Chapter 11.
Soil Testing and Fertility

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Soil testing is the single most important guide to the profitable application of fertilizer and lime. When soil test results are combined with information from the soil profile about the nutrients that are available to the various crops (Figures 11.15 and 11.16), the farmer has a reliable basis for planning the fertility program on each field.

Traditionally, soil testing has been used to decide how much lime and fertilizer to apply. With increased emphasis on economics and the environment, soil tests are also a logical tool to determine areas where adequate or excessive fertilization has taken place. In addition, soil tests are used to monitor the impact of past fertility practices on changes in a field's nutrient status. To accomplish this, one must (1) collect samples to the proper depth; (2) collect enough samples per unit of land area; (3) collect samples from precisely the same areas of the field that were sampled in the past; and (4) collect samples at the proper time.

Depth of sampling. The proper sampling depth for pH, phosphorus, and potassium is 7 inches. For fields in which reduced-tillage systems have been used, proper sampling depth is especially important, as these systems result in less thorough mixing of lime and fertilizer than a tillage system that includes a moldboard plow. This stratification of nutrients has not adversely affected crop yield, but misleading soil test results may be obtained if samples are not taken to the proper depth.

Under reduced-tillage systems, it is important to monitor surface soil pH by collecting samples to a depth of 2 inches from at least three areas in a 40-acre field. These areas should represent the low, intermediate, and high ground of the field. If surface soil pH is too high or too low, the efficacy of some herbicides and other chemical reactions may be affected.

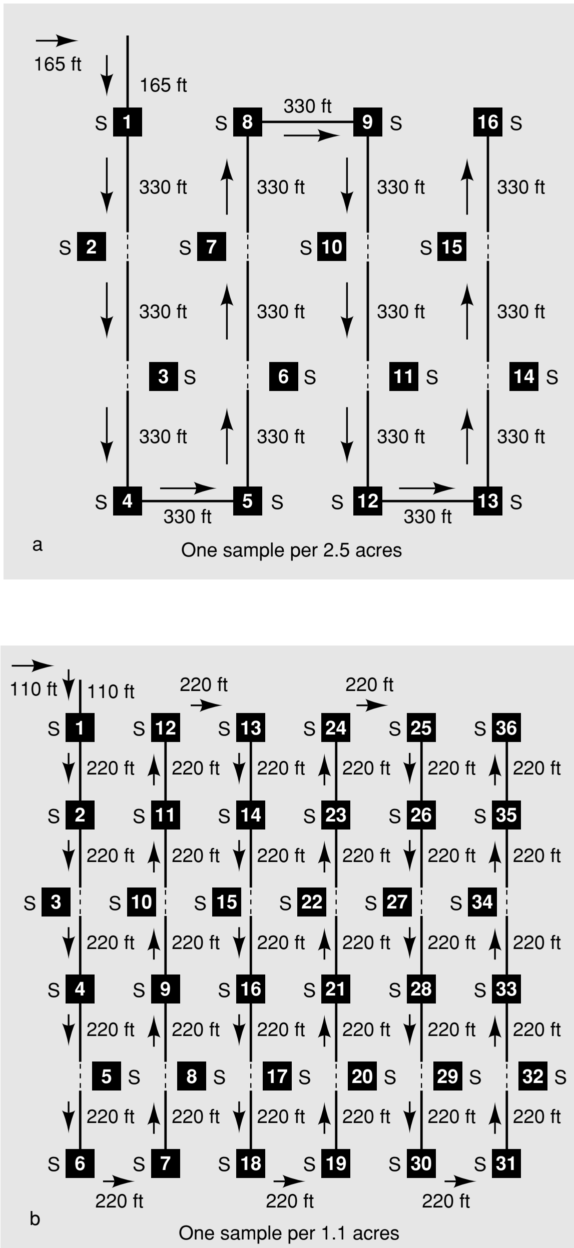
Number of samples per unit of land area. The number of soil samples taken from a field is a compromise between what should be done (information) and what can be done (cost). Sampling at the rate of one composite from each 2½-acre area is suggested. (See Figure 11.01 for sampling directions.)

Field sampling studies show large differences of soil test levels in short distances in some fields. If you can use computerized spreading techniques and suspect large variations in test values over a short distance, collecting one sample from each 1.1-acre area (Figure 11.01, bottom diagram) will provide a better representation of the actual field variability. The increased sampling intensity will increase cost of the base information but allows for more complete use of technology in mapping soil fertility patterns and thus more appropriate fertilizer application rates. The most common mistake is taking too few samples to represent a field adequately. Taking shortcuts in sampling may produce unreliable results and lead to higher fertilizer costs, lower returns, or both.

Precise sample locations. Since test results may vary markedly in short distances, it is important to collect soil samples from precisely the same points each time the field is tested. This practice reduces the variation often observed between sampling times. Sample locations may be identified using global positioning system (GPS) equipment or by accurately measuring the sample points with a device such as a measuring wheel. Once locations have been identified, collect and composite five soil core samples 1 inch in diameter to a 7-inch depth from within a 10-foot radius around each point.

How to sample. A soil tube is the best implement for taking soil samples, but an auger or a spade also can be used (Figure 11.02). Five soil cores taken with a tube will give a satisfactory composite sample of about 1 to 2 cups.

When to sample. Sampling every 4 years is strongly suggested. To improve the consistency of results, samples should be collected at the same time of year. Sampling done within a few months of lime or fertilizer treatment will be more variable than after a year.



Note: To avoid the influence of prior farming practices, it is suggested that samples be collected 30 feet to the side of the sampling line in the S2-S15 and S5-S32 rows in 11.01a and in the S3-S34 and S5-S32 rows in 11.01b, as shown.

Figure 11.01. How to collect soil samples from a 40-acre field. Each sample should consist of five soil cores, 1 inch in diameter, collected to a 7-inch depth from within a 10-foot radius around each point. Higher frequency sampling (lower diagram) is suggested for those who can use computerized spreading techniques on fields suspected of having large variations in test values over short distances.

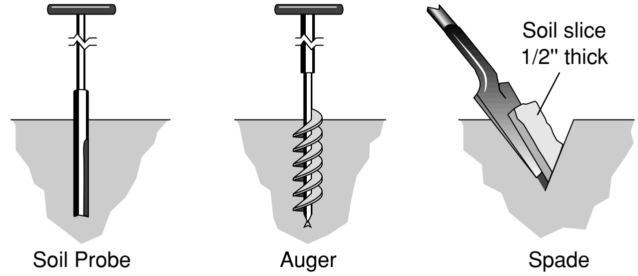


Figure 11.02. How to take soil samples with an auger, a soil probe, and a spade.

Late summer and fall are the best seasons for collecting soil samples because potassium test results are most reliable during these times. The potassium soil test tends to be cyclic, with low test levels in late summer and early fall and high test levels in late January and early February.

Where to have soil tested. Illinois has about 40 commercial soil-testing services. An Extension office or a fertilizer dealer can provide information about soil-testing services available in your area.

Information to accompany soil samples. The best fertilizer recommendations are based on both soil test results and a knowledge of field conditions that will affect nutrient availability. Because the person making the recommendation does not know the conditions in each field, it is important that you provide adequate information with each sample.

This information includes cropping intentions for the next 4 years; name of the soil type or, if not known, the nature of the soil (clay, silty, or sandy; light or dark color; level or hilly; eroded; well drained or wet; tiled or not; deep or shallow); fertilizer used (amount and grade); lime applied in the past 2 years; and proven yields or yield goals for all proposed crops.

What tests to have made. Soil fertility problems in Illinois are largely associated with acidity, phosphorus, potassium, and nitrogen. Recommended soil tests for making decisions about lime and fertilizer use are the water pH test, which shows soil reaction as pH units; the Bray P_1 test for plant-available soil phosphorus, which is commonly reported as pounds of phosphorus per acre (elemental basis); and the potassium (K) test, which is commonly reported as pounds of potassium per acre (elemental basis). Guidelines for interpreting these tests are included in this section. An organic-matter test made by some laboratories is particularly useful in selecting proper rates of herbicide and agricultural limestone.

Because nitrogen can change forms or be lost from soil, testing to determine nitrogen fertilizer needs for Illinois field crops is not recommended in the same sense as testing for the need for lime, phosphorus, or potassium fertilizer. Testing soil to predict the need for nitrogen fertilizer is complicated by the fact that nitrogen availability—both the release from soil organic matter and the loss by leaching and denitrification—is regulated by unpredictable climatic conditions. Under excessively wet conditions, both soil and fertilizer nitrogen may be lost by denitrification or leaching. Under dry conditions, the amount of nitrogen released from organic matter is low, but under ideal moisture conditions, it is high. Use of the organic-matter test as a nitrogen soil test, however, may be misleading and result in underfertilization.

Attempts to identify new nitrogen soil tests have been ongoing for several years. Specifics of the tests, along with an evaluation of their potential and limitations for Illinois, are discussed in the nitrogen section of this chapter. Guidelines for planning nitrogen fertilizer use are also provided.

Tests are available for most secondary nutrients and micronutrients, but interpretation of these tests is less reliable than tests for lime, phosphorus, and potassium. Complete field history and soil information are especially important in interpreting results. Even though these tests are less reliable, they may be useful in two ways:

1. *Troubleshooting* (diagnosing symptoms of abnormal growth). Paired samples representing areas of good and poor growth are needed for analyses.
2. *"Hidden-hunger checkup"* (identifying deficiencies before symptoms appear). Soil tests are of little value in indicating marginal levels of secondary nutrients and micronutrients when crop growth is apparently normal. For this purpose, plant analysis may yield more information.

Soil test ratings (given in Table 11.01) have been developed to put into perspective the reliability, usefulness, and cost-effectiveness of soil tests as a basis for planning a soil fertility and liming program for Illinois field crops. Additional research will undoubtedly improve some test ratings.

Interpretation of soil tests and formulation of soil treatment program. See page 97 for suggested pH goals and pages 116 and 119 for phosphorus and potassium information. Formulate a soil treatment program by preparing field soil test maps to observe areas of similar test levels that will benefit from similar treatment. Areas with differences in soil test pH of 0.2 unit, phosphorus test of 10, and potassium test of 30 are reasonable to designate for separate treatment.

When the soil test is variable. When there is large variation among tests on a field, the reason and, more important, what to do about it may not be obvious. *First* look at the pattern of the tests over the field. *If there is a definite pattern* of high tests in one part and low in another, check to see whether there is a difference in soil type. *Second*, try to recall whether the area was farmed as separate fields in the recent past. *Third*, check records for this field from previous tests or, if there are no records, try to remember whether portions were ever limed or fertilized differently during the past 5 to 10 years. Whether or not the explanation for large differences in tests is found, split the field and apply basic treatments of lime and fertilizer according to need.

