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with plant food

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Fertilization for Conservation Tillage – Fitting the Pieces Together

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Fertilization for Conservation Tillage

IN THE HISTORY of North American agriculture, few practices have been adopted as rapidly as growers have converted to conservation tillage in recent years. While there are many benefits, there are also many questions associated with the various types of conservation tillage.

This special issue of *Better Crops with Plant Food* presents a composite of current information on **fertilization** for conservation tillage, featuring articles prepared by leading researchers.

As identified by our cover, there are many pieces to be properly balanced and fit together. The positive interactions from these management systems are essential for achieving maximum economic yields (MEY). ■

Fertilization for Maximum Economic Yield under Conservation Tillage

By E.E. Schulte

IN 1983, an estimated 125,848,000 acres or 38% of U.S. cropland was in some form of **conservation tillage.** This compares with 12% in 1973. Of the total acreage in conservation tillage, 12% was no-till, till-plant or rotary tillage in 1983. It's estimated that 65% of the U.S. crop acreage will be in no-till by the year 2000.

Conservation tillage systems create a soil environment that is different from that encountered with moldboard plowing. The differences result from the effects of surface residue and reduced soil disturbance on the physical, chemical and biological properties of the soil. All of these factors interact to influence nutrient availability and plant growth. In addition, nutrient stratification and fertilizer placement create new challenges for soil test calibration and sampling.

The Soil under Conservation Tillage

The principal feature of conservation tillage is the crop residue left on the soil surface. This residue protects the soil from the adverse effects of raindrop impact. The rate of water movement downslope is reduced, and the rate of infiltration frequently increases. The debris also shades the soil from direct solar radiation. Plowing (conventional tillage) incorporates crop residues and applied nutrients and aerates the surface horizon. Thus, different tillage systems are likely to result in differences in the physical properties of soil which, in turn, affect nutrient availability. Also, crop residue must pass through various stages of decomposition before some nutrients it contains can be recycled for use by the next crop. The activity of microorganisms involved in such processes as N immobilization, mineralization and denitrification is very sensitive to tillage-imposed microclimates.

PHYSICAL PROPERTIES

Residue

Numerous studies of the amount of residue left on the soil surface by different tillage systems have been reported. The most residue is left with the no-till system. Some incorporation of residue takes place during planting with the till-plant system and during cultivation and ridging. The amount of residue left with a chisel plow depends on a number of factors, including depth of plowing, shank spacing and design, ground speed, soil conditions, etc. **(continued on next page)**

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Soil Temperature

Surface residue shades the soil from direct solar radiation. In addition, residue reduces the harmful effects of raindrop impact on soil structure and reduces the rate of flow of water downslope, resulting in greater infiltration and higher soil moisture. Thus, soil temperature during the early part of the growing season up to canopy closure is typically lower under conservation tillage than with conventional tillage. For a research site at Lancaster, Wisconsin, the mean difference in soil temperature at 2 inches between no-till and moldboard plowed plots in Fayette silt loam was 4.2 °F (2.3 °C) over the first eight weeks. Greater differences were observed on clear days.

This may not appear to be a large difference, but soil temperatures in the Northern Corn Belt are usually low at planting and frequently remain so for several weeks after planting. Planting is done as early as possible to take maximum advantage of a limited growing season. It is frequently observed that early planted corn in no-till plots appears to be one to two weeks behind corn planted at the same time in moldboard plowed plots. When one considers that the rate of many biochemical reactions approximately doubles for every 18 °F (10 °C) rise in temperature, the influence of a 3.6 °F (2 °C) difference on early corn growth is understandable. This may also be a problem for early planted corn in warmer climates.

Bulk Density Moisture and Aeration

Reduced tillage should result in less tractor traffic and, therefore, less soil compaction. However, tillage, especially moldboard plowing, loosens and aerates the soil. Soil bulk density was measured in late summer on two soils as an indication of soil compaction resulting from different tillage systems. Soil moisture was measured at the same time. Total pore space and soil volume occupied by water and air were calculated. As bulk density increases due to compaction or natural settling processes, air space decreases, the large pores being compacted first.

In the Plano soil, the increased soil moisture in the till-plant system, along with a somewhat higher bulk density compared to chisel and moldboard plowing, resulted in a lower percentage of air space. This effect was even greater in the Fayette soil with the no-till system. In this case, the advantages of greater moisture could be offset by reduced aeration, resulting in a greater likelihood of denitrification and reduced N and K availability.

Other research shows that soil compaction will be confined to the tilled layer if the axle weight does not exceed 5 tons. Wheel traffic for most tractors involved in conservation tillage systems would not be expected to compact the subsoil but may alter physical properties within the tilled layer. These changes are likely to persist throughout the growing season but should be improved by freezing and thawing in cold climates.

A combine with a six-row corn header will commonly have a load of 10 tons on the front axle without any grain in the bin, and tricycle type fertilizer spreaders with flotation tires will carry 14 tons on the rear axle when loaded. Theory predicts that subsoil compaction is a function of the total load, rather than load per square inch at the soil surface. Subsoil compaction is not readily reduced by freezing and thawing.

Long-term effects of tillage on soil tilth were studied on a Nicollet silty clay loam (Alfisol) in Minnesota. Soil tilth was evaluated by measuring bulk density, clod density and aggregate size distribution in plots that were moldboard plowed to a depth of 12 inches or tandem disked or chisel plowed to a depth of 8 to 10 inches. Primary tillage was done in the fall and all plots were tandem disked once in spring. Wheel traffic from all field operations occurred on the same path for the nine-year duration of the experiment.

Moldboard plowing produced a more porous soil in the 0 to 6 inch depth than did the disked or chisel plowed plots initially. After three to four years, however, the reduced tillage resulted in greater porosity than did moldboard plowing. A similar effect was observed in the 6 to 12 inch layer, but about seven years of reduced tillage were needed to give soil porosity equal to that in moldboard plowed plots. Continuous conservation tillage resulted in larger diameter, more porous aggregates than did continuous moldboard plowing. Wheel traffic eliminated these differences.

BIOLOGICAL PROPERTIES

A study of microbial and biochemical components of surface soils from long-term no-till and conventional tillage plots at seven U.S. locations found that counts of aerobic microorganisms were 1.14 to 1.58 times higher in no-till soils compared with moldboard plowed soils at the 0 to 3 inch depth. There were fewer aerobic microorganisms at 3 to 6 inches in the no-till soils, however. Facultative anaerobes (those not needing air) were higher in no-till soils at both depths. The population of denitrifying microorganisms in no-till soil was 7.3 times higher than that of moldboard plowed soils at 0 to 3 inch and 1.8 times higher at 3 to 6 inch. Higher decomposable crop residue levels at the soil surface, coupled with higher moisture and reduced pore space in the no-till soils apparently provides favorable conditions for denitrifiers. The higher population of aerobic microbes would accelerate oxygen depletion in the surface soil.

Research reported in 1980 pointed out that maximum aerobic microbial activity with conventional tillage extended to a greater depth than with no-till. Microbial populations under no-till decreased rapidly below 3 inches. The potential rate of mineralization and nitrification is higher with conventional tillage compared to no-till; whereas, the potential for denitrification is greater for no-till.

Phosphatase and dehydrogenase activity followed a trend similar to that of aerobic microbial activity in the study. Potentially mineralizable N at 0 to 3 inches ranged from 1.2 to 1.6 times higher in no-till soil at seven locations. Differences induced by tillage were insignificant at 3 to 6 inches.

Long-term effects of tillage on soil macrofauna will likely be influenced by kinds and rates of insecticides employed.

CHEMICAL PROPERTIES AND NUTRIENT AVAILABILITY

Nitrogen. Tillage had little effect on N release to corn from a Plano silt loam to which no N was applied. The situation was different with no-till corn production on Fayette silt loam, however. In 1979 and 1980, the influence of alfalfa plowed down with a manure application by the farmer-cooperator in 1977 is still evident. However, there is considerably less N released from no-till plots compared with moldboard or chisel plowed plots. This reduction in availability of native N was believed initially to be due to a reduced rate of mineralization of crop residue left on the soil surface and of soil organic matter owing to the cooler soil. If this were the case, it might be expected that after three or four years a steady state would be approached in which the rate of mineralization equaled the rate of crop residue addition. But after five years, less N is being released to corn from no-till plots than plowed plots.

A review of data suggests that conditions are optimal in no-till plots for denitrification during portions of the growing season. A reduction in the air space coupled with an increase in denitrifiers would support this idea.

When N was applied to the Fayette soil, the highest yields obtained were greater with no-till than with moldboard or chisel plowed plots. This is believed to be due to the higher moisture levels in the no-till plots. Apparently, sufficient N was added at the 200 lb/A rate to compensate for denitrification losses and reduced mineralization.

Other researchers have also found that corn grown under reduced tillage requires slightly higher rates of applied N to obtain yields comparable to those obtained by conventional plowing and tillage. Some of the reasons offered to explain this phenomenon are volatilization of surface-applied urea, immobilization, denitrification and leaching.

(continued on next page)

Phosphorus. There appears to be little effect of tillage on P availability to corn. Numerous research workers have observed that soil test levels of P and K tend to become stratified after a few years, with high levels in the surface soil. No one has shown that this surface P is unavailable to crops, however. As long as the soil remains moist enough for root activity, surface-applied nutrients should be available. Soil under reduced tillage usually contains more moisture than plowed soils. In dry climates, temporary unavailability of surface-applied nutrients could be a problem during drought periods, and deep placement would be recommended.

Uptake of P by small whole corn plants (8-leaf stage) grown in Plano silt loam was slightly higher in till-plant plots compared to corn grown in chisel or moldboard plowed plots, but dry matter and grain yield were lower. In a Minnesota study, there was no influence of soil test P on corn grain yields.

Potassium. The concentration of K in young (8-leaf stage) corn plants grown in Plano silt loam was significantly lower in till-plant plots than in chisel plowed plots, and both were lower than those in moldboard plowed plots. Uptake of K by young corn plants in the moldboard plowed plots was also higher than that of corn in till-plant plots. Reduction in K availability with reduced tillage is believed to result from reduced aeration, cold soil and restricted root development.

In 1978 and 1979, the above plots were split, and row fertilizer, 8-48-12, was applied to half of each plot at a rate of 143 lb/A. In 1980, K as K_2SO_4 alone was used in the row (2 x 2 placement) at a rate of 25 lb/A. An equivalent amount of S as gypsum was applied in the rows of the other half of each plot. Grain yields were increased by the use of row fertilizer at low soil K levels in each tillage system, but the response was greatest in the till-plant system.

The effect of tillage on K availability is manifest at low soil K levels — levels which give moderate yields under conventional tillage but much lower yields with reduced till. Since most tillage work is carried out at medium to high soil K levels, this effect may not be observed unless soil K level is a planned variable in the experiment.

In 1945, Iowa researchers reported that a reduction in K availability in corn was associated with reduced tillage in three soils of the state. They speculated that differences in K availability were due to tillage-imposed aeration differences. In a follow-up greenhouse study in 1946, K availability was much more strongly affected by aeration than was the availability of N, P, Ca or Mg.

The reduction in K availability can be overcome by increasing the bulk soil solution K level through fertilization. Tillage studies have been cited where corn grain yields were increased as much as 52 bu/A with 17 lb/A applied as a row fertilizer on low K soils. In 1980, Wisconsin research reported a corn grain yield increase of 46 bu/A with 10 lb/A of row-applied K with till-plant corn on a Plano silt loam soil. This response was reduced to 3.3 bu/A when soil test K was raised from 138 to 300 lb/A.

Conclusions

Research and observations of soil fertility-tillage interactions to date lead to the following general conclusions:

1. **Successful application of conservation tillage systems** requires a better-than-average manager. Yield reductions will be greater under conservation tillage if fertility or other management programs are neglected than in conventional cropping.
2. **Losses of N by denitrification and/or volatilization** are potential problems that require special consideration with reduced tillage systems. The increased moisture, surface residue and bulk density with conservation tillage systems are more conducive to denitrification

losses. Sidedress applications of N would minimize the likelihood of N loss by denitrification because the time between application and utilization by the plant is reduced.

3. **Loss of N by volatilization** is a problem mainly with urea or UAN solutions in no-till systems. In Wisconsin, cold temperatures and the likelihood of rain within a few days of application tend to minimize chances of significant N loss. In chisel plow and ridge systems, loss of urea N by volatilization can be minimized by taking advantage of the incorporation afforded by these systems. This means that urea or UAN solutions should be applied just before chisel plowing or other tillage operation. In the case of till-plant or ridge systems, application should be made shortly before planting or ridging.
4. **Plowdown adequate P and K,** as determined by soil test recommendations, to raise soil P and K to optimal levels before going to conservation tillage. Thereafter it will not be possible to incorporate fertilizer throughout the "plow layer".
5. **In cold climates where soils warm up slowly in the spring,** apply both P and K in the row at planting. The row K is especially important in soils that compact easily.
6. **Apply lime as required** to prevent the formation of an acid surface layer that could reduce herbicide activity, root development and nutrient availability.

