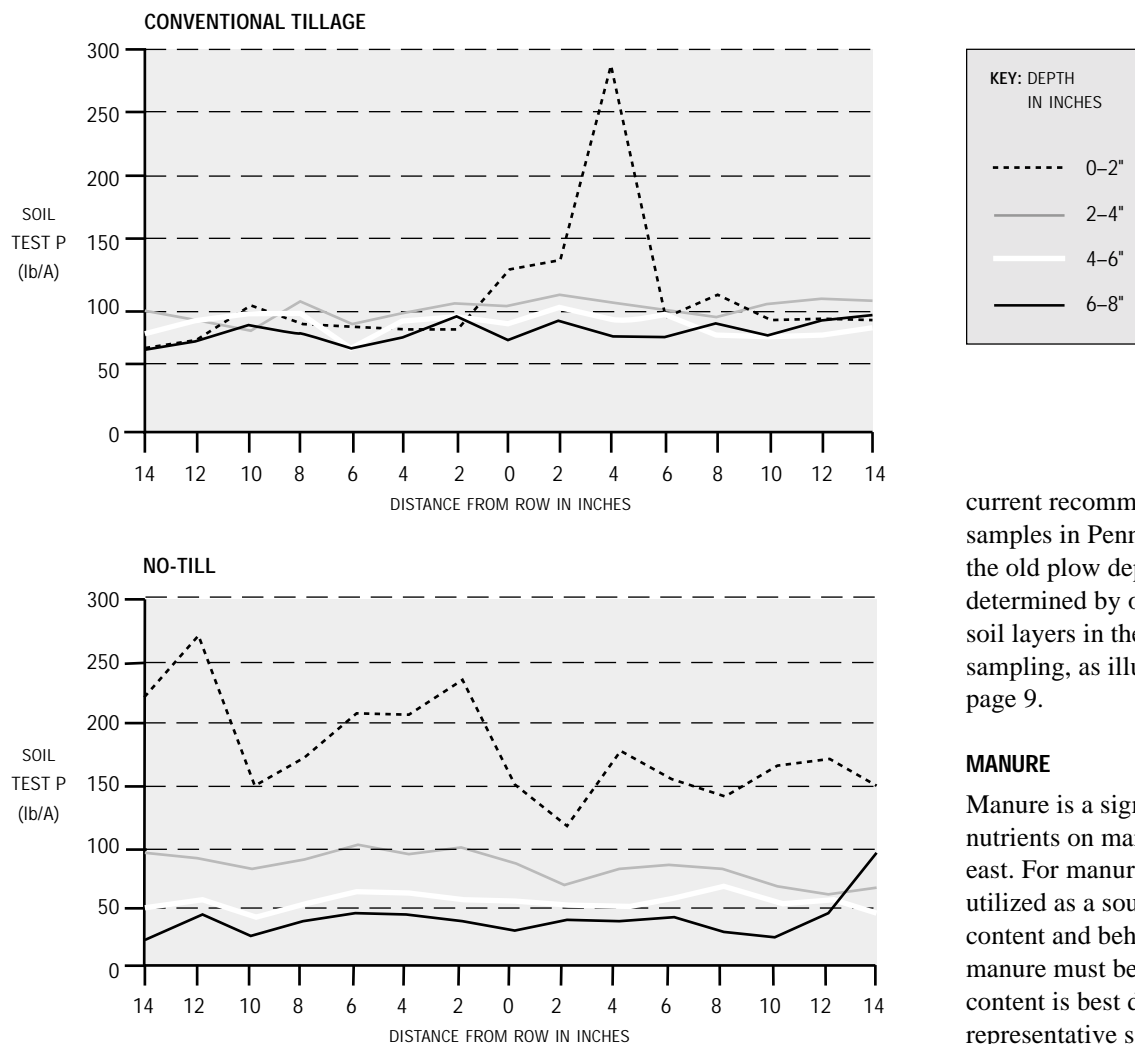


Figure 3 illustrates the different distribution of P across a corn row under conventional and no-till systems.

In a conventional tillage system, the only pattern that is apparent is the high soil P from the previous starter fertilizer band in the surface layer. Therefore, soil samples should be taken from the middle of the old rows. Samples that are taken too close to the row may show an artificially high soil test level from the fertilizer concentration in the starter band. As seen with pH results, some random variation is natural in a heterogeneous material like soil. In the no-till system, however, there is a very distinct pattern in soil P. Large amounts of P are present near the surface, and these amounts tend to decrease with depth.

This decrease is due to the immobility of the surface-applied P, which tends to stay where it is applied.

Even though some tillage occurs in reduced tillage systems, the pattern for pH and P stratification is very similar to those seen in Figures 2 and 3 for no-till. Because conservation tillage is designed to not incorporate the crop residue, there is little vertical mixing. Therefore, sampling depth is critical when soil testing conservation tillage fields. Producers using conventional tillage systems will get approximately the same results regardless of how deep they sample within the plow layer. In conservation tillage, shallow samples generally will show lower pH levels and higher P and K levels than deeper samples. The

current recommendation for taking soil samples in Pennsylvania is to sample to the old plow depth, which is best determined by observing the different soil layers in the soil probe while sampling, as illustrated in Figure 4 on page 9.