If there is no consistent pattern of high and low tests, select the median test, which is the test that falls in the middle of a ranking of tests from the area from low to high. If no explanation for large differences in tests is found, consider taking a new set of samples.

Cation-exchange capacity. Chemical elements exist in solution as cations (positively charged ions) or anions (negatively charged ions). In the soil solution, the plant nutrients hydrogen (H), calcium (Ca), magnesium (Mg), potassium (K), ammonium (NH_4), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) exist as cations. The same is true for nonplant nutrients such as sodium (Na); barium (Ba); and metals of environmental

Table 11.01. Ratings of Soil Tests

Test	Rating*
Water pH	100
Salt pH	30
Buffer pH	30
Exchangeable H	10
Phosphorus	85
Potassium	60
Boron (alfalfa)	60
Boron (corn and soybeans)	10
Iron (pH > 7.5)	30
Iron (pH < 7.5)	10
Organic matter	75
Calcium	40
Magnesium	40
Cation-exchange capacity	60
Sulfur	40
Zinc	45
Manganese (pH > 7.5)	40
Manganese (pH < 7.5)	10
Copper (organic soils)	20
Copper (mineral soils)	5

*On a scale of 0 to 100; 100 indicates a very reliable, useful, and cost-effective test, and 0 indicates a test of little value.

concern, including mercury (Hg), cadmium (Cd), chromium (Cr), and others. Cation-exchange capacity is a measure of the amount of attraction for the soil with these chemical elements.

In soil, a high cation-exchange capacity is desirable, but not necessary, for high crop yields, as it is not a direct determining factor for yield. Cation-exchange capacity in soil arises from negatively charged electrostatic charges in minerals and organic matter.

Depending on the amount of clay and humus, soil types have a characteristic amount of cation exchange. Sandy soils have up to 4 milliequivalent (meq) per 100 grams of soil; light-colored silt loam soils have 8 to 12 meq; dark-colored silt loam soils have 15 to 22 meq; and clay soils have 18 to 30 meq.

Cation-exchange capacity facilitates retention of positively charged chemical elements from leaching, yet it gives nutrients to a growing plant root by an exchange of hydrogen (H). Farming practices that reduce soil erosion and maintain soil humus favor the maintenance of cation-exchange capacity. The cation-exchange capacity of organic residues is low but increases as the residues convert to humus, which requires from 5 years to centuries.

Plant Analyses

Plant analyses can be useful in diagnosing problems, in identifying hidden hunger, and in determining whether current fertility programs are adequate. For example, they often provide more reliable measures of micronutrient and secondary nutrient problems than do soil tests.

How to sample. When making a plant analysis to diagnose a problem, select paired samples of comparable plant parts representing the abnormal and normal plants. Abnormal plants selected should represent the first stages of a problem.

When using the technique to diagnose hidden hunger in corn, sample several of the leaves opposite and below the ear at early tassel time. For soybeans, sample the most recent fully developed leaves and petioles at early podding. For alfalfa, sample the upper 6 inches of stems and leaves at early bloom. Samples taken later will not indicate the nutritional status of the plant. After collecting the samples, deliver them immediately to the laboratory. They should be air dried if they cannot be delivered immediately or if they are going to be shipped.

Environmental factors may complicate the interpretation of plant analysis data. The more information provided concerning a particular field, the more reliable the interpretation will be. Suggested critical nutrient levels are provided in Table 11.02. Lower levels may indicate a nutrient deficiency.

SPAD Meter

Sometimes called the green meter or chlorophyll meter, this instrument is used to measure the relative greenness of leaf tissue. Since greenness can be related to nitrogen level in the plant, using this meter, especially where nitrogen has been applied to a reference strip of the same corn hybrid at a rate somewhat above that necessary for optimal growth, can help identify deficiency in-season. According to Nebraska research, SPAD readings of less than 95 percent of the reference-strip reading indicate that more nitrogen is necessary for optimal yield. This technique is effective on irrigated fields where additional nitrogen can be applied through the irrigation system with little application cost and without damage to the crop. This technique can also be useful for areas of fields that have had

Table 11.02. Suggested Critical Plant Nutrient Levels for Corn and Soybeans

Crop	Plant part	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B
		- - - - - -	- - - -	*percent*	- - - -	- - - -	- - - -	- - - -	- - - -	*ppm*	- - - -	- - - -
Corn	Leaf opposite and below the ear at tasseling	2.9	0.25	1.90	0.40	0.15	0.15	15	25	15	5	10
Soybeans	Fully developed leaf and petiole at early podding	. . .	0.25	2.00	0.40	0.25	0.15	15	30	20	5	25
Alfalfa	Upper 6 inches at early bloom	. . .	0.25	2.00	1.00	0.25	0.22	15	25	20	7	25

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, Zn = zinc, Fe = iron, Mn = manganese, Cu = copper, B = boron.

significant nitrogen loss due to excessive water. University of Illinois data have shown that nitrogen applied to dry-land corn as late as tasseling can provide a significant yield increase on corn that is deficient. Increased grain yield requires a rain of 0.5 inch or more soon after the fertilizer is applied The rain moves the nitrogen down into the rooting zone for plant uptake.

Fertilizer Management Related to Tillage Systems

Fertilizer management will be affected by tillage systems because relatively immobile materials such as limestone, phosphorus, and potassium move slowly in most soils unless they are physically mixed by tillage operations. Such “stratification” of nutrients, with higher concentrations developing near the surface, has been well documented in a number of studies but has not been shown to reduce yields of corn or soybeans in Illinois. Limited research indicates that plants develop more roots near the soil surface in conservation-tillage systems, due apparently to both the improved moisture conditions caused by the surface mulch of crop residues and the higher levels of available nutrients. With continued reduced-tillage practices, soil fertility levels at deeper depths may be depleted such that future soil fertility practices may need adaptation.

Soil tests are important for phosphorus, potassium, and limestone management under any tillage system. Consult the earlier section on “How to sample,” and make sure the samples are taken from the full 7-inch depth. If either limestone (which raises pH) or nitrogen fertilizer (which lowers pH) is applied to the surface and not incorporated with tillage, pH tests of the upper 2 inches of soil are needed to aid in the management of some herbicides.

See guidelines for adjusting limestone application rates under different tillage systems. For any system, the rate of application information in the later section on “Phosphorus and Potassium” is valid.

Nitrogen fertilizer management may be affected to a limited extent by changing tillage systems. The information in the section on “Nitrogen” will be valid in all tillage systems, with only the following exceptions:

- Where crop residue is present, a coulter may be needed in front of an applicator knife to properly inject anhydrous ammonia or liquid nitrogen fertilizers.
- In no-till systems, where the surface soil may be firm, special care is needed to make sure that the slit left by an ammonia applicator knife is completely closed to prevent nitrogen loss through the escape of gaseous ammonia.
- Because crop residue in reduced-tillage systems may inhibit urea or urea-containing fertilizers from making direct contact with the soil and thus increase the possibility of nitrogen loss through volatilization, these materials should be mechanically incorporated. Urease inhibitors will aid in preventing this loss (see section on urease inhibitors, page 115).
- The higher moisture conditions under a residue mulch may also cause a higher rate of nitrogen loss through denitrification. Judicious management—including timing of application and the use of nitrification inhibitors—may help avoid significant denitrification losses.
- A risk of occasional anhydrous ammonia damage to corn seed and seedlings exists in fields with any tillage system, especially when the soil is dry, the ammonia is placed shallow, or corn is planted immediately after ammonia application. Corn in no-till fields seems to be particularly vulnerable to such damage in spring preplant ammonia applications whenever the seed is placed directly over the ammonia band. Keeping the anhydrous ammonia and the corn separated in either distance or time will reduce the potential for this problem.

Table 11.03. Effect of Starter Fertilizer on Grain Yield of No-Till Corn

Starter fertilizer (lb/A)			Location/previous crop			
N	P_2O_5	K_2O	Ashton/corn	Gridley/soybean	Pana/soybean	Oblong/soybean
			yield (bu/A)			
0	0	0	131	120	128	146
25	0	0	141	123	136	150
25	30	0	147	129	139	155
25	30	20	146	137	133	160

N = nitrogen, P_2O_5 = phosphorus, K_2O = potassium.

Starter fertilizer. Starter fertilizer is more effective than broadcast applications under cool, moist conditions when phosphorus soil test levels are low, irrespective of tillage system. At high soil test levels, starter fertilizer often results in early growth response on conventional tillage systems but seldom results in increased yield at harvest.

Early season growth of no-till corn is frequently less vigorous than conventional tillage. This slower growth is likely the result of cooler soil temperatures and higher soil moisture conditions associated with the high residue mulch. Both of these conditions tend to slow root growth and thus the ability of the plant to absorb nutrients.

In a 3-year study at four locations, starter fertilizer placed 2 inches below and 2 inches to the side of the seed increased grain yield at 10 of the 11 site years (Table 11.03). Study results revealed several important considerations when deciding whether to use starter fertilizer for no-till corn.

1. Nitrogen provided the majority of the response.
2. Addition of phosphorus with the nitrogen increased yield more than enough to pay for the phosphorus. This was true even at Ashton, which had a soil test level in excess of 90 pounds of phosphorus per acre.
3. Including potassium in the starter did not significantly affect yield at either Ashton or Pana. At the other two locations, potassium had a significant impact in 1 of the 3 years of the study. At Gridley, the increase from potassium occurred in a year with a wet spring, which resulted in delayed planting, followed by very dry conditions during early plant growth. Since this was a long-term no-till field, the inherent potassium was primarily in the upper inch of the soil profile, where root activity was limited during the dry period. There was adequate moisture at the 4-inch depth for good root activity and potassium uptake from the fertilizer band. At Oblong, the soil test potassium was low. In the year in which potassium had not been broadcast prior to planting, there was good response to potassium in the starter. However, in the other 2 years, when potassium was broadcast, there was no response to starter potassium.

Attempts to attain the starter response with other application techniques met with mixed success. While placement of up to 10 pounds of nitrogen per acre directly with the seed increased yield, the increase was not as consistent as with 2 x 2 starter. And in a dry spring, placement of as little as 10 pounds of nitrogen per acre significantly reduced stand in some experiments. Placement of a band of nitrogen (25-0-0) or nitrogen plus phosphorus (25-30-0) on the soil surface near the seed row resulted in higher average yields than with no starter, but yield increases were not as high or as consistent as for the banded treatments.