Needs for the Future — Fertilization for Maximum Economic Yields

Much work is underway on improving N fertilizer efficiency in reduced tillage systems. Nitrogen carriers, timing, placement and the use of nitrification and urease inhibitors are being researched. The effect of rotations in N management must also be studied.

The reasons for reduced N availability with reduced tillage are not clearly defined. More research must be done to sort out the effects of immobilization, mineralization, volatilization, denitrification and leaching. When the contribution of each of these factors on the overall N economy is better understood, more efficient N fertilization schemes can be devised.

The effects of soil compaction on aeration and root impedance should be investigated in relation to K availability. The volume of the root zone that must be fertilized for maximum yield should be studied, along with fertilizer placement methods.

Agronomic practices that have been studied in conventional tillage must be researched for reduced tillage. These include hybrid selection, planting date, plant population, and other practices.

Perhaps the most challenging task for soil fertility researchers is that of devising soil sampling techniques to assess the fertility status of reduced tillage fields with localized fertilizer placement. Present soil tests are calibrated on "plow layer" samples. With different degrees of tillage and fertilizer incorporation, terms such as "plow layer" and pounds per acre have dubious meaning. ■

Nitrogen Management for No-Till Corn

By V. Allan Bandel

AS NO-TILL CORN PRODUCTION gained momentum in the 1970's, there was an observed "apparent" need for more nitrogen (N) on no-tillage corn than on conventional tillage corn. However, when properly managed, the no-till method provided a more efficient vehicle for N utilization.

Research has found that low to moderate N rates for no-till often resulted in corn exhibiting severe N deficiency, while conventional tillage did not. But to conclude from these symptoms that no-till corn requires more N and is a less efficient system for N would be incorrect. Properly managed, no-till corn has the potential to outyield conventional tillage corn, and also to use N more efficiently.

To illustrate, we can refer to results from one of the long-term N rate-by-tillage tests established at several Maryland locations in 1973. N was applied annually to both no-till and conventional tillage corn at rates of 0, 80, 120, 160 or 240 lb/A **(Table 1).**

In this case, the 160 lb/A N rate appeared to result in highest yields for both tillage systems. However, neither of these curves actually "peaked" at 160 lb/A. Curvilinear regression analysis clearly showed that grain yields for both tillage systems would have continued to increase to some N rates **between** 160 and 240 lb/A. The analysis showed that highest yields would have occurred at 195 lb N/A for no-till and 177 lb N/A for conventional tillage corn.

These values illustrate typical differences in N requirements often observed between the two tillage systems. Experience in Maryland has also shown that such differences have varied from less than 10 to more than 60 lb N/A. The magnitude of this difference depends upon many factors, such as soil type, past cropping history, seasonal rainfall and temperature, soil pH, etc. These all are factors which directly influence the level of residual soil N available to the growing crop.

From the data in **Table 1**, it can be shown that N rates of less than 120 lb/A required the same amount of N per bushel for no-till and conventional tillage corn. But at N rates of 120 lb/A or more, no-till corn required less N per bushel than did conventional tillage corn.

Nitrogen efficiency relative to grain yields declined for both tillage systems as N rates increased, but N efficiency for no-till was always greater than that for conventional tillage at N rates of 120 lb/A or more. Thus, properly managed no-till corn can be expected to use N more efficiently, produce higher yields, and return more profit per acre than conventional tillage corn.

Table 1. Grain Yields for Conventional and No-till Corn with Different Nitrogen Rates.

Tillage System	N - lb/A: 0	80	120	160	240	Mean
	bu/A					
No-till	23.7	135.5	169.8	189.6	186.2	141.0
Conventional	60.9	133.4	153.8	163.6	151.6	132.7
Mean	42.3	134.4	161.8	176.6	168.9	136.8

NOTE: Data points taken from best fitting curvilinear regressions. Poplar Hill Research Farm. 1981.

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Table 2. Influence of N Source and Placement on No-Till Corn Grain Yields, 1983.

N Treatment	Poplar Hill	Forage Farm
	bu/A	
Check	25.6	91.0
Ammonium Nitrate	94.7	135.0
UAN Broadcast	75.9	108.4
UAN Dribbled	84.1	122.2
UAN Injected	114.4	152.0

N rate = 120 lb/A

Nitrogen Source, Placement and Timing

Surface applications of urea or urea-based N fertilizers in the presence of crop residues, such as with no-till corn, can result in the loss of significant quantities of N due to ammonia volatilization. Maryland research has been directed toward ways of improving the efficiency of UAN applied to no-till corn.

Despite soil moisture extremes, dribbling UAN increased yields 8 to 14 bu/A over broadcast UAN in 1983 **(Table 2).** Injected UAN produced yields greater than dribbled UAN or ammonium nitrate. Although a severe drought occurred in 1983 which restricted yields, the 1983 growing season was unusually wet early in the spring. It is expected that in a normal rainfall season dribbling will be almost as efficient as injection for applying UAN solution. But in wet years when denitrification is a problem, injection will be a superior application method for UAN solution.

Proper timing of N applications cannot be overemphasized, particularly for no-till crops. For most crops, the best "rule of thumb" for N fertilization is to: "Apply N as closely as possible to the time of plant need." This guideline should always apply to crops grown on light sandy soils where nitrate leaching is a potential problem. It has not generally been considered as important on medium to heavy textured soils where leaching is not as likely to occur. This recommendation was developed before no-till became an important corn growing method. Proper timing of no-till N applications has been found to be more important on all soils because of increased chances for N loss if not properly managed.

Under no-till, N may be lost from the soil by ammonia volatilization and/or denitrification, or it may be tied up temporarily by biological immobilization. With the exception of leaching, all of these processes can be more serious under no-till than under conventional tillage.

Because of the potential seriousness of improper N timing on no-till corn, tests have been conducted since 1980 to measure the impact upon yields and any relationship to method of application or placement. **Table 3** gives the results from two locations over a 4-year period.

Although considerable variability occurred, there was a tendency favoring the delayed N, particularly for surface applications. Timing was not as critical when N was soil injected 4 to 6 inches deep. ■

Table 3. No-Till Corn Yields—Influence of Time of Application and Placement of 120 lb N/A as 30% UAN Solution.

Method	1980	1981	1982	1983	Mean
			Poplar Hill Yield-bu/A		
Broadcast Early[1]	107.5	180.0	147.1	75.0	127.6
Broadcast Late[2]	106.5	181.3	165.2	96.7	137.4
Injected Early[1]	124.6	188.5	158.4	114.4	146.5
Injected Late[2]	124.7	178.8	177.7	97.0	144.6
			Wye Institute Yield-bu/A		
Broadcast Early[1]	104.4	134.4	116.0	67.9	105.7
Broadcast Late[2]	114.5	167.0	124.5	73.7	119.9
Injected Early[1]	102.8	164.9	143.6	76.0	121.8
Injected Late[2]	111.1	176.0	147.7	81.9	129.2

[1]Applied at or near planting. [2]Applied about 4 weeks after planting. Poplar Hill and Wye Institute, 1980 to 1983.

P and K Fertilization for Reduced Tillage

By David B. Mengel

MANY FARMERS in the Midwest are abandoning the moldboard plow, and switching to a reduced or conservation tillage system. There are probably as many types of reduced tillage systems as there are farmers. However, all of these systems have some common characteristics which affect phosphorus (P) and potassium (K) fertilization.

Residue Effects

As tillage is reduced, the portion of the soil surface which remains covered with crop residues increases markedly. Using a moldboard plow, essentially all residue is incorporated leaving a clean, residue-free surface. However, as tillage is reduced, the amount of residue remaining on the surface increases. The increased surface residue serves as an insulating layer to lower soil temperature and reduce evaporation. This can also enhance the infiltration of water into the soil. Thus the cooler, and in some cases wetter soils common to reduced tillage systems, particularly no-till, tend to respond favorably to treatments which enhance early season growth, such as starter fertilizer.

A number of states, particularly some in the northern and eastern portions of the Corn Belt, are reporting responses to starter fertilizer in corn grown in reduced tillage where responses would not be expected were conventional tillage used. Some data collected at Purdue illustrate this point. The effect of tillage and residue on soil temperature is illustrated in **Table 1.** Soil temperatures remain as much as 5 to 6 degrees lower in no-till or chisel plowed plots than in plowed plots. This can result in a response to starter fertilizer as illustrated in **Table 2.** At high fertility (Bray P_1-P greater than 100 lb/A, exchangeable K greater than 300 lb/A) starter fertilizer responses are not common in conventional tillage in Indiana. However, when no-till is adapted, starter responses do occur. Recent work would suggest that starter responses could be expected over 50% of the time in no-till corn in Indiana, regardless of P levels.

Table 1. Mean soil temperature over the first eight weeks after planting.

Tillage System	Northern Indiana: Tracy Sandy Loam	Northern Indiana: Runneymede Loam	Eastern Indiana: Blount Silt Loam	Southern Indiana: Bedford Silt Loam
	Soil Temperature (°F)			
Spring Plow	72.4	71.0	75.8	79.0
Chisel	68.1	67.2	72.4	75.6
Ridge till	69.9	69.4	74.1	77.2
No-till	65.9	64.7	71.7	74.2
Avg. Planting Date	April 27	May 2	May 14	May 6

Griffith et. al, IN. (4 tillage systems, 4 soils)

Nutrient Stratification

In addition to the accumulation of residue on the surface, P and K accumulate near the soil surface in many reduced tillage situations, particularly where the cation

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Table 2. Effect of starter fertilizer on the yield of corn grown under four tillage systems.

Tillage System	1982 No starter	1982 Starter[1]	1983 No starter	1983 Starter
	Corn Yield, bu/A			
Conventional	204	206	170	172
Subsoil	202	204	171	171
Coulter Chisel	202	209	171	171
No-till	201	213	156	161

Mengel, IN.

exchange capacity (CEC) is fairly high. This is primarily due to less incorporation of fertilizer materials. But in addition a natural biocycling of nutrients occurs where nutrients such as P and K are taken up by crop roots from the lower portion of the old plow layer and are deposited on the soil surface with the crop residue.

In many cases this stratification of nutrients is also followed by an increase in plant roots in the same areas, and nutrient uptake is not affected. However, under dry conditions, when the surface few inches of soil dry out, nutrient availability is reduced and problems can develop. The plant analysis data in **Table 3** illustrate this point.

With dry weather K uptake is reduced in all tillage systems, but especially so with reduced tillage. However, in normal years when water is less limiting, no difference in K uptake is seen between tillage systems.

Table 3. Nitrogen, phosphorus and potassium content of corn as affected by tillage system.

Tillage System	Percent N 1980 "dry"	Percent N 1981 "wet"	Percent P 1980 "dry"	Percent P 1981 "wet"	Percent K 1980 "dry"	Percent K 1981 "wet"
	Concentration in corn leaf					
Plow	2.82%	2.79%	0.24%	0.31%	1.77%	2.27%
Chisel	2.73	2.89	0.23	0.32	1.56	2.21
No-till	2.77	2.84	0.23	0.33	1.49	2.27

Cruz, IN.

The reduced K availability in dry years is a problem which probably won't be seen in the first few years of reduced tillage, or in systems where occasional deep tillage is used to minimize the stratification. Rather, it is a product of long-term reductions in tillage and fertilizer incorporation. To avoid this problem we suggest that farmers build K levels to the high or very high level before shifting to a continuous no-till system. We also recommend that they monitor the K level of the lower part of the old plow layer through soil testing. If the K level in this zone drops below medium, then some measure should be considered to replace some of the K removed from these deeper areas. Occasional tillage, or deeper placement of K fertilizer, are two alternatives which may prevent this interaction of "weather x K" from cutting yields.

Summary

Adapting reduced tillage (particularly no-till) in Indiana and similar areas requires some changes in fertilizer practices. The cooler soil temperatures found as residue levels go up increase the potential for a starter fertilizer response. A small amount of P_2O_5 (15-20 lb/A) placed near the seed to enhance early growth is profitable.

The gradual depletion of K in the lower half of the old plow layer or tillage zone has presented some problems in Indiana, particularly in dry years. Occasional deep tillage or deep placement of K may minimize this problem.

In conclusion, soil fertility problems in conservation tillage do exist, but they can be solved. However, no-till or conservation till farmers will need to do a better job of managing fertilizers to make these systems work reliably. ■

Liming the Soil – A Production Priority for High-Yield Agriculture with Conservation Tillage

By Bruce W. Remick

BENEFITS OF CONSERVATION TILLAGE farming are well known. However, a characteristic common to all conservation tillage farming systems is that their continued use will cause the accumulation of fertilizer, herbicide, and crop residues in the surface layers of soil which can encourage the development of strongly acid conditions in the seed zone.