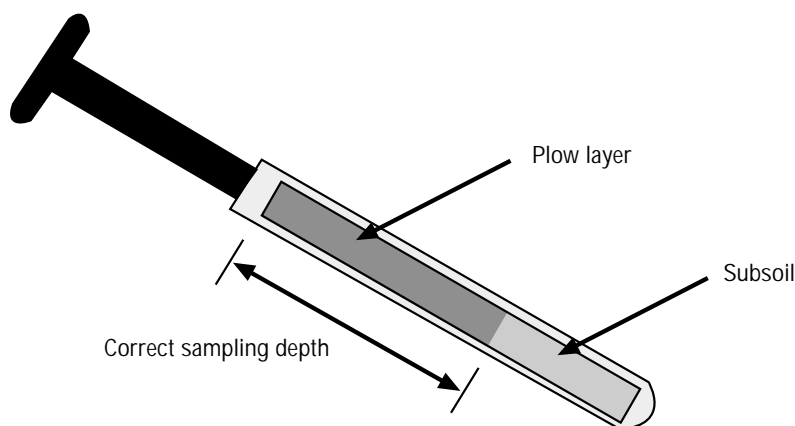
#### MANURE

Manure is a significant source of nutrients on many farms in the Northeast. For manure to be effectively utilized as a source of nutrients, the content and behavior of the nutrients in manure must be known. Manure nutrient content is best determined by analyzing a representative sample of the manure. Book values provide good average nutrient contents, but actual individual analyses may vary from book values by as much as plus or minus 100 percent. Nutrient behavior in manure varies with the nutrient. Thus, management considerations for manure use in conservation tillage also vary.

The N in manure can be divided into two functional fractions: an unstable organic fraction and a stable organic fraction. The unstable organic fraction is mostly urea and is mineralized very rapidly to ammonium N and subsequently nitrified to nitrate N. This mineral N behaves as described in the earlier section on N relationships in conservation tillage. However, there are some unique interactions between manure N and conservation tillage systems. Because most of this N is urea,



Figure 4. Soil probe showing the recommended sampling depth regardless of tillage system.



there is a large potential for N loss through ammonia volatilization if the manure is not incorporated, as is the case in a no-till system. The N availability from unincorporated manure is generally less than half that of manure immediately incorporated.

Incorporating manure in conservation tillage systems does increase the availability of manure N. However, the goal of conservation tillage is to leave as much residue on the soil surface as possible. Maximizing the availability of manure N requires that the manure be thoroughly mixed with the soil. Probably the best compromise currently available is injection of liquid manure directly into the soil. This practice completely incorporates the manure and results in minimal incorporation of existing surface residue. Also, as with urea fertilizer, 0.5 inch of soaking rain immediately after application will reduce the losses. Another consideration is the acidifying effect of the manure nitrogen, a process discussed under soil acidity.

Because the mineral N in manure is applied along with a large amount of organic material, use of manures will result in additional buildup of organic matter near the surface in conservation tillage systems. As noted earlier, this surface organic matter accumulation in conservation tillage can increase

N losses through immobilization and denitrification of added N. The potential for denitrification loss is significant with injected manure. If manure is injected, the injection zone will have all of the requirements for denitrification: nitrate N, organic matter, and saturated moisture conditions.

The stable organic N will slowly become available over a period of years as the manure is decomposed by soil microbes. Because this process is biological, it will be very sensitive to the conditions present where the manure is decaying. In reduced tillage, particularly no-till systems, the environment will be different than in conventional tillage systems, so the breakdown of this organic fraction and release of the N will occur at different rates. Generally, the rate of manure breakdown will be slower in reduced tillage systems because of the reduced manure and soil mixing, reduced aeration, higher moisture levels, and lower soil temperatures.

The P in manure is only slowly available to a crop. However, the P in manure is not as readily tied up in unavailable forms in the soil as are the highly soluble P fertilizers. The net result is that for building soil P, the rate of availability of P in manure will be very similar to that of P in fertilizer, although accomplished by different mechanisms.

Thus, manure P can be substituted for P in fertilizer on a one-to-one basis. There is one exception to this rule. Because manure P is released slowly, it cannot be substituted for starter fertilizer P, which can be very important in conservation tillage systems. Thus, even if manure P is applied in amounts adequate to meet the needs of a crop, there may still be some benefit to using a starter fertilizer. As with the organic fraction of manure N, the reduced tillage that occurs in conservation tillage systems will have an effect on the biological activity of the soil and thus on the rate of P release. Under reduced tillage, manure P will accumulate in the soil. Thus, P in manure, applied in excess of the needs of one crop, can be effectively used by a later crop in the rotation.

The K in manure is mostly in a soluble form similar to the K in fertilizer. Therefore, the manure K can be substituted one-to-one for fertilizer K. The high solubility of manure K can result in excessive soluble salt levels if too many manure applications are made, particularly on lighter soils. Excessive salt levels are especially problematic when poultry manure is applied at high rates immediately before a crop is planted. Like P, K will accumulate in the soil and thus can be built up in one part of the rotation to be used later in another. As was discussed earlier, K management is not greatly influenced by the tillage system.

There is an apparent tendency, particularly in no-till systems, for more problems with soil compaction when manure is used as a nutrient source. The logistical pressure to get the manure spread in a timely manner in the spring and the lack of tillage to alleviate the compaction effects of heavy equipment combine to increase this problem. The easiest way to stop soil compaction is to avoid spreading manure on wet soils. Other publications in this series provide information on compaction in no-till systems.

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