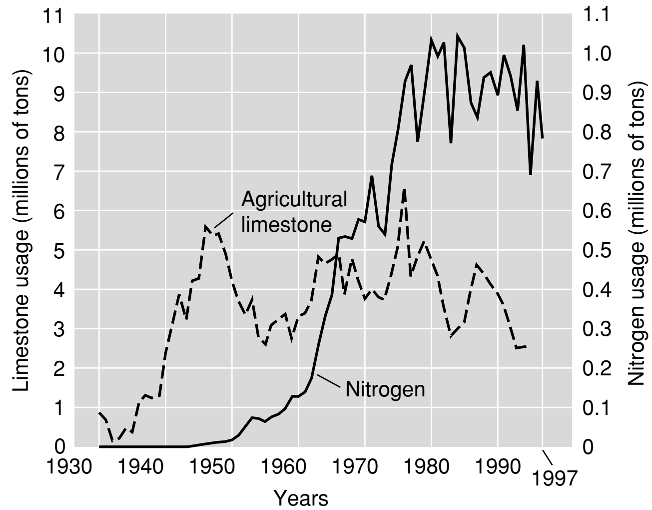


Figure 11.03. Use of agricultural limestone and commercial nitrogen fertilizer, 1930–1997.

Lime

Soil acidity is one of the most serious limitations to crop production. Acidity is created by removal of bases by harvested crops, leaching, and an acid residual that is left in the soil from nitrogen fertilizers. During the last several years, limestone use has tended to decrease in Illinois while crop yields and nitrogen fertilizer use have increased (Figure 11.03).

At the present rate of limestone use, no lime is being added to correct the acidity created by the removal of bases or the acidity created in prior years that has not been corrected. A soil test every 4 years is the best way to check on soil acidity levels.

The effect of soil acidity on plant growth. Soil acidity affects plant growth in several ways. Whenever soil pH is low (and acidity is high), several situations may exist:

A. The concentration of soluble metals may be toxic. Damage from excess solubility of aluminum and manganese due to soil acidity has been shown in field research.

B. Populations and the activity of the organisms responsible for transformations involving nitrogen, sulfur, and phosphorus may be altered.

C. Calcium may be deficient. This usually occurs only when the cation-exchange capacity of the soil is extremely low.

D. Symbiotic nitrogen fixation in legume crops is impaired greatly. The symbiotic relationship requires a narrower range of soil reaction than does the growth of plants not relying on nitrogen fixation.

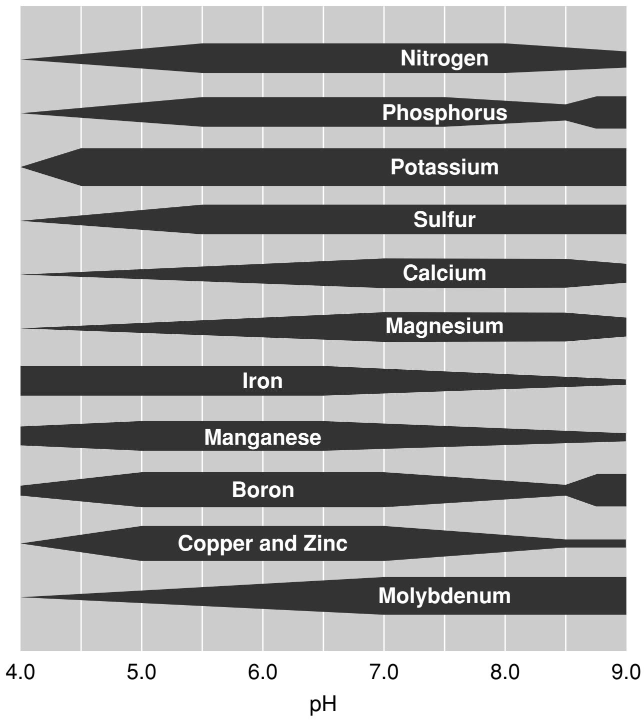


Figure 11.04. Available nutrients in relation to pH.

E. Acidic soils are poorly aggregated and have poor tilth. This is particularly true for soils that are low in organic matter.

F. The availability of mineral elements to plants may be affected. Figure 11.04 shows the relationship between soil pH and nutrient availability. The wider the dark bar, the greater the nutrient availability. For example, the availability of phosphorus is greatest in the pH range between 5.5 and 7.5, dropping off below 5.5. Because the availability of molybdenum is increased greatly as soil acidity is decreased, molybdenum deficiencies usually can be corrected by liming.

Suggested pH goals. For cash-grain systems (no alfalfa or clover), maintaining a pH of at least 6.0 is a realistic goal. If the soil test shows that the pH is 6.0 or less, apply limestone. After the initial investment, it costs little more to maintain a pH at 6.5 than at 6.0. The profit over 10 years will be little affected because the increased yield will approximately offset the cost of the extra limestone plus interest.

Research indicates that a profitable yield response from raising the pH above 6.5 in cash-grain systems is unlikely.

For cropping systems with alfalfa and clover, aim for a pH of 6.5 or higher unless the soils have a pH of 6.2 or higher without ever being limed. In those soils, neutral soil is just below plow depth; it will probably not be necessary to apply limestone.

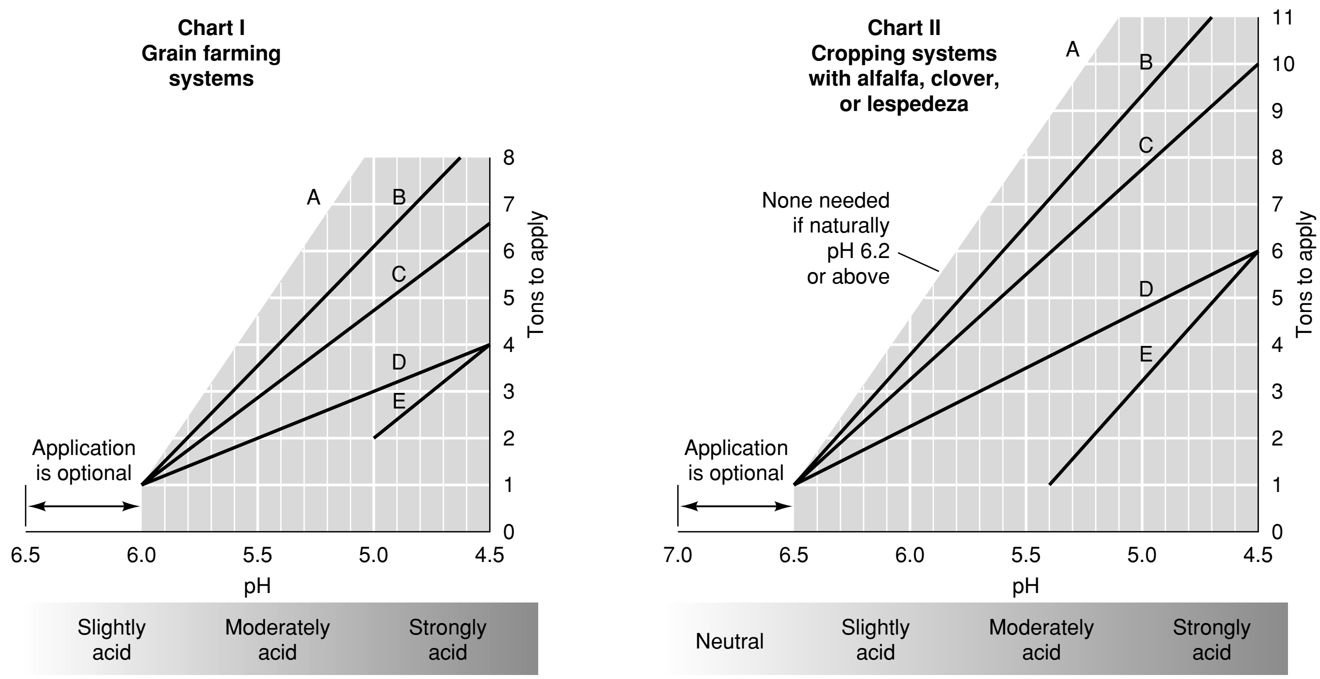


Figure 11.05. Suggested limestone rates based on soil type, pH, cropping systems, and 9-inch depth of tillage.

Liming treatments based on soil tests. The limestone requirements in Figure 11.05 assume the following:

A. **A 9-inch plowing depth. If plowing is less than 9 inches, reduce the amount of limestone; if more than 9 inches, increase the lime rate proportionately.** ***In no-till systems, use a 3-inch depth for calculations (one-third the amount suggested for soil moldboard-plowed 9 inches deep).***

B. Typical fineness of limestone. Ten percent of the particles are greater than 8-mesh; 30 percent pass an 8-mesh and are held on 30-mesh; 30 percent pass a 30-mesh and are held on 60-mesh; and 30 percent pass a 60-mesh.

C. A calcium carbonate equivalent (total neutralizing power) of 90 percent. The rate of application may be adjusted according to the deviation from 90.

Instructions for using Figure 11.05 are as follows:

1. Use Chart I for grain systems and Chart II for alfalfa, clover, and lespedeza.
2. Decide which classification fits the soil:
   A. Dark-colored silty clays and silty clay loams (CEC > 24)
   B. Light- and medium-colored silty clays and silty clay loams; dark-colored silt and clay loams (CEC 15–24)
   C. Light- and medium-colored silt and clay loams; dark- and medium-colored loams; dark-colored sandy loams (CEC 8–15)
   D. Light-colored loams; light- and medium-colored sandy loams; sands (CEC < 8)
   E. Muck and peat

Soil color is related to organic matter. Light-colored soils usually have less than 2.5 percent organic matter; medium-colored soils have 2.5 to 4.5 percent organic matter; dark-colored soils have more than 4.5 percent organic matter; sands are excluded.