It has been demonstrated in field trials in Kentucky **(Table 1)** that the 0-2 inch soil layer becomes more acid after several years of continuous no-till corn than does the surface layer of the same soil farmed under conventional tillage.

In other trials in Maryland, the application of 160 lb of nitrogen (N) per acre to no-till corn has caused the surface soil pH to drop by as much as 1.5 pH units within a matter of several weeks. Soil acidity increases of this magnitude, unless corrected by the application of agricultural limestone, can contribute to a number of stress factors that can limit crop yields. These conditions can cause severe economic loss to the farmer, such as:

- reduced availability of many essential plant nutrients
- increased solubility of certain micronutrients and aluminum to soil levels toxic to crops
- reduced activity of beneficial soil microorganisms and increased activity of disease-producing species that thrive under acid soil conditions
- poor herbicide performance, especially of the triazines, and yield losses due to heavy weed infestation and inefficient operation of harvest equipment

These problems are associated with soil acidity generally. However, they are accentuated under conservation tillage, particularly where "zero" tillage or no-tillage is used. The advantages of using conservation tillage are widely recognized as is the necessity of using high rates of nitrogen to achieve high yields. However, strong soil acidity, an undesirable side effect of these production practices, must be eliminated from the crop environment if desired yield objectives are to be realized. A well-planned and executed liming program, based on a representative sampling and testing of the soil from fields to be treated, is the most effective means available to the farmer for getting this important job done.

Liming benefits the farmer in several important ways. Soils that are regularly limed are more productive and responsive to good production practices, and provide the root environment necessary for high crop yields. As soils are limed to the

Table 1. Effect of 5 years continuous corn on soil pH.

Soil depth in.	Control plots	pH of unlimed plots after 5 years					
		No N		75 lb N/A/yr		150 lb N/A/yr	
		No-till	Conv. till	No-till	Conv. till	No-till	Conv. till
0-2	5.3	5.2	5.5	4.8	5.4	4.6	5.1
2-6	5.5	5.5	5.6	5.2	5.6	5.4	5.1
6-12	5.6	5.6	5.7	5.5	5.7	5.6	5.4

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A REGULAR LIMING PROGRAM based on soil test recommendations helps to assure that soils will remain fertile and productive.

recommended pH, herbicide effectiveness increases, which helps to assure good weed control, especially critical in reduced tillage systems. The Pennsylvania data in **Table 2** show the direct relationship of pH in the top inch of soil to the control of fall panicum when treated with atrazine and cyanazine, two primary members of the triazine group.

Table 2. Effect of soil pH on fall panicum control. Atrazine and cyanazine at 1 + 2 lb/A (a.i.) in no-till corn, 1978 - 1980.

Soil pH Top inch	Panicum yield lb/A
5.6	1,517
6.4	820
6.9	749
7.2	349

N.L. Hartwig, Penn State

The efficiency of applied fertilizer is similarly affected by liming. The pH of the soil is one of the single most important factors affecting fertilizer performance. This is especially critical in conservation tillage. Therefore, in most acid soil situations, fertilizer performance can be directly enhanced by liming alone.

Table 3. Corn yields with rates of phosphorus at two soil pH levels.

	Corn yields—bu/A	
	----------Soil pH----------	
P_2O_5 lb/A	5.1	6.1
0	90	119
30	119	135
60	127	132
90	123	138

Wisconsin

Tables 3 and 4, which deal with corn and soybeans, respectively, clearly demonstrate this point.

Table 4. Soybean response to aglime and fertilizer.

Treatment	Yield bu/A
No lime, P or K	15.7
Lime by soil test, no P or K	28.3
No lime, +150 lb/A P_2O_5, 150 lb/A K_2O	35.1
Lime by soil test, +150 lb/A P_2O_5, 150 lb/A K_2O	46.2

Kansas

The increased yields and crop values at all fertility levels, over and above the fertilizer treatments in each of the preceding trials, were obtained by liming. Had they been obtained under commercial cropping conditions, the farmer would have realized a significant increase in cash flow from his operation from liming alone.

If the type of response to liming demonstrated in **Tables 3 and 4** is an indication of what is possible in the commercial cropping situation, farmers in conservation tillage can ill afford not to lime. Farmers who have been on conservation tillage for any length of time regard the practice of liming as essential to success with this crop production technology. Liming will never take the place of fertilizer in conservation tillage. However, liming can complement fertilizer, and gain importance as a crop production practice as acreage farmed in the U.S. using conservation tillage methods increases. ■

Starter Fertilizers and Tillage Affect Yields on Compacted Soils

By Joe Touchton

IN SANDY COASTAL PLAIN SOILS, soil compaction can cause severe problems in crop production. These problems can result from subsurface plow pans caused by tillage implements and/or surface soil compaction caused by some conservation tillage systems.

Roots of many plants cannot penetrate severely compacted pans, and the effective rooting depth is restricted to the soil above the pan. When root growth is restricted or prohibited by the plow pan, nutrients and water located beneath the pan are not available for plant uptake, and soil productivity can be greatly reduced. With an 8-inch plow depth, the plow pan will generally be located in the 8 to 10-inch deep soil layer. But in some soils, disking after plowing can produce a shallow plow pan 2 to 3 inches below the soil surface. Plow pans can actually exist in most any soil, but if the pan is not dense enough to prohibit root penetration, the plow pan will probably not reduce yields.

Surface soil compaction in some reduced tillage systems is due to soil settling which results from variables such as traffic and rainfall. In conventional tillage systems, tillage implements will generally eliminate surface soil compaction. With surface soil compaction, root growth is generally not prohibited as it is with plow pans. However, root growth is often restricted or limited, and the extensive root growth with excellent soil proliferation necessary for high yields does not exist. Changing from conventional to conservation tillage can, in some soils, result in surface soil compaction plus plow pans created by years of conventional tillage.

During the past 15 to 20 years, tillage implements designed to eliminate the adverse effects of compaction on crop yields have been developed. The most effective equipment probably are models with under-the-row subsoilers. These subsoilers, which can generally subsoil at depths up to 16 inches, fracture plow pans and permit root growth below the root restricting pans. During the past decade, the under-the-row (commonly called in-row) subsoilers have been adapted for planting in conservation tillage systems. With some models, subsoiling and planting are separate operations, but with others, planters are mounted directly behind the subsoil shank, and planting and subsoiling are one-trip operations.

The effects of in-row subsoiling on crop yields will vary with factors such as crop, soil type, and climatic conditions

Table 1. Effect of tillage and in-row subsoiling on three-year relative yields for four soils using conventional tillage (moldboard plow) as a standard.

Tillage	In-row subsoil	Decatur silt loam	Hartsell sandy loam	Cabaha sandy loam	Dothan sandy loam
Convent.	No	100	100	100	100
	Yes	97	95	145	149
None	No	112	105	86	72
	Yes	113	110	125	134

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during the growing season. The effects of in-row subsoiling on corn yields are illustrated in **Table 1.** The Decatur silt loam and Hartsell sandy loam generally do not develop root-restricting plow pans, and regardless of tillage system, in-row subsoiling doesn't have much effect on yields.

The Cabaha and Dothan soils, however, will develop severe root restricting hardpans, and in-row subsoiling can greatly improve yields regardless of tillage system. Low yields with no-till without in-row subsoiling are probably results of surface soil compaction plus root restricting plow pans. The in-row subsoilers only shatter soil strips 8 to 10-inches wide at the soil surface and do not always eliminate surface soil compaction in the row middles which may explain why no-till plus subsoiling resulted in lower yields than conventional tillage plus subsoiling.

Data from recently conducted research indicate that in soils and years where no-till plus subsoiling result in lower yields than conventional tillage plus subsoiling, yield reductions with no-till may be due to poor nutrient availability. Greater yield response to fertilizers placed in subsoil tracks at planting have been obtained with no-till than with conventional tillage for corn **(Table 2)** and sorghum **(Table 3).** In some studies, no-till cotton did not respond to in-row subsoiling unless fertilizers were placed in the subsoil track at planting.

In-row subsoilers are not an absolute answer to soil compaction, and in some situations, their use creates problems. Horsepower requirements often exceed 30hp/row, and in addition, planting speeds are slow. Minimum row width is generally 30 inches or greater. Seedbeds behind the shanks are sometimes rough and cloddy, and seed/soil contact is not adequate for acceptable germination and stand establishment. In early spring, planting is sometimes delayed 1 to 3 weeks because of high soil moisture a few inches below the soil surface. With some soils, yield responses to in-row subsoiling are negative as often as they are positive. The criterion for in-row subsoiling is simple: **"If there is a need for in-row subsoiling, economical crop yields are difficult to obtain without their use; but if not needed, their use may result in uneconomical yields."**

The major problem is that on many soils it is difficult to determine whether or not there is a need for in-row subsoiling, primarily because the need for subsoiling varies with many factors such as type of crops being grown, varieties, previous crop and tillage system, and climatic conditions during the growing season. ■

Table 2. Corn grain yields from a Dothan sandy loam soil as affected by tillage, in-row subsoiling, and starter fertilizer applied at planting.

N-P-K Fertilizer	In-row Subsoiled	Till	No-till
lb/A		------ bu/A ------	
0	No	41	33
	Yes	110	109
20-0-0	No	51	52
	Yes	117	111
20-20-0	No	56	57
	Yes	122	125
20-20-8	No	55	57
	Yes	121	130

Soil test: P, K, Ca, Mg all high; pH 6.0

Table 3. Yield of grain sorghum planted with an in-row subsoiler as affected by tillage, starter fertilizer (100 lb/A of 20-18-0) applied in the in-row subsoil track, and sidedressed N.

Sidedress N	Starter fertilizer	Grain Yield	
		Till	No-till
lb/A		------ bu/A ------	
0	No	44	39
	Yes	55	50
40	No	71	62
	Yes	73	72
80	No	81	72
	Yes	83	85
120	No	81	76
	Yes	81	92

Soil test: P, K, Ca, Mg all high; pH 6.1

Fertilizer Management in Conservation Tillage of Pacific Northwest Cereals

By Paul E. Rasmussen

CONSERVATION TILLAGE, which leaves crop residue near the soil surface for erosion control, requires changes in fertilization practices to maximize fertilizer efficiency. Nitrogen (N) and sulfur (S), the most needed nutrients for wheat and barley grown in the Pacific Northwest, are subject to substantial "immobilization" by residue-decomposing organisms at about the time when young plants have their highest nutrient uptake rate.

Nutrients with limited mobility in soil, such as phosphorus (P), potassium (K), and zinc (Zn), may be deficient during early seedling growth because of less-developed root systems induced by cooler soil temperature, antagonistic effects of soil pathogens, and poorer seed/soil contact. Nutrient availability also becomes much more critical when annual cropping replaces a cereal/fallow rotation because there is no fertility buildup from fallowing.

Banding of fertilizer usually produces higher yields than broadcasting when residues are left on or near the soil surface. Banding was superior to broadcast in 4 of 6 conservation tillage experiments receiving N plus P and S **(Table 1).** Broadcasting was especially inferior when only N was applied (see 1983 and 1984 results). Apparently broadcast N stimulated microbial activity in the residue zone and immobilized native soil P and S whereas N banded below the residue did not, thus leaving more P and S available to young wheat plants. These data illustrate the need to correct all nutrient deficiencies as well as use proper placement of fertilizer to obtain maximal yield in conservation tillage.

The need for P and S fertilization to obtain maximum yield from N is further illustrated in **Figure 1.** Winter wheat and spring barley yields with NPS fertilization were two to fourfold higher than the unfertilized check, and nearly double the yield of N alone. Fertilizers in this experiment were banded below the seed to insure maximum availability. When not

Table 1. The effect of fertilizer placement on wheat yield with conservation tillage.

Year	Crop†	N applied (lb/A)	P & S applied‡	Fertilizer broadcast	Fertilizer banded
				----- Grain yield, bu/A -----	
1981	S. Wheat	80	yes	29	31*
1981	S. Wheat	80	yes	21	29*
1982	W. Wheat	80	yes	54	70*
1982	W. Wheat	80	yes	80	79
1983	W. Wheat	120	no	33	58*
1983	W. Wheat	120	yes	64	65
1984	W. Wheat	100	no	31	47*
1984	W. Wheat	100	yes	66	73*

†S. Wheat = Spring Wheat; W. Wheat = Winter Wheat (Northcentral Oregon)

‡Soil test values were medium for P and low for S at all sites. P_2O_5 application rate: 20 to 30 lb/A; S application rate: 12 to 20 lb/A.

* = significant yield increase from banding (5% probability level).