Worksheet

Evaluation for 1 year after application of lime

			Efficiency factor	
% of particles greater than 8-mesh	=	$\frac{\_\_\_\_}{100}$	x 5	=
% of particles that pass 8-mesh and are held on 30-mesh	=	$\frac{\_\_\_\_}{100}$	x 20	=
% of particles that pass 30-mesh and are held on 60-mesh	=	$\frac{\_\_\_\_}{100}$	x 50	=
% of particles that pass 60-mesh	=	$\frac{\_\_\_\_}{100}$	x 100	=

Total fineness efficiency _______

ENV = total fineness efficiency x $\frac{\text{\% calcium carbonate equivalent}}{100}$

Correction factor = $\frac{\text{ENV of typical limestone (46.35)}}{\text{ENV of sampled limestone (\_\_\_)}}$

Correction factor x limestone requirement (from Figure 11.05) = _____tons of sampled limestone needed per acre

Evaluation for 4 years after application of lime

			Efficiency factor	
% of particles greater than 8-mesh	=	$\frac{\_\_\_\_}{100}$	x 15	=
% of particles that pass 8-mesh and are held on 30-mesh	=	$\frac{\_\_\_\_}{100}$	x 45	=
% of particles that pass 30-mesh and are held on 60-mesh	=	$\frac{\_\_\_\_}{100}$	x 100	=
% of particles that pass 60-mesh	=	$\frac{\_\_\_\_}{100}$	x 100	=

Total fineness efficiency _______

ENV = total fineness efficiency x $\frac{\text{\% calcium carbonate equivalent}}{100}$

Correction factor = $\frac{\text{ENV of typical limestone (67.5)}}{\text{ENV of sampled limestone (\_\_\_)}}$

Correction factor x limestone requirement (from Figure 11.05) = _____tons of sampled limestone needed per acre

Example from the worksheet
1 year

$$\frac{13.1\%}{100} \times 5 = 0.65$$

$$\frac{40.4\%}{100} \times 20 = 8.08$$

$$\frac{14.9\%}{100} \times 50 = 7.45$$

$$\frac{31.6\%}{100} \times 100 = \underline{\underline{31.60}}$$

Total fineness efficiency: 47.78

$$\text{ENV} = 47.78 \times \frac{86.88}{100} = 41.51$$

$$\frac{46.35}{41.51} \times 3 = 3.35 \text{ tons per acre}$$

4 years

$$\frac{13.1\%}{100} \times 15 = 1.96$$

$$\frac{40.4\%}{100} \times 45 = 18.18$$

$$\frac{14.9\%}{100} \times 100 = 14.90$$

$$\frac{31.6\%}{100} \times 100 = \underline{\underline{31.60}}$$

Total fineness efficiency: 66.64

$$\text{ENV} = 66.64 \times \frac{86.88}{100} = 57.9$$

$$\frac{67.5}{57.9} \times 3 = 3.5 \text{ tons per acre}$$

Limestone quality. Limestone quality is measured by the neutralizing value and the fineness of grind. The neutralizing value of limestone is measured by its calcium carbonate equivalent: the higher this value, the greater the limestone's ability to neutralize soil acidity. Rate of reaction is affected by particle size; the finer that limestone is ground, the faster it will neutralize soil acidity. Relative efficiency factors have been determined for various particle sizes (Table 11.04).

Table 11.04. Efficiency Factors for Various Limestone Particle Sizes

	Efficiency factor	
Particle sizes	1 year after application	4 years after application
Greater than 8-mesh	5	15
8- to 30-mesh	20	45
30- to 60-mesh	50	100
Passing 60-mesh	100	100

If you are liming an acid soil just before seeding alfalfa, it is important to have highly reactive particles; the figures for 1 year are the best guide. If you apply lime before corn, the 4-year values are adequate.

The quality of limestone is defined as its effective neutralizing value (ENV). This value can be calculated for any liming material by using the efficiency factors in Table 11.04 and the calcium carbonate equivalent for the limestone in question. The "typical" limestone on which Figure 11.05 is based has an ENV of 46.35 for 1 year and 67.5 for 4 years.

The Illinois Department of Agriculture, in cooperation with the Illinois Department of Transportation, collects and analyzes limestone samples from quarries that wish to participate in the Illinois Voluntary Limestone Program. These analyses, along with the calculated correction factors, are available from the Illinois Department of Agriculture, Division of Plant Industries and Consumer Services, P.O. Box 19281, Springfield, IL 62794-9281, in the annual publication *Illinois Voluntary Limestone Program Producer Information.* To calculate the ENV for materials not reported in that publication, obtain the analysis of the material in question from the supplier and use the worksheet provided here for making calculations.

As an example, consider a limestone that has a calcium carbonate equivalent of 86.88 percent and a sample that has 13.1 percent of the particles greater than 8-mesh, 40.4 percent that pass 8-mesh and are held on 30-mesh, 14.9 percent that pass 30-mesh and are held on 60-mesh, and 31.6 percent that pass 60-mesh. Assume that 3 tons of typical limestone are needed per acre (according to Figure 11.05). The amounts of limestone with these characteristics that would be needed to meet the 3-ton recommendation would be 3.35 tons and 3.5 tons on a 1- and 4-year basis, respectively. (See the calculations to the left.)

At rates up to 6 tons per acre, if high initial cost is not a deterrent, the entire amount may be applied at one time. If cost is a factor and the amount of limestone needed is 6 tons or more per acre, apply it in split applications of about two-thirds the first time and the remainder 3 or 4 years later.

Fluid lime suspensions (liquid lime). These products are obtained by suspending very finely ground limestone in water. Several industrial by-products with liming properties also are being land applied as suspensions, either because they are too fine to be spread dry or they are already in suspension. These by-products include residue from water treatment plants, cement plant stack dusts, paper mill sludge, and other waste products. These materials may contain as much as 50 percent water.

The chemistry of liquid liming materials is the same as that of dry materials. Research results have confirmed that the rate of reaction and the neutralizing power for liquid lime are the same as for dry materials when particle sizes are the same.

Results from one study indicate that application of liquid lime at the rate of material calculated by the following equation is adequate to maintain soil pH for at least 4 years at the same level as typical lime.

$$\frac{\text{ENV of typical limestone [use 46.35]}}{\text{100 (fineness efficiency factor)} \times \frac{\text{\% calcium carbonate, equivalent, dry matter basis}}{100} \times \frac{\text{\% dry matter}}{100}}$$

$$\times \text{ tons of limestone needed per acre} = \text{tons of liquid lime needed per acre}$$

During the first few months after application, the liquid material will provide a more rapid increase in pH than will typical lime, but after that the two materials will provide equivalent pH levels in the soil.

As an example, assume a lime need of 3 tons per acre (based on Figure 11.05) and liquid lime that is 50 percent dry matter and has a calcium carbonate equivalent of 97 percent on a dry-matter basis. The rate of liquid lime needed would be calculated as follows:

$$\frac{46.35}{100 \times \frac{97}{100} \times \frac{50}{100}} \times 3 = 2.87 \text{ tons of liquid lime per acre}$$

Lime incorporation. Lime does not react with acidic soil very far from the particle, but special tillage operations to mix lime with soil usually are not necessary in systems that use a moldboard plow. Systems of tillage that use a chisel plow, disk, or field cultivator rather than a moldboard plow, however, may not mix limestone deeper than 4 to 5 inches.

Acidifying soils. While high-pH soils (pH > 7.4) result in reduced availability of several nutrients, particularly phosphorus, zinc, iron, and manganese, decreasing soil pH has not been shown to be economical for the production of agronomic crops. Acidification of soils to produce crops such as blueberries and cranberries is essential if the pH is high. Acidification can be accomplished by applying elemental sulfur, aluminum sulfate, or iron sulfate. The amount of elemental sulfur needed to reduce soil pH depends on the initial pH and the desired pH (Table 11.05).

Table 11.05. Amount of Elemental Sulfur Needed to Reduce Soil pH

	Soil group[1]			
Original pH	A	B	C	D
Elemental sulfur (lb/A) needed to reach pH 5.0				
6.4	2,700	2,100	1,400	700
6.2	2,400	1,800	1,200	600
6.0	2,150	1,625	1,075	550
5.8	1,925	1,450	950	475
5.6	1,700	1,275	850	425
5.4	1,225	925	625	300
5.2	775	575	375	200
5.0				
Elemental sulfur (lb/A) needed to reach pH 4.5				
6.4	4,000	3,000	2,000	1,000
6.2	3,800	2,800	1,900	950
6.0	3,525	2,650	1,775	925
5.8	3,300	2,475	1,650	825
5.6	3,075	2,300	1,525	775
5.4	2,600	1,950	1,300	650
5.2	2,150	1,625	1,075	550
5.0	1,375	1,050	700	350

[1]See descriptions on page 98.

Calcium-Magnesium Balance in Illinois Soils

Soils in northern Illinois usually contain more magnesium than those in central and southern Illinois because of the high magnesium content in the rock from which the soils developed and because northern soils are geologically younger. This relatively high level of magnesium has caused speculation as to whether the level is too high. Although there have been reported suggestions that either gypsum or low-magnesium limestone should be applied, no research data have been put forth to justify concern over a too-narrow ratio of calcium to magnesium.

On the other hand, concern is justified over a soil magnesium level that is low—because of its relationship with hypomagnesaemia, a prime factor in grass tetany or milk fever in cattle. This concern is more relevant to forage production than to grain production. Very high potassium levels (more than 500 pounds per acre) combined with low soil magnesium levels contribute to low-magnesium grass forages. Research data to establish critical magnesium levels are very limited. However, levels of soil magnesium less than 60 pounds per acre on sands and 150 pounds per acre on silt loams are regarded as low.

Calcium and magnesium levels of agricultural limestone vary among quarries in the state. Dolomitic limestone (material with an appreciable magnesium content, as high as 21.7 percent MgO or 46.5 percent $MgCO_3$) occurs predominantly in the northern three tiers of Illinois counties, in Kankakee County, and in Calhoun County. Limestone occurring in the remainder of the state is predominantly calcitic (high calcium), although it is not uncommon for it to contain 1 to 3 percent $MgCO_3$.

There are no agronomic reasons to recommend either that grain farmers in northern Illinois bypass local limestone sources, which are medium to high in magnesium, and pay a premium for low-magnesium limestone from southern Illinois or that grain farmers in southern Illinois order limestone from northern Illinois quarries because of magnesium content.

For farmers with a livestock program or who produce forages in the claypan and fragipan regions of the south, where soil magnesium levels may be marginal, it is appropriate to use a soil test to verify conditions and to use dolomitic limestone or magnesium fertilization or to add magnesium to the feed.

Nitrogen

About 40 percent of the original nitrogen and organic-matter content has been lost from typical Illinois soils since farming began, the result of erosion and increased oxidation of organic matter. Erosion reduces the nitrogen content of soils because the surface soil is richest in nitrogen and it erodes first. Farming practices that improve aeration of the soil, including improved drainage and tillage, have increased the rate of organic-matter degradation. Further nitrogen losses result from denitrification and leaching.

Because harvested crops remove more nitrogen than any other nutrient from Illinois soils, the use of nitrogen fertilizer is necessary if Illinois agriculture is to be competitive in the world market. Economics, along with concern for the environment, makes it imperative that all nitrogen fertilizers be used as efficiently as possible. Factors that influence efficiency are discussed in the following sections.

Nitrogen Recommendation Systems

Nitrogen recommendations in the humid regions of the Corn Belt have been based primarily on expected yield, with an adjustment for previous crop and management programs. Although this system has worked well, there are documented reports of near-optimal corn yields with little or no supplemental nitrogen. Such results have encouraged researchers to develop a reliable and practical soil nitrogen test that would let farmers and advisers identify conditions where the nitrogen application rate could be modified to enhance crop profits without harming the environment.