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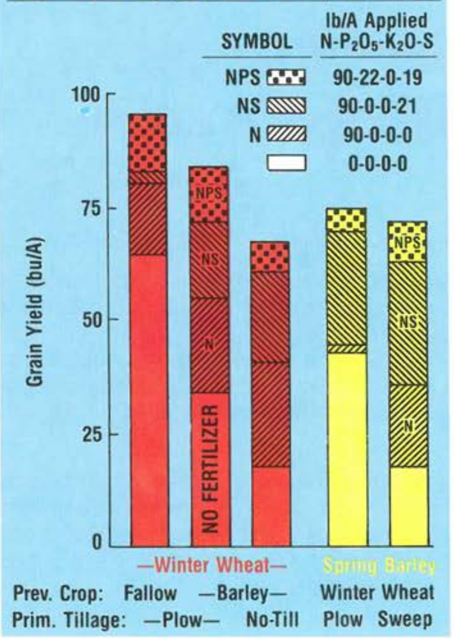
Figure 1. Winter wheat and spring barley response to nitrogen, sulfur, and phosphorus.



fertilized, annual-crop yield was 59% of the yield following fallow, and conservation tillage yield was 47% of conventional-tillage yield. With NPS fertilization, these percentages were 83% and 88%, respectively.

To insure the highest efficiency, fertilizer applied in conservation tillage should be deep banded below the zone of residue accumulation (the upper 4 inches of soil). Fertilizer application can be coupled with tillage operations in minimum-till, or seeding in no-till, to achieve vigorous early growth of cereals while minimizing the number of trips across the field. When applied before seeding, band spacing is important since nutrients (especially P) may not be readily available during early plant growth if located more than 6 inches laterally from the seed.

Listed below are several application options for conservation tillage which avoid broadcasting fertilizer. All options which involve fertilization at seeding require equipment modification or addition.

1. **Deep band (6 inches deep) all fertilizer before seeding with 12 to 18 inch band spacing.** The wide band spacing may lower the efficiency of fertilizer utilization, especially P and N applied to spring cereals. This application method is not possible for no-till seeding.
2. **Deep band most of the N and S with a 12 to 18 inch spacing; apply some of the N and S, and all the P with the seed as a starter fertilizer.** More than 20 lb/A N plus S as a starter will delay emergence and may reduce stand if soil temperatures are high and soil moisture is low. Up to 40 lb/A N plus S can be applied with the seed if the soil is cool and wet. This requires minimum drill modification.
3. **Apply starter fertilizer containing N, P and S with the seed at rates described in No. 2.** Apply the remainder of the N as a spring topdress when the crop is in late tillering stage. However, if grassy weeds are not controlled completely, topdressed N will stimulate their growth substantially and increase competition for nutrients and water.
4. **Band the N and S between the row at seeding about 6 inches deep and apply a starter fertilizer with the seed.** This procedure is utilized by some of the commercially-available no-till drills. Other drills require modification. Either liquid or granular fertilizers may be used. Starter fertilizer with the seed can usually be omitted if row spacing is less than 8 inches.
5. **Band all of the N, P and S below the seed at seeding.** This is the most efficient method of application, especially for no-till, but requires either a modification of the seed opener or a separate shank placed ahead of the opener. Fertilizer should be placed at least 2 inches below, or below and to the side of, the seed to avoid seedling injury. Anhydrous ammonia injection directly below the seed is not recommended because of possible migration into the seed zone without proper closure of soil behind the shank. ■

In the Pacific Northwest

Optimum Fertilizer Placement with Reduced Tillage Systems

By B. R. Bock and R. L. Wilson

IN THE PACIFIC NORTHWEST, reduced-tillage systems must function with relatively high levels of crop residue on the soil surface in order to adequately control soil erosion. This is because of steep slopes, up to 50%, and predominantly winter precipitation that occurs when crops provide little protection from erosion. Thus, TVA-supported fertilizer research in the Pacific Northwest has emphasized reduced-tillage systems that leave most or all of residues from the previous crop on the soil surface.

Optimizing fertilizer placement with reduced tillage requires an integrated systems approach because placement affects not only fertilizer use by the crop but also several other important systems considerations. This article reviews systems considerations for optimizing fertilizer placement with reduced tillage. Our remarks are limited to small grain production in the inland Pacific Northwest.

Systems Considerations

Fertilizer placement has important effects on fertilizer uptake and use by crops under reduced tillage in most regions. With reduced tillage, fertilizer placement can also have important effects on weed control; residue clearance and seed placement with drills; moisture conservation; and labor, fuel, and equipment requirements as outlined below. Fertilizer placement effects on weed control and drill performance appear to be particularly important for reduced-tillage small grains in the Pacific Northwest.

Efficient Fertilizer Use by the Crop—Particularly where there is inadequate tillage to incorporate broadcast fertilizer, evidence suggests that N, P, and S are used more efficiently with subsurface banding than with broadcasting in the Pacific Northwest. For example, in a three-year no-till study, subsurface banding of N and S increased yields an average of 4 bu/A for winter wheat and 11 bu/A for spring wheat. The greater advantage for subsurface banding of N and S with spring small grains has been reported in other studies.

There has been little evaluation of broadcast P with reduced tillage in the Pacific Northwest. However, researchers predict there is often too little root activity near the soil surface to enable efficient recovery of relatively immobile P from broadcast, unincorporated applications. As with conventional tillage, less P fixation by soil is expected with banding than with broadcasting. Thus, it appears that some method of subsurface banding will be required for efficient use of N, P, and S fertilizers by reduced-tillage small grains in the Pacific Northwest.

Weed Control—Weed control considerations also favor subsurface fertilizer banding with reduced-tillage small grains, particularly if fertilizer can be banded with minimum disturbance of soil and residue. Broadcast, unincorporated fertilizer often

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stimulates germination and growth of weeds in the Pacific Northwest, especially downy brome and wild oats. Also, nitrification of broadcast ammonium fertilizers (including urea) lowers pH at the soil surface, a process known to reduce the activity of certain herbicides. Eliminating these problems by banding fertilizer below the soil surface should result in more effective and less costly herbicide programs.

However, soil disturbance associated with subsurface banding can stimulate weed germination in the injection zone, in which case fertilizer is positioned favorably for the weeds. Thus, subsurface banding with minimum soil disturbance is desirable. Another way to minimize this problem is to band fertilizer below or slightly to the side and below seed rows to enhance crop competition with weeds in the fertilizer injection zone. This requires fertilizer application during seeding.

Optimum fertilizer placement can't substitute for other weed control practices but can complement them.

Residue Clearance and Seed Placement with Drills – By loosening soil and crop residue, preplant subsurface banding of fertilizer can cause residue plugging and poor seed placement in the subsequent seeding operation, particularly with high levels of wheat and barley residue common to the Pacific Northwest. These problems arise mainly because the shearing action of coulters and disk openers and the orientation of loosened residue relative to seed openers are less than optimum for proper drill operation.

Adverse effects of preplant subsurface banding on the subsequent seeding operation can be reduced by applying fertilizer well in advance of seeding, allowing natural soil firming before seeding, and by seeding diagonally relative to direction of fertilizer banding.

Moisture Conservation – Soil moisture conservation is particularly critical in the intermediate and low rainfall areas of the inland Pacific Northwest. In terms of subsurface fertilizer placement, banding techniques that give the least disturbance of soil and residue will likely be most effective in conserving soil moisture. Compared with preplant subsurface banding, the one-pass concept holds promise for subsurface banding with less soil and residue disturbance and enhanced moisture conservation.

Labor, Equipment, and Fuel Requirements – Compared with preplant subsurface banding and subsequent seeding, seeding and subsurface banding in one operation obviously eliminates a trip over the field. However, some savings associated with eliminating preplant banding are offset in the one-pass concept by time and labor requirements to tend fertilizer at seeding time, drill fertilizer attachments, heavier drills to penetrate hard soils and support fertilizer openers, and added power to pull heavier drills with fertilizer openers. Time and labor requirements for tending fertilizer are particularly critical if they delay seeding. Drill and draft requirements increase with depth of fertilizer banding.

In summary, efficient fertilizer use by reduced-tillage small grains in the Pacific Northwest is favored by subsurface banding but optimum placement relative to seed rows has not been well characterized. Sufficient separation between seed and fertilizer to avoid adverse effects on germination and seedling vigor will be required. Weed control is favored by subsurface banding near seed rows with minimum soil disturbance. Residue clearance, seed placement, moisture conservation, and fuel and equipment requirements are favored by minimum disturbance of soil and residue.

It is obviously not feasible to achieve maximum effectiveness of fertilizer placement in reduced-tillage systems with respect to each of these considerations. A more realistic approach is to accept tradeoffs regarding some factors, and to seek maximum economic returns for the whole system rather than for each component. High yield levels will have to remain as an important characteristic of these systems to ensure widespread adoption of reduced-tillage practices in the Pacific Northwest.

We conclude that the one-pass concept holds promise for optimizing fertilizer placement for reduced-tillage small grains in the Pacific Northwest. ■

Soil Sampling

PROPER soil sampling techniques for soil tests in conservation tillage systems have received much attention. Some universities have completed research on sampling methods. Others have developed recommendations for soil test sampling for conservation tillage. The four articles on these pages represent some of the sampling methods, findings, and recommendations for soil testing in conservation tillage systems.

—Dr. W. R. Thompson, Jr.
Potash & Phosphate Institute

Sampling Soils for Testing Under Conservation Tillage

By E.E. Schulte and L.G. Bundy

THE PROMINENT FEATURE of conservation tillage systems is the crop residue left on the soil surface. This residue reduces the harmful effects of raindrop impact on soil structure and reduces the rate of downslope movement of water and sediment. The surface residue is a result of reduced tillage which also reduces incorporation of surface applied nutrients. Hence, many researchers have observed a stratification of P and K after a few years of conservation tillage.

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Soil Sampling for No-till: How Different Is It?

By Lloyd Murdock

MANY FARMERS became so dependent on tillage that it was difficult to understand how no-tillage could possibly be successful. But it did become successful, and with amazingly few changes. Even though fertilizer is simply broadcast on the soil surface for no-till, it is readily available to the plant.

With this method, immobile or slightly mobile nutrients, such as phosphorus (P), potassium (K) and calcium (aglime) form a horizontal band on the surface of the soil. In effect, it is a form of banding fertilizer and is probably one of the reasons it is readily available to the plant.

This type of fertilization program presents a problem in soil testing. The slow moving nutrients such as P and K remain near the surface of the soil and questions arise: **1) How deep should one sample? 2) Should the fertilizer recommendations change?**

Research in Kentucky and surrounding states indicates that the fertilizer recommendations of P and K should remain the

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Soil Sampling in No-tillage Cropping

By Donald D. Tyler

NO-TILLAGE crop production has gained wide acceptance in many areas of the United States. In continuous no-tillage cropping, fertilizer nutrients such as nitrogen (N), phosphorus (P), and potassium (K) are typically broadcast and not mixed with the soil. With conventional-tillage, fertilizer is usually partially mixed with the soil to the depth of tillage. Many soil testing labs choose an approximate mixing depth of 6 inches to convert nutrient concentration to a soil weight-volume basis. This allows nutrient concentrations to typically be reported as pounds per acre (lb /A) in a 6-inch furrow slice. **Many soil test correlations were established using a six-inch soil depth nutrient concentration to compare with applied fertilizer yield response. However, broadcast application in no-tillage systems may result in nutrients and acidity accumulating near the soil surface.**

This nutrient accumulation was evaluated in Tennessee after 5 years (1979-83) of continuous no-tillage and conventional-tillage corn. The no-tillage corn was planted in a chemically-killed wheat cover crop. Five nitrogen rates, 0, 50, 100, 150, and 200 lb N/A as ammonium nitrate at two application times, were compared in each tillage system. The soil was a Loring silt loam (Typic Fragiudalf). Plots were limed

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Dr. Tyler is Associate Professor, Plant and Soil Science, University of Tennessee. We gratefully acknowledge the cooperation of the Ames staff and the Ames Foundation under terms of a perpetual trust to the University of Tennessee by Mrs. Julia C. Ames.

Soil Sampling for Best Results in Continuous No-till Fields

By M.J. Letaw, V. Allan Bandel, and M.S. McIntosh

UNDER NO-TILL MANAGEMENT, fertilizers are generally broadcast on the soil surface or banded near the seed at planting. Under conventional tillage, lime and fertilizer are usually mixed into the plow layer. Since there is generally no mechanical cultivation for no-till corn, one or more herbicides, often including a triazine, are applied to the soil surface for annual broadleaf and grass weed control. An increase in soil acidity and organic matter enhances soil adsorption and deactivation of the triazines. This subsequently decreases herbicide persistence and phytotoxicity.

Researchers have reported that applications of nitrogen fertilizers in the ammonium form increase soil acidity following nitrification. Acidity is more of a problem under no-tillage because acid-forming fertilizers, primarily nitrogen types, are usually concentrated near the soil surface. In one study, researchers measured weed control in corn under no-tillage with and without lime applications. Weed control increased from 46% to 80% with lime additions. Another study found a greater pH response to lime applications near the surface on soils under no-tillage than those under conventional tillage.

Fertilizer applications on untilled soils may also affect available P and K levels. It has been reported that P and K from fertilizer applications accumulate in approximately the 0 to 2-inch layer. Since soil test levels were not uniform with depth, soil sampling depth needs to be considered when fertilizer recommendations are developed.

In Maryland, as well as many other areas, lime and P and K fertilizer recommendations are developed on the basis of soil test pH and available P and K levels in the

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Sampling Soils for Testing Under Conservation Tillage
By E.E. Schulte and L.G. Bundy
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The data in **Table 1** are typical. There appears to be little difference between disking and no-till with regard to vertical distribution of P and K. In all reduced tillage systems, stratification intensifies with time. Nevertheless, in humid regions of the Corn Belt, it has yet to be demonstrated that surface-applied nutrients are unavailable to crops. Purdue research has shown greater proliferation of corn roots in the top three inches of soil under no-till compared with conventional tillage.

Table 1. Influence of continuous tillage methods on the distribution of soil P and K within the 0 to 12 inch profile at Waseca after four years (1973) and eight years (1977).*

	Primary tillage			
Depth	Moldboard plow	Chisel plow	Disk	No tillage
	P (ppm) 1973			
0-2	34	49	54	54
2-4	34	38	28	24
4-6	33	19	15	16
6-9	24	9	8	12
9-12	12	4	4	4
	1977			
0-2	28	57	68	69
2-4	29	52	53	43
4-6	32	38	25	22
6-9	35	18	14	17
9-12	22	9	8	12
	K (ppm) 1973			
0-2	160	260	290	270
2-4	135	150	150	130
4-6	125	115	95	100
6-9	120	100	85	95
9-12	100	95	85	85
	1977			
0-2	135	265	290	300
2-4	125	195	160	175
4-6	135	135	110	105
6-9	130	95	90	95
9-12	125	90	85	100

*Randall, 1980.

In Minnesota research, the 10-year average corn yield in no-till cropping was 15 bu/A lower than in moldboard plowing **(Table 2)**; no-till yield was 11 bu/A less than disk tillage. Because there was little difference in nutrient distribution between no-till and disking **(Table 1)** some factor besides stratification must be responsible for the yield effects.

Table 2. Corn yield as influenced by nine years of continuous tillage at Waseca, Minn.*

Primary tillage	Grain yield 1979	10 year average
	---- bu/A ----	
Moldboard plow	177	138
Chisel plow	169	136
Disk	169	134
No-tillage	132	123

*Randall, 1980.

The results in **Table 1** are presented in ppm. If the data are converted to pounds per acre-increment, stratification is less pronounced. This has been done for the 1977 K data in **Table 3.**

Table 3. Conversion of K data (1977) in ppm from Table 1 to lb/A increments.

Depth increment	Moldboard plow	Chisel plow	Disk	No tillage
inches	------- lb/A increment* -------			
0-2	77	151	166	171
2-4	71	111	91	100
4-6	77	77	63	60
6-9	111	81	77	81
9-12	107	77	73	86
Total	443	497	470	498

*Assumes 2 million lb of soil per 7-inch soil layer.

Numerous studies have shown that soil under reduced tillage is higher in moisture than conventionally plowed and tilled soil. So long as the soil is moist, plant roots should be active near the surface and extract nutrients applied at the surface. In subhumid areas there might be

IN THIS PLOT, the middle row received no starter fertilizer. The row to the left received 133 lb/A of 6-36-9, while the row to the right received 100 lb/A of 8-48-12.

cause for concern about positional unavailability of surface-applied nutrients during periods of prolonged moisture stress. In Wisconsin, however, and other humid areas of the Corn Belt, prolonged drought is less likely. During short drought periods, plants can draw from nutrients further down the profile. Thus, we recommend that soil P and K (and pH) be brought up to "high" levels throughout the plow layer before going into conservation tillage.

Acidity produced by nitrification of ammonium nitrogen in surface-applied fertilizers can cause development of a low pH soil layer near the soil surface. Low pH at the soil surface can reduce the effectiveness of triazine herbicides such as atrazine, simazine (Princep), cyanazine (Bladex) and metribuzin (Sencor and Lexone). The availability of some plant nutrients, such as phosphorus, can be reduced in the acid soil layer, and, at very low pH levels, aluminum or manganese toxicity is a potential problem.

Sampling Soils for Testing

The distribution of nutrients and localized changes associated with conservation tillage systems indicate that some adjustments in soil sampling methods are needed to obtain reliable estimates of lime, P and K requirements in conservation tillage systems. What sampling depth best reflects the nutrient status of the soil? Unfortunately, there has been little research to answer this question. Moreover, present P and K recommendations have been based on "plow layer" sampling. Because most of a plant's feeder roots are found in the top six inches of soil, there is little justification for changing the recommended depth of sampling until research indicates that some other depth is preferable.

Following are the sampling recommendations for conservation tillage in Wisconsin. Regardless of the tillage method, basic procedures for taking reliable samples must be followed. These include considerations of area per sample, number of cores per composite sample, areas to avoid, etc., and will not be discussed here. Where localized placement of fertilizer has been practiced, special care must be taken to obtain a representative sample.

Chisel plowing and offset disking. Take soil samples to three-fourths of the tillage depth used. When possible, take soil samples before fall or spring tillage. Sampling depth can be determined more accurately, and fertilizer bands applied for the previous crop can be avoided when fields are sampled before tillage.

No-till. Take soil samples to a depth of 7 inches for fertilizer recommendations. Sample between rows to avoid old fertilizer bands. When N is surface-applied, take an additional shallow sample (0 to 2 inches) to monitor pH changes and development of an acid layer near the soil surface. Be sure to notify the soil testing lab of the sampling depth.

Till-plant and ridge tillage. Sample ridges to the 6-inch depth and between rows (furrows) to a depth of 4 inches. Combine soil cores from ridges and furrows in equal numbers to make up the composite sample. ■

Soil Sampling for No-Till: How Different Is It?

By Lloyd Murdock

(continued from page 20)

same. It also indicates that the soil sampling depth should change. A depth of sampling is necessary that will give no-till similar soil test readings as conventional tillage for similar crop responses to P and K.

The differences in soil sampling depth will be most important on low testing soils that are in continuous no-till for a number of years. If the soil tests high in P and K before one begins no-till, then the differences between horizontal banding in the surface (top 2 to 3 inches) and the lower levels of the tillage zone are much smaller. Therefore, the differences in soil sampling by depth will not be great.

If a farmer has a no-till system that uses some tillage from time to time, then this stratified zone of nutrients at the surface will be incorporated into the tillage zone and again the differences due to sampling depth will be reduced and more closely reflect a conventional system.

Let's take the worst case situation (low soil test of P and K and continuous long-term no-tillage) and see what different soil sampling depths give us. The present recommended sampling depth for conventional tillage is to the depth of the tillage zone. In most cases this is 6 to 8 inches. Since an acre furrow slice is considered 6-⅔ inches, many calculations and assumptions in soil testing are based on soil sampling to this depth.

Table 1 shows the effect of different sampling depths with the conventional and no-tillage systems in this type of situation. The site was sampled in one-inch increments to allow calculations of this type. As can be seen in the table, the nutrients (P and K) are thoroughly mixed through the profile with the conventional tillage and so depth of sampling is not nearly as critical. With no-till, soil test values drop rapidly as the soil sampling depth increases. This is an indication of the stratification of these nutrients at the soil surface and the natural low fertility of this soil.

The 4-inch sampling depth in no-tillage corresponds closely to the 7-inch depth in conventional tillage. These values are identified by asterisks (*) in **Table 1.** The comparison is very close with P and close with K. Any other depth would be more of a compromise. The K accumulation at the soil surface in the no-tillage plots is not as great in this experiment as is sometimes experienced in no-till situations. Based on a number of experiments like these, a soil sampling depth of 4 inches was chosen as the depth that would most closely correlate soil test results of conventional and no-till systems that had received equivalent fertility.

With this approach, the only change

Table 1. Comparison of P and K soil testing results with depth of sampling from initial low testing soil using both conventional and no-till systems.[1]

Soil Sampling Depth	Soil Test Results (lb/A)			
	P[2]		K[2]	
Inches	Conventional[3]	No-till[3]	Conventional	No-till
0 to 1	48	80	426	320
0 to 2	44	55	330	259
0 to 3	43	42	290	220
0 to 4	42	35*	268	198*
0 to 5	39	30	249	181
0 to 6	36	27	231	168
0 to 7	33*		215*	

[1] Initial soil test was very low in P and low in K. The experiment ran 7 continuous years with 90 lb/A P_2O_5 and 120 lb/A K_2O added each year. The average yields were about 120 and 140 bu/A for conventional and no-till, respectively.

[2] P soil test was using weak Bray (P_1) and K soil test was neutral normal ammonium acetate.

[3] Conventional tillage was moldboard plow and disk. No-till involved planting and no additional tillage.

that is necessary is depth of soil sampling. Fertilizer recommendations based on soil test values for both conventional and no-tillage would remain the same. The compensation would be made in soil sampling.

Just as important as nutrient stratification is the pH stratification that occurs in no-till. Table 2 shows the radical pH drop that takes place when nitrogen is added to the soil surface over a period of a few years. Most of the common sources of nitrogen (urea, ammonium nitrate, and liquid N) have high amounts of the ammonium form of nitrogen that is responsible for this pH drop as the ammonium nitrifies. Most of this pH change takes place in the top 2 inches of the soil.

Table 2. Changes in pH with different soil depths and tillage after five years of corn production on an acid soil.

Soil Depth	pH		
Inches	Initial[1]	Conventional	No-till
0 to 2	5.7	5.2	4.6
2 to 4	5.7	5.4	5.5
4 to 8	5.5	5.6	5.5
8 to 12	5.1	5.2	5.1

[1] pH of the soil prior to experiment.

The soil in **Table 2** is quite acid. Consequently the differential pH between the top 2 inches and lower zones is not as great as it would be in a soil with a higher natural pH. Soil sampling of no-till to depths greater than 4 inches could easily dilute the low pH zone at the surface to the point that it would be dismissed as a slightly acid profile rather than a strongly acid soil surface. This would be a serious problem not only in terms of crop production but also with weed control. Sampling depths of less than 4 inches would increase the sensitivity of the test for recognizing the surface pH zone, but it would also require a separate lime recommendation for no-till since the zone tested would be only 2 inches in depth.

Based on the above arguments, the soil sampling depth for no-till is recommended to be 4 inches. Most no-till farmers perform some tillage operations every second or third year. Although this tillage may be no more than a disking, it mixes the nutrients in the top few inches and makes the soil sampling depth less critical. The 4-inch soil sampling depth is still recommended for these farmers if the tillage is only occasional. This recommended sampling depth has worked well on the medium textured soils in Kentucky. Modifications may be necessary for soils high in sand or clay or under highly different enviromental conditions. ■

Soil Sampling in No-Tillage Cropping
By Donald D. Tyler (continued from page 21)

before the second growing season. Initial soil test levels were 40 lb P/A (high) and 210 lb K/A (high) based on a 6-inch sample. Annual applications of 60 lb P_2O_5 and 60 lb K_2O per acre were applied to the entire area to prevent these nutrients from becoming limiting. Each plot was sampled in the fall of 1983 after the fifth corn harvest. The depths sampled were 0-2, 2-4, 4-6, and 0-6 inches. Samples were analyzed at the University of Tennessee soil test lab for P and K.

Analyses of shallow (0-2 or 0-3 inch) samples from no-tillage plots in Tennessee and other states have shown a problem of severe surface acidity resulting from the use of high N fertilizer rates. In some cases, a standard 6-inch sample will buffer the very acid surface inch or two when mixed with the lower 4 to 5 inches of the "plow layer." The inability to adequately find the surface acid layer in a 6-inch sample led many states, including Tennessee, to recommend shallow sampling for no-tillage crops. This does help in evaluating surface acidity. In no-tillage, a shallow sample may also contain higher levels of P and K than the plow layer as a whole.

Distribution differences for P and K in our study at the 150 lb N rate are shown in **Figures 1** and **2.** Phosphorus, and to a lesser extent, potassium have become concentrated in the top 2 inches of soil with continuous surface application and no soil mixing.

Accumulation of nutrients near the surface has produced some questions concerning the soil weight-volume calculation procedures designed for a 6-inch sample. Presently, in Tennessee and most other states, no provision has been made for shallower sampling depths in calculating and reporting results in lb /A. Most soil test labs assume the sample's parts per million (ppm) concentration is distributed evenly through the surface 6-inch-acre-furrow slice.