Total soil nitrogen. Because 5 percent of soil organic matter is nitrogen, some have theorized that organic matter content of a soil could be used as an estimate of the amount of supplemental nitrogen that would be needed for a crop. As a rough guideline, many assume that 2 percent of the organic nitrogen will be released each year. This would amount to a release of 100 pounds of nitrogen per acre on fields with 5 percent organic matter. Attempts to use this procedure have been unsuccessful because mineralization of organic matter varies significantly over time due to variation in available soil moisture. Additionally, soils high in organic matter usually have a higher yield potential due to their ability to provide a better environment for crop growth.

Early spring nitrate nitrogen. This procedure has been used for several years in the more arid parts of the Corn Belt (west of the Missouri River) with reasonable success. It involves collecting soil samples in 1-foot increments to a 2- to 3-foot depth in early spring for analysis of nitrate nitrogen. Although the use of the information varies somewhat from state to state, the consensus is to reduce the normal nitrogen recommendation by the amount found in the soil profile sampled. Results obtained by scientists in both Wisconsin and Michigan have found this procedure to work well, but research in Iowa indicated that the procedure did not accurately predict nitrogen needs.

Since samples are collected in early spring, this procedure measures potential for nitrogen carryover from the previous crop. It thus will have the greatest potential for success on continuous corn, especially in fields where adverse growing conditions have limited yields the previous year. Additional work is needed to ascertain the sampling procedure that will best characterize the field conditions, especially when nitrogen has been injected in prior years. When excessive precipitation is received in late spring or early summer, this procedure will not likely be successful because most of the nitrogen that is detected early may be leached or denitrified before the plant has an opportunity to absorb it from the soil.

Late-spring nitrate nitrogen. Success with this procedure was first observed with work in Vermont. Follow-up work in some of the Corn Belt states also indicates that the procedure accurately characterizes nitrogen needs. Soil samples are collected to a 1-foot depth when corn plants are 6 to 12 inches tall and analyzed for nitrate nitrogen. University agronomists suggest that no additional nitrogen be applied when soil test levels exceed 22 to 25 parts per million and that full rate be applied if nitrate nitrogen levels are less than 10 parts per million. They suggest proportional adjustments in nitrogen rates when test levels are between 10 and 26 parts per million. To minimize the potential for decreased yield that might be caused by delayed nitrogen application, agronomists at Iowa State University suggest that 50 to 70 percent of the normal nitrogen application be applied preplant. If the fertilizer was broadcast, they suggest collecting 16 to 24 core samples within an area not exceeding 10 acres. If the fields have been fertilized with anhydrous ammonia, they suggest a modified soil test. The modified test can be used under the following conditions: (a) the rate of ammonia application did not exceed 125 pounds of nitrogen per acre; (b) the soil sample is derived from at least 24 cores collected without regard to location of ammonia injection bands; and (c) fertilizer nitrogen recommendations are adjusted to reflect that one-third of the nitrogen applied was not revealed by the soil test.

By sampling later in the season, this test provides a measure of the mineralization of organic nitrogen that has occurred and the amount of residual carryover that is still present in the soil. Obvious limitations of this procedure include these: (a) its use only on fields that receive sidedress application of nitrogen; (b) the short time available between sampling and the need to apply fertilizer, which could be especially critical in wet years and could result in corn plants becoming too large to use conventional application equipment; and (c) no existing correlation for use of the procedure on fields that have received a banded nitrogen application.

Illinois nitrogen soil test (amino sugar-N test). Recent studies have shown that the concentration of amino sugar-N provides an indication of whether corn will respond to the application of nitrogen fertilizer. Amino sugar-N is an organic form of nitrogen that is apparently easily mineralized under normal growing conditions. Initial results have shown that the majority of the fields that have amino sugar-N values greater than approximately 240 parts per million nitrogen need no supplemental nitrogen fertilizer for optimal yield. Additional research is needed to:

- calibrate this test (determine the rate of nitrogen needed to optimize corn production at soil test levels less than 240 parts per million nitrogen)
- establish soil sampling protocol (determine the best time, depth, and number of soil samples necessary to adequately characterize the amount of nitrogen needed to optimize corn production for the entire field)
- determine soil and environmental characteristics that might result in inaccurate predictions of nitrogen need. (Preliminary work has shown that, although this test works well on many fields, there have been a limited number of instances in which the soil test level was high—greater than 240 ppm N, yet the corn crop responded well to the application of nitrogen fertilizer.)
- determine previous management characteristics that are most likely to result in high amino sugar-N soil tests. (Preliminary results have indicated that fields that have a previous history of manure application, long-term forage legume production, and/or high rates of nitrogen fertilizer use are the most likely to have high amino sugar-N tests. However, some fields with high amino sugar-N do not have either of these characteristics.)

The University of Illinois and many other midwestern universities are conducting research to answer these important questions.

Because none of the nitrogen soil test procedures have been adequately calibrated to provide a reliable estimate of the rate of nitrogen needed for optimum corn production, their use is not encouraged under Illinois conditions. It is suggested that nitrogen rates be determined using the following materials as a guide.

Yield potential. Research trials conducted by the University of Illinois Crop Sciences Department have demonstrated that use of the following system for determining nitrogen rate will optimize yield. There are years when this system will recommend more nitrogen than needed but very few years in which the recommendation will be so low as to markedly reduce yield. It appears that use of this system will help reduce the amount of nitrogen being lost to the environment.

Nitrogen Rate Worksheet for Corn

1. Determine your average yield for the last 5-year period:

Yield last 5 years (bu/A)					Sum across years	Divided by number of years	Average
Year 1	Year 2	Year 3	Year 4	Year 5			

2. Multiply average yield by 1.05 to obtain target yield; the increase of 0.05 accounts for increased yield potential due to improved variety and cultural practices.

_________________ x 1.05 = _________________ bu/A
Average yield — Target yield

3. Multiply target yield by 1.20 lb N/bu to obtain N needed per acre:

_________________ bu/A x 1.20 = _________________ lb N/A
Target yield — N needed

4. Reduce N needed by subtracting all N credits (adjust for all of the following that apply):
   a) Previous crop of soybeans (40 lb N/A). _________________
   b) Previous crop of alfalfa/clover (> 5 plants/ft = 100 lb N; 2–4 plants/ft = 50 lb N). _________________
   c) Application of ammoniated phosphate (multiply lb material by percent N). Ex.: 200 lb 18-46-0 = 200 x 0.18 = 36 lb N/A. _________________
   d) Manure application (total lb N in manure divided by 2). _________________
   e) Weed and feed N (multiply gallons per acre times 3 for 28% N or times 3.5 for 32% N solutions). _________________
   f) Starter (multiply rate by percent N). _________________
   g) N in irrigation water (inches irrigation water x ppm $NO_3 - N \times 0.23$). _________________

   Total N credits (a + b + c + d + e + f + g) _________________

5. Amount N to apply: (N needed) – (N credit)

The worksheet on page 103 is designed to help you determine your fertilizer nitrogen need. You can also use this equation to calculate nitrogen need for corn:

Fertilizer nitrogen needed = (Target yield in bu x 1.2 lb N/bu) – legume N – manure N – incidental N

Target yield is one of the major considerations in determining the optimal rate of nitrogen application for corn. The target yield should be established for each field, taking into account the soil type and management level under which the crop will be grown. If yield records are available, use the 5-year average yield as the basis. When figuring the average, eliminate years of abnormally low yields that resulted from drought or other weather-related conditions. Increase the average yield by 5 percent because of improved varieties and cultural practices.

If yield records are not available for a particular field, suggested 10-year mean corn yield estimates for each soil type are given in *Average Crop, Pasture, and Forestry Productivity Ratings for Illinois Soils* (Bulletin 810, Office of Research, University of Illinois, College of ACES, Urbana, Illinois 61801) or at the following Web site: http://www.nres.uiuc.edu/soilproductivity. Yield goals are presented for both basic and high levels of management. Annual variations in yield of 20 percent above or below the 10-year mean corn yield estimates for each soil type are common because of variations in weather conditions. However, applying nitrogen fertilizer for yields possible in the most favorable year will not result in maximum net return when averaged over all years.

The 1.2 lb N/bushel coefficient was derived assuming a corn-to-nitrogen price ratio (price of corn per bushel divided by the price of N per pound) between 10:1 and 20:1. If the price ratio goes above 20:1, then the optimal rate would increase to 1.3 lb N/bushel.

Take credit for "homegrown" nitrogen, including corn following a legume crop such as soybean, alfalfa, or clover and for manure applied to the field. (See the subsection about rate adjustments on page 99.) Incidental nitrogen is that nitrogen applied with phosphates, applied as a part of the starter fertilizer, and/or applied as a carrier for herbicides.

Soybeans. Based on average Illinois corn and soybean yields from 2000 and 2001 and average nitrogen content of the grain for these two crops, the total nitrogen removed per acre by soybeans (158 pounds) was greater than that removed by corn (121 pounds). Research results from the University of Illinois, however, indicate that when properly nodulated soybeans were grown at the proper soil pH, the symbiotic fixation was equivalent to 63 percent of the nitrogen removed in harvested grain. Thus, the net nitrogen removal by soybeans (58 pounds) was less than that of corn (121 pounds).

This net removal of nitrogen by soybeans in 2000–2001 was equivalent to 34 percent of the amount of fertilizer nitrogen used in Illinois. On the other hand, symbiotic fixation of nitrogen by soybeans in Illinois (525,000 tons of nitrogen) was equivalent to 58 percent of the fertilizer nitrogen used in Illinois.

Even though there is a rather large net nitrogen removal from soil by soybeans (58 pounds of nitrogen per acre), research at the University of Illinois has generally indicated no soybean yield increase caused by either residual nitrogen in the soil or nitrogen fertilizer applied for the soybean crop.

1. *Residual from nitrogen applied to corn* (Table 11.06). Soybean yields at four locations were not increased by residual nitrogen in the soil, even when nitrogen rates as high as 320 pounds per acre had been applied to corn the previous year.
2. *Nitrogen on continuous soybeans* (Table 11.07). After 18 years of continuous soybeans at Hartsburg, yields were unaffected by applications of nitrogen fertilizer.

Table 11.06. Soybean Yields at Four Locations as Affected by Nitrogen Applied to Corn the Preceding Year (4-Year Average)

N applied to corn (lb/A)	Soybean yield (bu/A)				
	Aledo	Dixon	Elwood	Kewanee	Average
0	48	40	37	40	41
80	49	40	36	38	41
160	48	39	36	40	41
240	48	42	36	40	41
320	48	42	36	37	41

Table 11.07. Yields of Continuous Soybeans with Rates of Added Nitrogen at Hartsburg

Nitrogen (lb/A)	Soybean yield (bu/A)	
	1968–71	1954–71
0	43	37
40	42	36
120	43	37

Table 11.08. Soybean Yields at Urbana as Affected by High Rates of Nitrogen

Nitrogen (lb/A)			Soybean yield (bu/A)		
1st year	2nd year	3rd year	1st year	2nd year	3rd year
0	0	0	54	53	40
40	200	200	54	57	41
80	400	400	56	57	45
120	800	800	53	55	42
160	1,600	1,600	55	34	36

3. *High rates of added nitrogen* (Table 11.08). Moderate rates of nitrogen were applied to soybeans in the first year of a study at Urbana. Rates were increased in the second year so that the higher rates would furnish more than the total nitrogen needs of soybeans. Yields were not affected by nitrogen in the first year, but with 400 pounds per acre of nitrogen, a tendency toward a yield increase occurred in the second and third years. However, the yield increase would not pay for the added nitrogen at current prices.

Kansas researchers have reported soybean yield increases associated with the application of up to 40 pounds nitrogen per acre at the R4 stage of growth. Generally, these responses have occurred on irrigated, high-yielding (check yields of 58 bushels per acre) fields. In 1995, yield increases ranging from 9 to 12 bushels per acre were observed at 3 of 4 locations. The control yield at the nonresponding location was 43 bushels per acre.

Wheat, oats, and barley. The rate of nitrogen to apply on wheat, oats, and barley depends on soil type, crop and variety to be grown, and future cropping intentions (Table 11.09). Light-colored soils (low in organic matter) require the highest rate of nitrogen application because they have a low capacity to supply nitrogen. Deep, dark-colored soils require lower rates of nitrogen application for maximum yields.

Estimates of organic-matter content for soils of Illinois may be obtained from Agronomy Fact Sheet SP-36, *Average Organic Matter Content in Illinois Soil Types*, or by using University of Illinois publication AG-1941, *Color Chart for Estimating Organic Matter in Mineral Soils.*

Nearly all modern varieties of wheat have been selected for improved standability, so concern about nitrogen-induced lodging has decreased considerably. Varieties of oats, though substantially improved with regard to standability, will still lodge occasionally; nitrogen should be used carefully. Barley varieties, especially spring barley, are prone to lodging, so rates of nitrogen application shown in Table 11.09 should not be exceeded.

Some wheat and oats in Illinois serve as companion crops for legume or legume–grass seedings. On those fields, it is best to apply nitrogen fertilizer at well below the optimal rate because unusually heavy vegetative growth of wheat or oats competes unfavorably with the young forage seedlings (Table 11.09). Seeding rates for small grains should also be somewhat lower if used as companion seedings.

The introduction of nitrification inhibitors and improved application equipment now provide two options for applying nitrogen to wheat. Research has shown that when the entire amount of nitrogen needed is applied in the fall with a nitrification inhibitor, the resulting yield is equivalent to that obtained when a small portion of the total need was fall-applied and the remainder was applied in early spring. Producers who are frequently delayed in applying nitrogen in the spring because of muddy fields may wish to consider fall application with a nitrification inhibitor. For fields that are not usually wet in the spring, either system of application will provide equivalent yields.

Table 11.09. Recommended Nitrogen Application Rates for Wheat, Oats, and Barley

Soil situation	Organic matter	Fields with alfalfa or clover seeding		Fields with no alfalfa or clover seeding	
		Wheat	Oats and barley	Wheat	Oats and barley
		nitrogen (lb/A)			
Low in capacity to supply nitrogen: inherently low in organic matter (forested soils)	< 2%	70–90	60–80	90–110	70–90
Medium in capacity to supply nitrogen: moderately dark-colored soils	2–3%	50–70	40–60	70–90	50–70
High in capacity to supply nitrogen: deep, dark-colored soils	> 3%	30–50	20–40	50–70	30–50

Table 11.10. Nitrogen Fertilization of Grass Hay

	Time of application			
Species	Early spring	After first harvest	After second harvest	Early September
	nitrogen (lb/A)			
Kentucky bluegrass	60–80			(see text)
Orchardgrass	75–125	75–125		
Smooth bromegrass	75–125	75–125		50*
Reed canary grass	75–125	75–125		50*
Tall fescue for winter use		100–125	100–125	50*

*Optional if extra fall growth is needed.

The amount of nitrogen needed for good fall growth is not large because the total uptake in roots and tops before cold weather is not likely to exceed 30 to 40 pounds per acre.

Grass hay. The species grown, period of use, and yield goal determine optimal nitrogen fertilization (Table 11.10). The lower rate of application is recommended on fields where inadequate stands or moisture limits production.

Kentucky bluegrass is shallow-rooted and susceptible to drought. Consequently, the most efficient use of nitrogen by bluegrass is from an early spring application, with September application a second choice. September fertilization stimulates both fall and early spring growth.

Orchardgrass, smooth bromegrass, tall fescue, and reed canarygrass are more drought-tolerant than bluegrass and can use higher rates of nitrogen more effectively. Because more uniform production is obtained by splitting high rates of nitrogen, two or more applications are suggested.

If extra spring growth can be utilized, make the first nitrogen application in March in southern Illinois, early April in central Illinois, and mid-April in northern Illinois. If spring growth is adequate without extra nitrogen, the first application may be delayed until after the first harvest to distribute production more uniformly throughout the summer. Total production likely will be less, however, if nitrogen is applied after first harvest rather than in early spring. Usually the second application of nitrogen is made after the first harvest; to stimulate fall growth, however, this application may be deferred until August or early September.

Legume–grass mixtures should not receive nitrogen if legumes make up at least 30 percent of the mixture. Because the main objective is to maintain the legume, the emphasis should be on applying phosphorus and potassium rather than nitrogen. See Table 11.23 for phosphorus and potassium maintenance required for various hay yields.

After the legume has declined to less than 30 percent of the mixture, the objective of fertilizing is to increase the yield of grass. The suggested rate of nitrogen is about 50 pounds per acre when legumes make up 20 to 30 percent of the mixture.

Pasture fertilization. The producer must consider the productivity of the grazing animals, the plant species present, and the management level and goals for the pasture. If legumes comprise 30 percent or more of the sward, do not apply nitrogen fertilizer because an adequate amount will be contributed through fixation. If the legume portion is less than 30 percent, grass will probably respond to nitrogen fertilizer. If applying 100 pounds of nitrogen per acre, apply the first 50 pounds in early to mid-June when the spring flush of grass growth is over, and apply the second 50 pounds in late July to early August. Because early-season growth is generally excessive, an early spring application is not suggested unless the first harvest can be efficiently grazed or will be harvested as hay or silage. Nitrogen application early in the season can make grazing management of the spring flush more difficult.

Source of nitrogen is important for summer application. Use a dry nitrogen source, ammonium nitrate, ammonium sulfate, or urea. Do not apply liquid urea–ammonium nitrate solutions to an actively growing pasture.

Once the soil is corrected to optimal soil-test levels for phosphorus (P_1 of 40 to 50 pounds per acre) and potassium (K of 260 to 300 pounds per acre), monitor their status by soil testing every four years. Optimal levels will vary by soil type, area of the state, and, to a certain extent, by the species grown. Once these optimal levels have been reached, additional phosphorus and potassium fertilizer is not considered economical nor does it provide for consistent yield responses. Sixty to 80 percent of the phosphorus and potassium removed by grazing is recycled on the pasture in the form of manure and urine. Manure distribution is greatly affected by grazing management; for example, a high stocking density and short grazing period will improve uniformity of manure distribution.

Rate Adjustments

In addition to determining nitrogen rates, producers should consider other agronomic factors that influence available nitrogen. These factors include past cropping history and the use of manure (Table 11.11), as well as the date of planting.

Previous crop. Corn following another crop consistently yields better than continuous corn. This is especially true for corn following a legume such as soybeans or alfalfa (Figure 11.06). This is due in part to residual nitrogen from the legumes as the differences in yield between rotations become smaller with increasing nitrogen rates. When no nitrogen was applied, the data indicate that soybeans and alfalfa contributed the equivalent of 65 and 108 pounds of nitrogen per acre, respectively. At the optimal production level, soybeans contributed the equivalent of about 40 pounds of nitrogen per acre. The contribution of legumes, either soybeans or alfalfa, to wheat will be less than the contribution to corn because the oxidation of the organic nitrogen from these legumes will not be as rapid in early spring, when nitrogen needs of small grain are greatest, as it is in the summer, when nitrogen needs of corn are greatest.

Corn following oats had a higher yield than continuous corn (Figure 11.06). Although oats are not a legume, a part of this yield differential may be because nitrogen was released from the soil after the oat crop had completed its nitrogen uptake, and thus it was carried over to the next year’s corn crop.

Idled acres. Depending on the crop grown, the nitrogen credit from idled acres may be positive or negative. Plowing under a good stand of a legume that had good growth will result in a contribution of 60 to 80 pounds of nitrogen per acre. If either stand or growth of the legume was poor or if corn was no-tilled into a good legume stand that had good growth, the legume nitrogen contribution could be reduced to 40 to 60 pounds per acre. Because most of the net nitrogen gained from first-year legumes is in the herbage, fall grazing reduces the nitrogen contribution to 30 to 50 pounds per acre.

Table 11.11. Adjustments in Nitrogen Recommendations

		Factors resulting in reduced nitrogen requirement					
		1st year after alfalfa or clover			2nd year after alfalfa or clover		
		Plants/sq ft			Plants/sq ft		
Crop to be grown	After soy-beans	5	2–4	< 2	5	< 5	Manure
	- - - - - - - - *nitrogen reduction (lb/A)* - - - - - - - -						
Corn	40	100	50	0	30	0	5*
Wheat	10	30	10	0	0	0	5*

*Nitrogen contribution in pounds per ton of manure. See Table 11.12 for adjustments for liquid manure.