An approximate soil weight of 2 million lb per 6-inch-acre-furrow slice is used for conversion from concentration to lb /A. This conversion proceeds as follows: A one ppm P concentration is one lb P/1 million lb of soil or 2 lb P/2 million lb soil (2 lb /A). This multiplication by 2 allows rapid conversion of soil test levels from ppm to lb /A. This conversion is nearly accurate in Tennessee as long as the sample represents the top 6 inches of soil.

As seen in **Figure 1,** the top 2 inches do not reflect the P concentration in the top 6 inches for the no-tillage system. The P concentration in the top 2 inches was 51

Figure 1. Phosphorus distribution in pounds per sampling depth after 5 years of conventional and no-tillage corn.

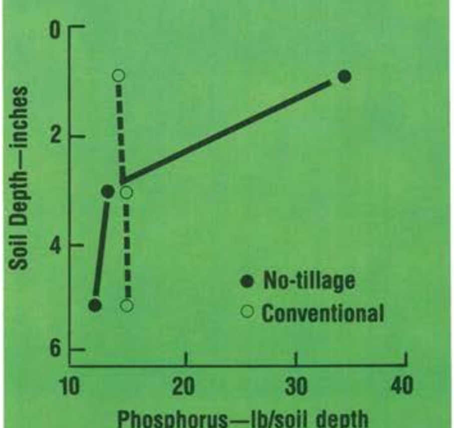
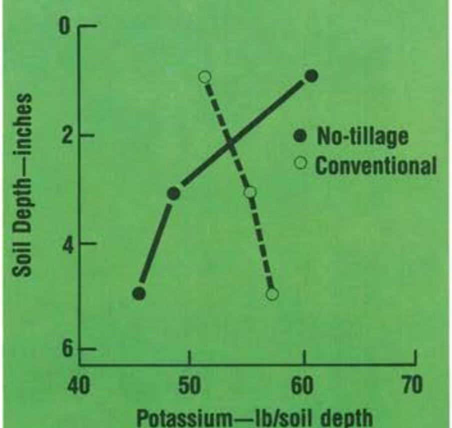


Figure 2. Potassium distribution in pounds per sampling depth after 5 years of conventional and no-tillage corn.



ppm but this concentration was present in only about 666,667 lb of soil. Correcting for soil volume results in 34 lb P present. However, without the correction for depth, many soil test labs would report the value as 102 lb P/A (51 ppm x 2). If the separate 0-2, 2-4, and 4-6 inch samples are computed on sample depth volume and added, the total is 59 lb P/A as compared to 67 lb P/A found in the separate 0-6 inch sample. Conventional-tillage gave a more uniform P distribution throughout the top 6 inches. The top 2 inches had a concentration of 19 ppm P. Corrected for depth this is 13 lb P. Since the P concentration is more evenly distributed, any sampling depth increment in the top 6 inches adequately reflects the P concentration. The 2-inch sample would result in a reported lab value of 38 lb P/A, very close to that found from the 0-6 inch sample which was 43 lb P/A. Adding the 0-2, 2-4, and 4-6 inch samples corrected for soil volume gives a value of 41 lb P/A. The same calculation problems occur with potassium but not to the same extent. This is partly due to greater potassium mobility.

Clearly, P can build up near the surface in continuous no-tillage cropping. Fertilizer recommendations can be incorrect with the present calculation procedure when this "buildup area" is sampled. An example is shown in **Table 1.** The 0-3 inch soil depth had a concentration of 16 ppm or approximately 16 lb P in 1 million lb of soil. While the 3-6 inch depth was not measured, if it contained zero to very low P the total extractable P for the 6-inch layer is only 16 lb. Presently, many soil labs would calculate, report, and make fertilizer recommendations based on 32 lb P/A (16×2). **This incorrectly changes the soil test level from low to high. Of course, the amount of P contained in the 3-6 inch depth may range from a low to a very high level but this cannot be determined from a 0-3 inch sample.**

Table 1. Example of potential problem in calculating lb/A of phosphorus (P) from a 3-inch soil sample and making subsequent fertilizer recommendations based on normal 6-inch sample procedure.

Soil depth [1] inches	P Measured [2] ppm	Soil P level, lb/A		Soil P rating [5]	
		Measured [3]	6-inch procedure [4]	Measured	6-inch procedure
0-3	16	16	32	Low	High
3-6	Unknown	Not made		Not made	

[1] 0 to 3 inches of soil considered to weigh 1 million lb/A; 0 to 6 inches considered to weigh 2 million lb/A

[2] Mehlich 1 (Double acid) method

[3] 16 ppm x 1 million lb/A = 16 lb/A

[4] 16 ppm x 2 million lb/A = 32 lb/A

[5] Soil test range for Tennessee: 0-18 lb/A P, low; 19-30 lb, medium; 31-120 lb, high.

What are possible solutions to sampling depth problems in no-tillage? If a no-tillage cropping system involves almost no soil mixing and high rates of N fertilizer are used, a shallow sample may be necessary to detect acid layers. If this sample is used for P and K measurements, adjustments in calculation should be made. An alternative would be two samples, a shallow one for pH, and a deeper sample for P and K. Recorrelation of P and K levels at shallow depths with yield response should not usually be necessary since surface applications have been found to adequately fertilize the crop.

Under most conditions, knowing the total extractable P in the top 6 inches is more important than the way the P is distributed.

Shallow sampling does not appear to be necessary if sufficient tillage is done in a crop rotation system to mix P, K, and acidity. Even in continuous no-tillage systems the acid layer will probably develop much more slowly if the particular crop does not require high N fertilization. All things considered, many states should probably use the same soil sampling depth in no-tillage that is being used with conventional-tillage. ■

Soil Sampling for Best Results in Continuous No-till Fields

By M.J. Letaw, V. Allan Bandel, and M.S. McIntosh (continued from page 21)

0-8 inch soil depth (plow layer). It is questionable whether the 0-8 inch sampling depth is best suited for developing appropriate lime and fertilizer recommendations under continuous no-tillage.

Therefore, the objectives of this investigation were: 1) to determine the maximum depth in the 0-8 inch layer from which a soil sample could be taken in a continuous no-till field and still accurately reflect the soil pH of the 0-1 inch layer, and 2) to correlate surface soil test P and K values with those from the entire plow layer.

No-till corn tests for this project from 1980-1982 were on three sites: A. the Forage Research Farm near Clarksville, MD on a Delanco silt loam (fine silty, mixed, mesic Aquic Hapludult); B. Wye Institute near Queenstown, MD on a Mattapex silt loam (fine silty, mixed mesic Aquic Hapludult); and C. Poplar Hill on a Matapeake silt loam (fine silty, mixed, mesic Typic Hapludult).

At site A, ammonium nitrate was broadcast at rates of 0, 80, 120, 160, or 240 lb N/A before planting each year. No lime applications were made in 1981. **At sites B and C,** potassium chloride at rates of 0, 33, 66, 100, or 133 lb K/A and concentrated superphosphate at rates of 0, 18, 35, 53, or 70 lb P/A were broadcast each year before planting. On all tests, paraquat, simazine and atrazine were used for weed control. Pioneer 3184 corn was planted in May each year and grain was harvested from each location.

N Effect

A significant N rate effect on soil pH occurred at site A (Table 1). As N fertilization rate was increased, soil pH measurements decreased at all six sampling depths. Soil pH was significantly influenced by an N rate x sampling depth interaction. As N rates were increased, soil pH decreased more rapidly at shallow sampling depths than at deeper sampling depths.

Soil pH decreased as the rate of N fertilizer increased, probably due to increased nitrification. This increased soil acidity was more concentrated near the soil surface because the nitrogen fertilizers had been surface applied.

Table 1. Influence of Variable N Rate and Sampling Depth on Soil pH Under No-tillage.

N	Sampling Depth (inches)						
Rate	0-1	0-2	0-3	0-4	0-6	0-8	Mean
lb/A	pH						
0	7.3[1]	7.4	7.3	7.3	7.2	7.1	7.3
80	7.0	7.1	7.0	7.1	7.0	6.9	7.0
120	6.4	6.4	6.5	6.5	6.5	6.5	6.5
160	6.1	6.2	6.3	6.4	6.4	6.6	6.2
240	6.1	6.2	6.3	6.4	6.4	6.6	6.3
Mean	6.6	6.6	6.6	6.7	6.7	6.7	6.7

[1] Mean of two sampling dates and four replications. Site A—Forage Research Farm. 1981-1982.

K Recommendations

Currently, at the University of Maryland, K levels at the 0-8 inch depth have been categorized into several soil test K ranges which are used as a basis for K fertilizer recommendations **(Table 2).** Limiting values from these present soil test K ranges at 0-8 inches were entered into the appropriate regression equation to predict new values that might be used to limit soil test K in samples taken from the 0-2 inch layer. For instance, a soil test K value of 30 lb/A, representing one boundary of a VL soil

Table 2. Comparison of Soil Test K Ranges at 0-8 inches and Predicted Soil Test K Ranges at 0-2 inches.

Soil Test K Range	Current[1] Univ. of MD 0-8 inches	Predicted[2] (Average) 0-2 inches
	lb/A	
Very Low	0- 29	0-101
Low	30- 70	102-146
Medium	71-134	147-215
High	135-268	216-363
Very High	269 +	364 +

[1] Soil test K ranges at 0-8 inches presently in use for K fertilizer recommendations in Maryland.

[2] Predicted soil test K range at 0-2 inches based on linear regression utilizing soil test K at 0-8 inches as independent variable.

Table 3. Comparison of Soil Test P Ranges at 0-8 inches and Predicted Soil Test P Ranges at 0-2 inches.

Soil Test P Range	Current [1] Univ. of MD 0-8 inches	Predicted [2] (Average) 0-2 inches
	lb/A	
Very Low	0-12	0- 14
Low	13-27	15- 53
Medium	28-45	54-107
High	46-90	108-238
Very High	91 +	239 +

[1] Soil test P ranges at 0-8 inches presently in use for P fertilizer recommendations in Maryland.

[2] Predicted soil test P range at 0-2 inches based on linear regression utilizing soil test P at 0-8 inches as independent variable.

test K range, was used as the independent variable in the regression equation. A new limit, 90 lb/A, was calculated and defined the boundary for a VL soil test K range at 0-2 inches under no-tillage at site B. Soil test K ranges for samples taken from 0-2 inches at site C were generated in the same way.

Variable P Test

The highest soil test P values at the sites B and C were measured in samples from the 0-2 inch depth. Fertilizer P, broadcast on the surface, did not move downwards appreciably.

The linear relationship between soil test P values at 0-2 inches and soil test P at 0-8 inches at sites B and C were determined. New limits for soil test P ranges at 0-2 inches were then calculated and tabulated.

The wider differences between the variable P regression equations at site B and at site C suggested that averaging the data generated by these equations may not be as reliable as the data generated by averaging results from the soil test K regression equations. However, these averaged values should certainly be more realistic as a basis for fertilizer recommendations than the ones currently in use. New soil test ranges based upon these regressions could be used as a basis for fertilizer recommendations when soil samples are taken from the 0-2 inch depth under no-tillage **(Table 3).**

Conclusions

In farming areas where no-tillage or conservation tillage use is on the increase, there will be more and more situations develop where certain fields will remain untouched by the moldboard plow for several consecutive years. In such cases, where the soil is not moldboard plowed for two or more years, it is highly likely that nutrient levels, and particularly soil pH will become stratified in the soil. Shallow, more frequent soil sampling should be encouraged to detect the development of this phenomena, and to make proper lime and fertilizer recommendations.

It is also necessary that soil test ranges be adjusted so that plant response correlation to soil tests compensate for these nutrient accumulations near the soil surface. If moldboard plowing occurs every couple of years, it is not likely that nutrient stratification will seriously interfere with soil test interpretations. Frequent (at least annual) soil sampling at the two inch depth is recommended in all no-tillage situations to monitor surface pH, and recommend corrective lime applications. If soil pH is not maintained at recommended levels, especially where pH sensitive weed control chemicals are used, reduced yields and profits will result. ■

Planting Alfalfa No-till

By Harlan E. White and Dale D. Wolf

MOST OF THE APPROXIMATELY 100,000 ACRES of alfalfa grown in Virginia are on sloping fields subject to erosion. Many fields contain rocks that, when brought to the surface by tillage equipment, make it difficult to prepare fine seedbeds.

Producers have welcomed the opportunity to establish alfalfa on these fields using no-till procedures, especially since yields from no-till plantings have been equal to conventionally planted fields **(Table 1).** Farmers especially like being able to seed without delay because of less time required for seedbed preparation and the ability to plant when prepared seedbeds are too wet or too dry. Essentially no alfalfa was seeded no-till until 1981 when the extension education program was initiated. In 1983 there were nearly 250 no-till drills available which were used to plant 9,200 acres of no-till alfalfa that year and 9,080 in 1984.