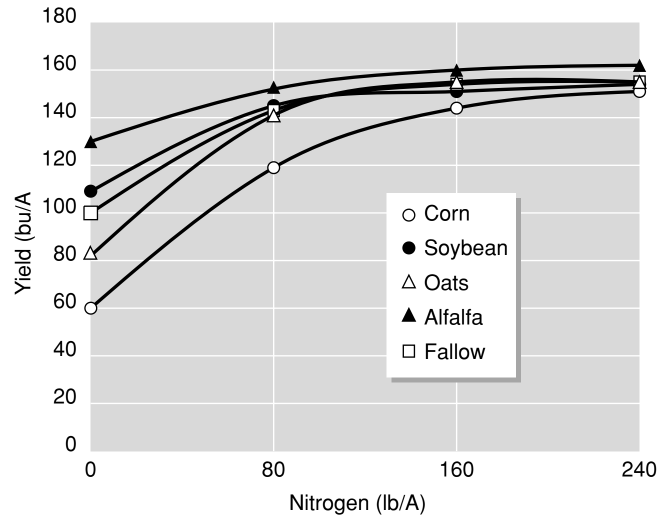


Figure 11.06. Effect of crop rotation and applied nitrogen on corn yield, DeKalb.

Manure. Nutrient content of manure varies with source and method of handling (Table 11.12). The availability of the total nitrogen content also varies by method of application. When manure is incorporated during or immediately after application, about 50 percent of the total nitrogen in dry manure and 50 to 60 percent of the total nitrogen in liquid manure will be available for the crop that is grown during the year following manure application.

Time of planting. Research at the Northern Illinois Research Center for several years showed that as planting was delayed, less nitrogen fertilizer was required for most profitable yield. Based upon that research, Illinois agronomists suggest that for each week of delay in planting after the optimal date for the area, the nitrogen rate can be reduced 20 pounds per acre down to 80 to 90 pounds per acre as the minimum for very late planting in a corn–soybean cropping system. Suggested reference dates are April 10 to 15 in southern Illinois, April 20 to May 1 in central Illinois, and May 1 to 10 in northern Illinois. This adjustment is of course possible only if the nitrogen is sidedressed.

Because of the importance of planting date, farmers are encouraged not to delay planting just to apply nitrogen fertilizer: plant, then sidedress.

Reactions in the Soil

Efficient use of nitrogen fertilizer requires understanding how nitrogen behaves in the soil. Key points to consider are the change from ammonium (NH_4^+) to nitrate (NO_3^-) and the movements and transformations of nitrate.

Table 11.12. Average Composition of Manure

	Nutrients		
Manure type	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Solid handling systems		*lb/ton*	
Dairy cattle (no bedding)	9	3	6
Beef cattle (no bedding)	11	7	10
Swine (no bedding)	11	8	5
Chicken (no bedding)	33	48	34
Liquid handling systems		*lb/1,000 gallon*	
Dairy cattle (liquid pit)	31	15	9
Dairy cattle (lagoon)	4	3	4
Beef cattle (liquid pit)	29	18	26
Beef cattle (lagoon)	4	3	4
Swine (liquid pit)	36	25	22
Swine (lagoon)	5	3	4
Poultry (liquid pit)	60	45	30

A high percentage of the nitrogen applied in Illinois is in the ammonium form or converts to ammonium (anhydrous ammonia and urea, for example) soon after application. Ammonium nitrogen is held by the soil clay and organic matter and cannot move very far until it nitrifies (changes from ammonium to nitrate). In the nitrate form, nitrogen can be lost by either denitrification or leaching (Figure 11.07).

Denitrification. Denitrification is believed to be the main process by which nitrate and nitrite nitrogen are lost, except on sandy soils, where leaching is the major pathway. Denitrification involves only nitrogen that is in the form of either nitrate (NO_3^-) or nitrite (NO_2^-).

The amount of denitrification depends mainly on (a) how long the surface soil is saturated; (b) the temperature of the soil and water; (c) the pH of the soil; and (d) the amount of energy material available to denitrifying organisms.

When water stands on the soil or when the surface soil is completely saturated in late fall or early spring, nitrogen loss is likely to be small because much nitrogen is still in the ammonium rather than nitrate form and because the soil is cool, and denitrifying organisms are not very active.

Many fields in east-central Illinois, and to a lesser extent in other areas, have low spots where surface water collects at some time during the spring or early summer. The flat claypan soils also are likely to be saturated, though not flooded, during that time. Sidedressing would avoid the risk of spring loss on these soils but would not affect midseason loss. Unfortunately, these are the soils on which sidedressing is difficult in wet years.

New scientific procedures now make it possible to directly measure denitrification losses. Results

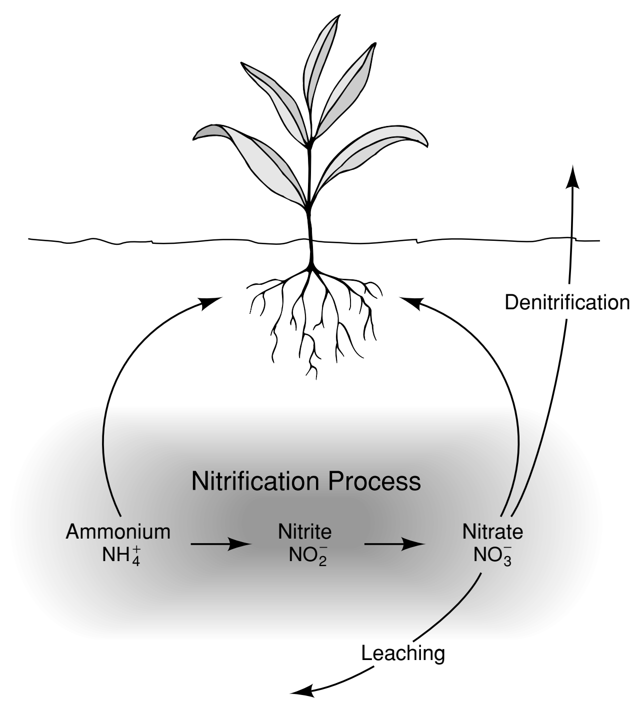


Figure 11.07. Nitrogen reactions in the soil.

collected over the past few years indicate that when soils were saturated for 3 days or longer, 5 percent of the nitrogen present in the nitrate form was lost per day of saturation.

Leaching. In silt loams and clay loams, 1 inch of rainfall moves down about 5 to 6 inches, though some of the water moves in large pores farther through the profile and carries nitrates with it.

In sandy soils, each inch of rainfall moves nitrates down about 1 foot. If the total rainfall at one time is more than 6 inches, little nitrate will be left within the rooting depth on sands.

Between rains, some upward movement of nitrates occurs in moisture that moves toward the surface as the surface soil dries. The result is that it is difficult to predict how deep the nitrate has moved based only on cumulative rainfall.

When trying to estimate the depth of leaching of nitrates in periods of very intensive rainfall, two points need to be considered. First, the rate at which water can enter the surface of silt and clay loams may be less than the rate of rainfall, which means that much of the water runs off the surface into low spots or into creeks and ditches. Second, the soil may be saturated already. In either of these cases, the nitrates will not move down the 5 to 6 inches per inch of rain as suggested previously.

Corn roots usually penetrate to 6 feet in Illinois soils. Thus, nitrates that leach only to 3 to 4 feet are well within normal rooting depth unless they reach tile lines and are drained from the field.

Nitrification Inhibitors

As Figure 11.07 shows, nitrification converts ammonium nitrogen into nitrate, the form susceptible to loss by denitrification or leaching. Use of nitrification inhibitors can retard this conversion. When inhibitors were properly applied in one experiment, as much as 42 percent of soil-applied ammonia remained in the ammonium form through the early part of the growing season, in contrast with only 4 percent that remained when inhibitors were not used. Inhibitors can therefore significantly affect crop yields. The benefit from using an inhibitor varies, however, with soil condition, time of year, type of soil, geographic location, rate of nitrogen application, and weather conditions that occur after the nitrogen is applied and before it is absorbed by the crop.

Considerable research throughout the Midwest has shown that only under wet soil conditions do inhibitors significantly increase yields. When inhibitors were applied in years of excessive rainfall, increases in corn yield ranged from 10 to 30 bushels per acre; when moisture conditions were not as conducive to denitrification or leaching, inhibitors produced no increase.

For the first 4 years of one experiment conducted by the University of Illinois, nitrification inhibitors produced no effect on grain yields because soil moisture levels were not sufficiently high. In early May of the fifth year, however, when soils were saturated with water for a long time, the application of an inhibitor in the preceding fall significantly increased corn yields (Figure 11.08). Furthermore, at a nitrogen application rate of 150 pounds per acre, the addition of an inhibitor increased grain yields more than did the addition of another 40 pounds of nitrogen (Figure 11.08). Under the conditions of that experiment, therefore, it was more economical to use an inhibitor than to apply more nitrogen.

Because soils normally do not remain saturated with water for very long during the growing season after a sidedressing operation, the probability of benefiting from the use of a nitrification inhibitor with sidedressed nitrogen is less than from its use with either fall- or spring-applied nitrogen. Moreover, the short time between application and absorption by the crop greatly reduces the potential for nitrogen loss.

The longer the period between nitrogen application and absorption by the crop, the greater the probability that nitrification inhibitors will contribute to higher yields. The length of time, however, that fall-applied inhibitors remain effective in the soil depends partly on soil temperature. On one plot, a Drummer soil that had received an inhibitor application when soil temperature was 55°F retained nearly 50 percent of the applied ammonia in ammonium form for about 5 months. When soil temperature was 70°F, the soil

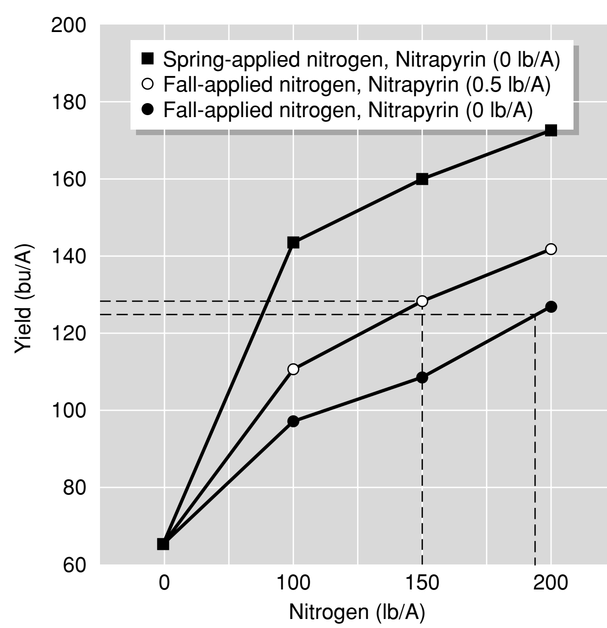


Figure 11.08. Effect of nitrification inhibitors on corn yields at varying nitrogen application rates, DeKalb.

retained the same amount of ammonia for only 2 months. Fall application of nitrogen with inhibitors should therefore be delayed until soil temperatures are no higher than 60°F; and though temperatures may decrease to 60°F in early September, it is advisable to delay applications until the second week of October in northern Illinois and the third week of October in central Illinois.