Several requirements for successful no-till establishment are:

1. **Competition from other plants must be minimized.**
2. **Heavy thatch and plant growth tall enough to shade the soil surface must be removed.**
3. **Protect the seedling from insects when seeding in sod.**
4. **Place seed no deeper than 1 inch.**
5. **Soil fertility must be medium to high with pH above 6.4.**
6. **Seed on the proper date.**

Table 1. Yields of no-till alfalfa planted at 2 dates into a tall fescue sod compared with conventional alfalfa planted into a seedbed prepared from the same tall fescue sod.

Seeding date	Conventional	No-till
	-------Tons per acre-------	
April 26	2.67	3.36
August 25	-----	-----
	Year after seeding	
April 26	5.70	5.44
August 25	5.10	5.03

The fertility program for no-till alfalfa is essentially the same as for alfalfa grown in tilled seedbeds. When seeding in soils testing medium for P_2O_5 and K_2O, apply 125 lb/A of each nutrient. On established stands in soils of above average productivity which test medium, topdress with 75 lb/A P_2O_5 and 165 lb/A of K_2O in late fall or after the spring harvest.

One of the primary concerns with soil fertility in no-till seeding is the inability to incorporate needed lime and fertilizer into the soil prior to seeding. It is emphasized to producers that soil pH needs to be adjusted by liming and that fertility must be raised to adequate levels in the cropping rotation at least one year in advance of no-till seeding.

No-till establishment of alfalfa is versatile and useful in many different cropping and forage systems. For example, spring no-till seeding into killed fescue sod, or August seeding after a summer annual "smother crop" are alternatives. Other choices include: spring no-till seeding in fields planted to corn the previous season; spring no-till seeding into small grain; or seeding into small grain stubble after a silage or grain harvest. ■

Note: More detailed information on various methods of no-till alfalfa seeding is available on request from the authors.

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Nutrient Losses in Runoff from Conventional and No-till Corn

By J. Scott Angle

NO-TILL CULTIVATION has long been known to reduce the quantity of runoff and associated sediment originating from agricultural land. The stubble-mulch residue on the surface of no-tilled land reduces runoff velocity and thus increases infiltration. The effect of no-till cultivation, however, on nutrient losses remains in question. Hence, the objective of the current study was to quantify nutrient losses from watersheds cropped to corn using conventional or no-till cultivation practices.

Two separate, but similar watersheds were instrumented to collect a small, known fraction of runoff. The following parameters were measured in each sample: sediment, ammonium-N, nitrate-N, total-N, ortho-PO_4, total soluble-P, and total-P. Results are expressed as the number of pounds of each material lost in runoff per acre. Results presented are a three-year average encompassing high, low, and intermediate rainfall years.

Total losses of runoff, sediment, and nutrients from both watersheds were found to be very low. Since an average of only 11 rainfall events each year produced runoff, little runoff was available to displace nutrients from the field. In general, an intense rainfall event was required for substantial nutrients to be lost via overland runoff.

While the total quantity of runoff, sediment, and nutrients lost from each watershed was small, significant differences in losses were observed between the conventional and no-tilled watersheds **(Table 1)**. No-till cultivation reduced the quantity of runoff originating from the watershed by over five times. Sediment carried with the runoff was also reduced by no-till cultivation. Sediment lost from the no-till watershed averaged 37 lb/A compared to 138 lb/A from the conventional-till watershed. The filtering capacity of the stubble-mulch residue removed much of the suspended sediment from the runoff.

Ammonium-N, nitrate-N, and total-N runoff losses were significantly reduced by no-till cultivation.

The loss of all forms of phosphorus was very small from each tillage system. There was no significant difference in the loss of ortho-PO_4 and total soluble-P between conventional and no-till cultivation. Only total-P losses were affected by tillage. Approximately 16 times more total-P was lost in runoff from the conventional-till watershed.

Table 1. Runoff, sediment, and nutrient losses from conventional and no-tilled corn watersheds.

Tillage treatment	Runoff volume	Sediment	Ammonium N	Nitrate-N	Total-N	Ortho-PO_4	Total soluble-P	Total-P
	gal/A				lb/A			
Conventional	30,510*	138*	0.20*	0.40*	1.06*	0.02	0.02	0.16*
No-till	4,999	37	0.01	0.05	0.13	0.01	0.02	0.01

*Indicates significance at 5% level of probability.

In summary, the loss of runoff, sediment, and nutrients from both conventional and no-till corn was very small. There was, however, a significant difference in the loss of sediment and nutrients between the two tillage systems. No-till cultivation reduced the loss of runoff, sediment, and most nutrients. ■

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Conservation Tillage Methods Reduce Soil, Water, and Phosphorus Losses

By B.J. Andraski, D.H. Mueller, and T.C. Daniel

A RAINFALL SIMULATOR was used to compare soil, water, and phosphorus (P) losses from conventional and three types of conservation tillage: chisel plow, till-plant, and no-till.

Trends in runoff results were observed as a function of date of simulation. Trials were conducted in September 1980; June and July 1981; October 1982; and June and July 1983.

Runoff volumes for conservation tillage treatments were consistently less than those observed for conventional tillage. The volume of runoff per applied rainfall for conventional tillage averaged 11, 20 and 52% higher than that observed for the conservation tillage treatments at the June 1983, July 1981 and 1983, and October 1982 sampling periods, respectively. Only the chisel plow treatment significantly reduced runoff relative to conventional tillage soon after planting. Among conservation tillage treatments, chisel plowing was significantly more effective in reducing runoff in September 1980. At the remaining sampling periods, differences among conservation tillage treatments were not significant.

An increase in residue cover consistently resulted in a decrease in sediment concentrations and, most often, a decrease in soil loss. Across all sampling periods, the no-till treatment consistently decreased soil loss by 80 to 90% relative to conventional, while soil losses for the chisel plow and till plant treatments varied, ranging from about 45 to 90% less than those for conventional. Only in September 1980 did low runoff for chisel plow result in soil loss which was less than that observed for no-till.

Simulated rainfall was also used to evaluate the comparative effects of different tillage systems on the losses of total phosphorus (P), dissolved molybdate-reactive P (DMRP) and algal-available P (AAP) when fertilizer was subsurface banded at planting. Across all sampling periods, the no-till, chisel plow, and till-plant treatments reduced total P losses by an average of 81, 70, and 59%, respectively, relative to conventional. **(Table 1.)**

Concentrations and losses of total P among tillage treatments generally followed those for sediment concentrations and losses. Concentrations of DMRP were, in most cases, lowest for conventional, although differences among treatments were generally not significant. The chisel plow treatment generally resulted in the lowest DMRP losses. However, only when substantial runoff reductions occurred, were DMRP losses significantly reduced by conservation tillage treatments relative to conventional. Differences in AAP concentrations varied among treatments and sampling periods.

Reductions in AAP losses generally followed those for total P. However, AAP loss reductions for conservation tillage treatments relative to conventional were about 20% less than the total P loss reductions.

Mr. Andraski is Research Assistant, Mr. Mueller is Program Coordinator, and Dr. Daniel is Professor, all with Department of Soil Science, University of Wisconsin-Madison.

Table 1. Total phosphorus concentrations and losses as affected by tillage.

Tillage	1980	1981[1]		1982[2]	1983[2]	
	Sept.	June	July	Oct.	June	July
		Total P Concentration, oz/gal x 10^{-4}				
Conventional	3.1	8.6[3]	10.5	4.3	3.9	1.5
Chisel plow	2.9	—	5.8	2.2	2.3	1.2
Till-plant	3.0	4.6	12.0	2.7	1.8	1.2
No-till	1.3	—	8.7	1.5	0.6	0.6
		Total P Loss, oz/A				
Conventional	19.2	1.1	33.1	31.7	25.2	3.2
Chisel plow	3.0	trace	2.9	5.3	9.6	1.6
Till-plant	12.0	0.6	12.5	5.8	10.4	1.4
No-till	5.6	trace	2.9	3.4	3.0	0.7

[1] Field sampling problems possibly resulted in high sediment concentrations which could influence total P concentrations and losses for all treatments.
[2] Simulated rainfall intensity of 3.5 inches/hour for Oct. and 5.4 inches/hour for June, remaining intensities were 2.8 inches/hour.
[3] Value is average of seven and three observations for conventional and till-plant, respectively, where measurable runoff occurred. No value for chisel plow and no-till because of insufficient sample for analysis.

Summary and Conclusions

Results of this study found runoff volumes for the conservation tillage treatments to be consistently less than those for conventional tillage. The magnitude of the difference between the conventional and conservation tillage treatments increased at later sampling periods relative to those measured soon after planting, being attributed to a greater degree of surface crusting on conventional tillage plots. Relative to conventional, only the chisel plow treatment significantly reduced runoff soon after planting. Among conservation tillage treatments, differences in runoff volumes were generally not significant. The runoff-reducing effectiveness of till-plant and no-till improved following the first year of our study. This was attributed to natural soil improvement and, in the case of till-plant, ridging operations.

At all sampling periods, sediment concentrations were highest for conventional, intermediate for chisel plow and till-plant, and lowest for no-till. Soil losses generally followed this same trend. The no-till system provided consistent soil loss reductions across all sampling periods, relative to conventional, while chisel plow and till-plant provided effective but more variable erosion control.

The sediment fraction was the major carrier of P for all tillage treatments. Conservation tillage reduced total P concentrations and losses by controlling erosion. The no-till, chisel plow, and till-plant treatments reduced total P losses by an average of 81, 70, and 59%, respectively, relative to conventional.

Concentrations of DMRP in runoff were generally higher for conservation tillage treatments, being attributed to leachates from unincorporated crop residues. When differences in runoff were not substantial enough to compensate for differences in DMRP concentrations, DMRP losses were similar among treatments. Concentrations of AAP varied depending on test and soil surface conditions for a given sampling period. Reductions in AAP losses generally followed those for total P. However, AAP loss reduction was about 20% less than the total P loss reduction.

The practice of subsurface banding of fertilizer P at planting appears to reduce this P input to runoff from conservation tillage land. Such a method of fertilizer incorporation can be done without incorporating protective crop residues needed for erosion control, and therefore, improves the runoff water quality from land under conservation tillage. ■

Some Quotes on Fertilization for Conservation Tillage

THE BRIEF quotes on these two pages present the thoughts of individuals from diverse geographical locations. While the specifics of fertilization for conservation tillage vary with regions and for different crops, it's clear there is widespread interest.

Minnesota

"For Minnesota conditions with conservation tillage systems, we encourage the use of starter fertilizer for corn as a management tool for all soil test levels. . .The starter fertilizer can supply needed nutrients early in the growing season when root growth may be restricted. The use of a starter fertilizer also reduces soil-to-fertilizer contact, thereby reducing the potential for fixation of P and/or K by soil chemical processes."

—Dr. George W. Rehm
Extension Specialist-Fertility
University of Minnesota

Oklahoma

"Because conservation tillage limits phosphorus incorporation as compared to conventional tillage, some new approaches to phosphorus fertilization are in order when considering conservation tillage. If soils are low in available phosphorus, a large dose can be applied and thoroughly incorporated prior to initiation of a conservation tillage program. The amount needed can be ascertained by proper soil analyses. Following the large buildup application, annual quantities of starter fertilizer can maintain phosphorus levels. If soils are already fairly well supplied with phosphorus, annual starter amounts, row applied, will suffice.

"Potassium uptake by plant is affected to some degree by compactness of the soil. As bulk densities increase potassium uptake decreases. This would be a consideration only on fine textured soil. Conservation tillage systems often result in more compacted soils.

"Slightly higher nitrogen rates will be required early in a conservation tillage program (20 lb N/A per ton of surface residue).

"Phosphorus should be applied into the root zone or row applied at seeding.

"Fertile soils are much easier to manage regardless of tillage program, but problems with low fertility are accentuated under minimum tillage programs. However, the problem can be overcome."

—Dr. Billy B. Tucker
Extension Agronomist
Oklahoma State University

Oregon

"Reduced tillage is receiving considerable attention on Oregon's Columbia Plateau where sloping terrain and silty soils combine to create a serious erosion hazard. Many grain growers in this region have adopted reduced tillage management practices. Two tillage systems being used to reduce soil erosion are trashy fallow and continuous cropping. These soil management systems replace a two year 'black' fallow/crop rotation in which the fallow operation where crop residue was plowed down created a serious erosion problem on sloping land.

"Fertilizer will play an important role in the success of these new tillage systems. Early research has shown dramatic and consistent yield increases to nitrogen, particularly on annually cropped shallow soils. Responses to banded phosphorus have also occurred in some cases. The frequency of responses to phosphorus fertilizer seems to be increasing under reduced tillage management.

—Dr. Hugh E. Gardner
Extension Soil Scientist
Oregon State University

Florida

"Acreage of minimum and no-till crops in Florida have expanded dramatically since about 1977. This has resulted in higher yields on many farms by reducing sandblasting and erosion on early planted corn and has made more timely planting of a second row crop after small grain for grazing or for grain. No-till farming expanded the ability for a farmer to plant a crop of grain sorghum or soybeans after irrigated corn. Fertilizer materials must be used wisely to enhance growth and development of crops with the end result of making the highest net profit for the farmer."

—Dr. D.L. Wright
Extension Agronomist
University of Florida

Alabama

"Corn and grain sorghum in conservation tillage systems sometimes yield less than in conventional tillage systems. My research results show that starter fertilizer can increase conservation tillage yields to equal or higher than those with conventional tillage. My data also indicate that starter fertilizer is needed in conservation tillage regardless of soil test levels of P and K."

—Dr. Joe Touchton
Agronomy and Soils Department
Auburn University

Ohio

"Based on no-till research conducted by Ohio State University (OSU) over the last several years, the following conclusions can be made regarding P and K fertility and soil sampling procedures.

"Starter fertilizer containing both P and K is recommended for no-till corn over a wide range of soil test levels. With starter fertilizer corn yields have consistently averaged about 10 bu/A higher than without starter.

"The quantities of P and K recommended for no-till corn will not differ from conventionally tilled corn except for P at very low soil test levels when higher yield goals are specified. For higher soil tests or lower yield goals the no-till P recommendations will not differ from conventional tillage.

"The degree of P, K and pH stratification varies widely among no-till fields. When attempting to take shallow samples in extreme cases of stratification, slight variations in sampling depth can have large effects on the results. OSU recommends taking no-till samples from 0-8″ to help minimize the large variation that already exists in soil test results due to sampling procedures. To check on surface soil pH an additional sample should be taken from 0-1″ every 3 to 4 years and analyzed for pH only."

—Dr. Don Eckert
Department of Agronomy
Ohio State University

Illinois

"Farmers need to be interested in conservation tillage, whether you are the landowner or the farm manager. . .We think farmers have one general objective: To produce the maximum economic yields on each field using sound soil conservation practices. . .To achieve this objective, the farmer must look at his income (price/yield) and his conservation management practices—and place equal importance on both. When you conserve your topsoil, you increase your chances of getting a better yield."

—Mr. Ernie Moody, Farm Manager
Illinois National Bank
Springfield, IL

Herman Warsaw

Conserving Soil through High Yield Corn Production

ONE OF THE BEST APPROACHES to soil conservation is to build productivity. Herman Warsaw, a central Illinois farmer, has demonstrated how this can be done. Over the past 25+ years, Herman has developed a corn management system that has drawn world-wide attention.

He has continued an intensive management program that over the past 14 years has averaged 267 bu/A, with four yields over 300 bu/A. This impressive record has been achieved while giving careful attention to conserving—and improving—the soil resources.

Yield records attract attention, but the thousands of people who have visited the Warsaw farm or heard him speak have found a sincere steward of the soil.

A central part of the Warsaw plan is removing soil fertility as a limiting factor. Beginning with a badly depleted and eroded farm in 1941, he has built soil test levels to current values **(Table 1).**

The very high nutrient levels in the top 10 inches of soil, along with a deep tillage program, have helped move nutrients deeper into the soil. This in turn promotes deeper rooting and further improvement of fertility, tilth, structure, and organic activity of the entire root zone.

Table 1. Herman Warsaw's High Yield Area—1985 Soil Test Levels—Top 10 Inches.

pH	P_1(lb/A)	K(lb/A)	O.M.(%)	C.E.C.
6.3	350	1,183	6.8	24

Potassium and phosphorus fertilizers, along with lime as needed, are applied in the fall. The N supplied in 18-46-0 aids in decomposition of residues. Stalks are shredded and incorporated by chisel plowing 15 inches deep in the fall, with a twisted-shovel chisel plow.

The total fertility program on Herman Warsaw's high yield plots includes annual applications of approximately 500 lb/A of N, 250 lb/A P_2O_5, and 250 lb/A K_2O. For planting dates before May 1, he uses 200 lb/A of starter fertilizer (13-13-13). In most years 10 to 20 tons/A of livestock manure are also applied.

From 1975 through 1984, the high-yield plots produced 2,758 bushels of corn, for an estimated 76 tons of stover and 57 tons of roots to improve the soil's capacity for holding water and nutrients. The fertilizer applied during the same period totalled 4,059 lb of N, 2,135 lb of P_2O_5, and 2,122 lb of K_2O per acre, along with 115 tons of manure and 10.5 tons of limestone. Zinc and sulfur are applied in most years, and other nutrients are applied if soil or plant analysis indicates a need.

He has shown that high fertility and high yield production are effective programs for soil conservation. ■

CONSERVATION TILLAGE on Herman Warsaw's farm encourages deeper rooting of crops.

Abstracts

IN RECENT YEARS issues of *Better Crops with Plant Food* have included numerous articles on various aspects of conservation tillage for crop production. Following are abstracts of those articles identified by title, author, publication date, and a short description of the message.

Buildup Soil K Levels Before Shifting to Minimum Tillage

Schulte, E. E., University of Wisconsin
Fall 1979, Vol. LXIII (63), pages 25-27

Increased K availability and higher soil K levels reduced the corn yield losses from no-till corn production. Potassium leaf analysis indicated the unplowed, till-planted corn had significantly lower K levels and plants from the highest K treatment were still relatively low in K. Higher N rates did not reduce the yield loss from no tillage.

Row fertilizer is important with conservation tillage systems. Row fertilizer (N and K) helped reduce yield losses of unplowed, till-planted corn. Leaf K levels were also increased. ■

Fertilization Decisions When Double Cropping Soybeans

Herbek, James, University of Kentucky
Summer 1983, Vol. LXVII (67), pages 3-5

Building and maintaining soil test levels to a medium to high range help ensure top yields. In wheat-soybean double crop systems fall fertilizer application to meet the needs of both crops before seeding the small grain crop is effective and practical. Broadcast surface applications of fertilizers in no-till double cropping systems have been effective and comparable to fertilizer incorporation. ■

Factors Other Than P Soil Test Affect Crop Response to Phosphate Fertilizer

Munson, R. D., PPI
Summer 1983, Vol. LXVII (67), pages 26-29

Tillage can affect crop response to P. Conventional tillage tends to increase the release of organic P and may improve P uptake, because of good soil aeration and tilth. Conservation tillage may slow release of organic P and increase soil compaction. This tends to increase crop response to applied P. ■

No-till Corn Highest Yield with Nitrogen and Potassium

Bitzer, Morris, University of Kentucky
Winter 1982-83, Vol. LXVII (67), page 19

No-till has a yield advantage over conventional till due to moisture conservation. A good fertility program is essential for this yield advantage. No-till corn fertilized with 150-0-120 lb of N-P_2O_5-K_2O per acre produced a 53 bu/A yield response to N and K while conventional tilled corn yields were increased only 13 bu/A. Soil tests were high in P and medium in K. The need for a good fertility program for successful no-till was demonstrated in this study. At low fertility conventional tillage was the highest yielding, but with adequate N and K, no-till was the highest yielding by 19 bu/A. ■

(continued on next page)

How to Establish Alfalfa by No-Till

Bryant, Harry, VPI
Summer 1983, Vol. LXVII (67), pages 24-25

Size of fall alfalfa seedlings in a fall no-till seeded system and 1st year harvest yields do best when seeding practices include a combination of Paraquat used for suppression of competition, high P available near the seed, and Furadan used for insect control. P application at seeding increased good seedling establishment and higher yields over the no P treatment even on high P testing soils.

No-till research demonstrates the need for a satisfactory environment for alfalfa establishment. Adding phosphorus to encourage early seedling development combined with Furadan for insect control appeared to have a favorable influence on alfalfa establishment. Reducing competition for water, light and phosphorus from the existing fescue sod by spraying with Paraquat had a beneficial influence on alfalfa establishment. ■

Grain Sorghum Response to Starter Fertilizers

Touchton, J. T., & Hargrove, W. L., Auburn University & University of Georgia
Spring 1983, Vol. LXVII (67), pages 3-5

Where adequate amounts of N (120 lb/A) were used no-tilled grain sorghum yields were as good or better than conventional tillage. Grain sorghum responded to starter fertilizer and the greatest response was under the no-tilled systems. ■

Compaction, Tillage, P-K Fertilization and P-K Soil Test Interpretation

Moncrief, J. F., Fenster, W. E. & Rehm, G. W., University of Minnesota
Fall 1984, Vol. LXVIII (68), pages 18-20

Row applied P and K are necessary for reduced tillage systems. The benefits of row application increased as residue levels increased and tillage decreased. Recommendations for soil test techniques in reduced tillage systems are given.

Compaction reduced corn yields as much as 50 bu/A on soils with poor internal drainage. Compaction effect was less on better drained soils. Avoid traffic and tillage when soil moisture is high. ■

Fertilizer Response of Reduced Tillage Wheat

Gardner, Hugh, & Nibler, Francis, Oregon State University
Summer 1984, Vol. LXVIII (68), pages 26-27

Farmers in Oregon's Columbia Plateau region are adjusting reduced wheat tillage systems for erosion control that include trashy fallow and continuous cropping. Fertilizer recommendations are based on "black" fallow/crop rotation systems. Fertility experiments using trashy fallow and continuous cropping found that on deeper soils higher N rates produced greater yields than lower rates used in recropping systems. P increased yields on two of the 9 sites studied. S increased yields at 2 of the 9 sites. Soil levels of P and S were evaluated. ■

A Few Whinnies (from past issues of *Better Crops with Plant Food)*

Teacher in geography class: "Where is Detroit?"
Young Ike: "In Chicago playing the White Sox."

Constable (to man staggering home at 3 o'clock in the morning): "Where are you going at this hour?"
Answer: "To a lecture."

Information Materials from PPI

THERE IS A YEAR-ROUND need for practical, reliable agronomic information on fertilization practices. Listed here are some materials now available from the Potash & Phosphate Institute (PPI).

"For 1986 Profit—Increase Yield to Lower Unit Cost"
This new folder from PPI examines the changing economics of crop production for 1986. The message emphasizes that farmers can **decrease unit cost** of production by **increasing yields. Copies of the folder are 25¢ each (15¢ MC*).** ______ $ ______

"Facts Favor Fall-Winter Fertilization" tells of the advantages fall-winter fertilization offers for reducing soil compaction, planting earlier in the spring, building soil fertility, and saving on taxes. **Copies of the folder are 25¢ each (15¢ MC*).** ______ $ ______

"It's Time to Build Soil Fertility" tells why you should build soil fertility, how much P & K it takes and why fall-winter is a good time to do it. **Copies of the folder are 25¢ each (15¢ MC*).** ______ $ ______

Plant Problem Insights for Maximum Economic Yields
This is a colorful new series of photo-cards, each with a concise discussion of a specific field problem, along with positive tips for increasing yields and profits. Topics currently available are: **Lodged Corn; Poor Early Wheat Growth;** and **Soybean Cyst Nematode. Cost per card: 10¢ each (5¢ MC*).** ______ $ ______

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To Till or Not to Till

"So he—found Elisha—who was plowing with 12 yoke of oxen." ***I Kings 19:19***

THE BIBLE SAYS man tilled the soil thousands of years ago. But change is the word today and tomorrow in agriculture. Few areas are changing faster than tillage practices.

I well remember the dust-darkened skies of the 30's. And whenever it rained, the rivers were loaded with soil—and deep gullies were common.

We will never stop all erosion. But we must leave the land a little better than we found it. Conservation tillage is one way to do that—to slow down the silent thieves of our nation's most precious asset.

There is a lot of information on conservation tillage—even a Conservation Tillage Information Center. Many leaflets, circulars, movies, and slide sets are available. Most deal with equipment and pesticides. Information on fertilization and maintenance of soil fertility is not as prominent.

Certainly, conservation tillage will lessen soil losses. But to be effective, it must be accompanied by top management that produces Maximum Economic Yields, a great insurance against soil depletion. Growers must recognize the importance of building and maintaining soil fertility levels along with conservation tillage.

The yield revolution in the last 40 years has made possible large reductions in acreage of certain crops. In the U.S., 55 million less acres are devoted to cotton and corn than in the peak years. High yields made this possible. Some erroneously point to high yields as an erosion culprit. Not so. When erosion was at its worst, wheat yields were 11 bushels, corn 26 bushels, soybeans 13 bushels, and cotton 154 pounds.

High yields keep food costs down—build and conserve soils—and protect the environment. So don't overlook the fact that good soil fertility and conservation tillage go hand in hand.

—*J. Fielding Reed*

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