In general, poorly or imperfectly drained soils probably benefit the most from nitrification inhibitors. Moderately well-drained soils that undergo frequent periods of 3 or more days of flooding in the spring also benefit. Coarse-textured soils (sands) are likely to benefit more than soils with finer textures because the coarse-textured soils have a higher potential for leaching.

Time of application and geographic location must be considered along with soil type when determining whether to use a nitrification inhibitor. Employing inhibitors can significantly improve the efficiency of fall-applied nitrogen on the loams, silts, and clays of central and northern Illinois in years when the soil is very wet in the spring. At the same time, currently available inhibitors do not adequately reduce the rate of nitrification in the low organic matter soils of southern Illinois when nitrogen is applied in the fall for the following year's corn. The lower organic matter content and the warmer temperatures of southern Illinois soils, both in late fall and early spring, cause the inhibitor to degrade too rapidly. Furthermore, applying an inhibitor on sandy soils in the fall does not adequately reduce nitrogen loss because the potential for leaching is too high. Fall applications of nitrogen with inhibitors thus are not recommended for sandy soils or for soils with low-organic-matter content, especially those found south of Illinois Route 16.

In the spring, preplant applications of inhibitors may be beneficial on nearly all types of soil from which nitrogen loss frequently occurs, especially on sandy and poorly drained soils. Again, inhibitors are more likely to have an effect when subsoils are recharged with water than when they are dry at the beginning of spring.

Nitrification inhibitors are most likely to increase yields when nitrogen is applied at or below the optimal rate. When nitrogen is applied at a rate greater than that required for optimal yields, benefits from an inhibitor are unlikely, even when moisture in the soil is excessive.

Inhibitors should be viewed as soil management tools that can be used to reduce nitrogen loss. It is not safe to assume, however, that the use of a nitrification inhibitor will make it possible to reduce nitrogen rates below those currently recommended, because those rates were developed with the assumption that no significant amount of nitrogen would be lost.

Time of Nitrogen Application

For nitrogen that is fall-applied without a nitrification inhibitor, farmers in central and northern Illinois should apply nitrogen in non-nitrate form in the late fall after the soil temperature at 4 inches is below 50°F, except on sandy, organic, or very poorly drained soils. Nitrogen, other than that included incidentally with the phosphorus application, should not be fall-applied for corn on sandy soils or on any soil south of a line roughly paralleling Illinois Route 16. Use of soil maps to determine appropriate application of fall nitrogen on certain fields located in the vicinity of this boundary line is acceptable. When applied properly, fall nitrogen on wheat is acceptable.

The 50°F level for fall application is believed to be a realistic guideline for farmers. Applying nitrogen earlier risks too much loss (Figure 11.09). Later application risks wet or frozen fields, which would prevent application and fall tillage. Average dates on which these temperatures are reached are not satisfactory guides because of the great variability from year to year. Soil thermometers should be used to guide fall applications of nitrogen.

In Illinois, most of the nitrogen applied in late fall or very early spring is converted to nitrate by corn-planting time. Though the rate of nitrification is slow (Figure 11.09), the soil temperature is between 32°F and 40° to 45°F for a long period.

In consideration of the date at which nitrates are formed and the conditions that prevail thereafter, the difference in susceptibility to denitrification and leaching loss between late fall and early spring applications of ammonium sources is probably small. Both are, however, more susceptible to loss than is nitrogen applied at planting time or as a sidedressing.

Anhydrous ammonia nitrifies more slowly than other forms and is slightly preferred for fall applications. It is well suited to early spring application,

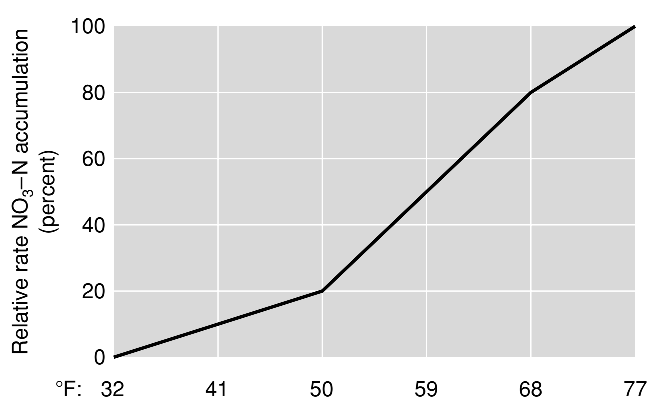


Figure 11.09. Influence of soil temperature on the relative rate of NO_3 accumulation in soils.

provided the soil is dry enough for good dispersion of ammonia and closure of the applicator slit.

Urea-containing fertilizers. Research at the University of Minnesota has clearly shown that fall-applied urea, even when it is incorporated, is not as effective at increasing crop yield as spring-applied urea or fall-applied ammonia (Table 11.13).

Sidedress application. Results collected from studies in Illinois indicated that nitrogen injected between every other row was comparable in yield to injection between every row. This finding was true irrespective of tillage system (Table 11.14) or nitrogen rate (Table 11.15). This outcome should be expected, as even with every-other-row injection, each row will have nitrogen applied on one side or the other (Figure 11.10).

Table 11.13. Effect of Time of Urea and Ammonia Application on Corn Grain Yield

Time of N application	Nitrogen source	Yield (bu/A)
—	None	113
Fall	Urea	155
Fall	Ammonia	170
Spring preplant	Urea	185

Source: University of Minnesota.

Table 11.14. Effect on Corn Yield of Ammonia Knife Spacing with Different Tillage Systems at Two Illinois Locations

	Yield (bu/A)			
Injector spacing (in.)	Plow	Chisel	Disk	No-till
DeKalb trials				
30	159	157	163	146
60	158	157	157	143
Elwood trials				
30	. . .	119	121	118
60	. . .	117	125	121

. . . = no data collected.

Table 11.15. Effect on Corn Yield of Injector Spacing of Ammonia Applied at Different Rates of Nitrogen at DeKalb

	Nitrogen (lb/A)		
Injector spacing (in.)	120	180	240
	- - - - - *yield (bu/A)* - - - - - -		
30	171	176	181
60	170	171	182

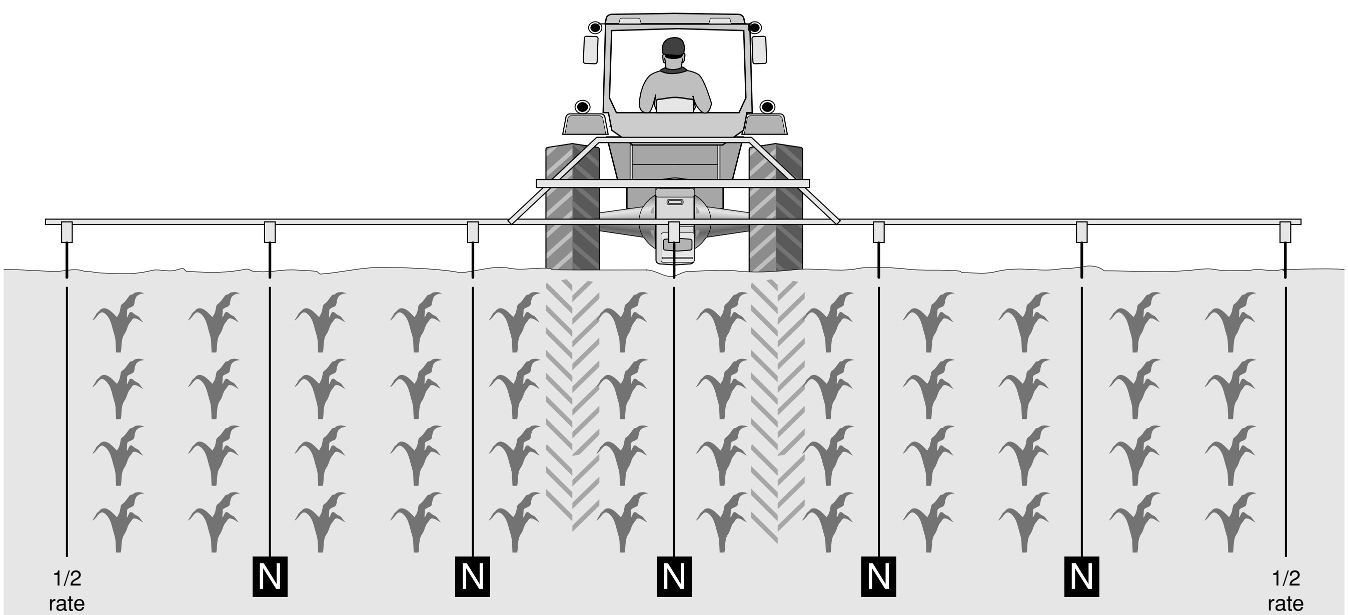


Figure 11.10. Schematic of every-other-row, sidedress nitrogen injection. The outside two injectors are set at one-half rate because the injector runs between those two rows twice.

Table 11.16. Effect of Source, Time, and Rate of Nitrogen Fertilizer on Corn Yield

Nitrogen treatment			Nitrogen (lb/A)			
Fertilizer material	Time of application	Method of application	0	120	180	240
			yield (bu/A)			
None (control)			89			
Urea	Winter	Surface		94	123	126
Urea	Spring	Incorporated		140	157	165
Anhydrous ammonia	Spring	Injected		149	157	158

Use of wider injection spacing at sidedressing allows for reduced power requirement for a given applicator width or use of a wider applicator with the same power requirement. From a practical standpoint, the lower power requirement frequently means a smaller tractor and associated smaller tire, making it easier to maneuver between rows and causing less compaction next to the row. With this system, injector positions can be adjusted to avoid placing an injector in the wheel track. When matching the driving pattern for a planter of 8, 12, 16, or 24 rows, the outside two injectors must be adjusted to half-rate application, as the injector will go between those two rows twice if one avoids having a knife in the wheel track. To avoid problems of back pressure that might be created when applying at relatively high speeds, use a double-tube knife, with two hoses going to each knife; the outside knives would require only one hose to give the half-rate application.

Winter application. Based on observations, the risk of nitrogen loss through volatilization associated with winter application of urea for corn on frozen soils is too great to consider the practice unless one is assured of at least 0.5 inch of precipitation occurring within 4 to 5 days after application. Yield loss of 30 to 40 bushels per acre occurred when urea was surface-applied in late February to frozen soils (Table 11.16). In most years, application of urea on frozen soils has been an effective practice for wheat.

Aerial application. Under some conditions, aerial application of dry urea results in increased yield. This practice should not be considered a replacement for normal nitrogen application but rather an emergency treatment in situations where corn is too tall for normal applicator equipment. Aerial application of nitrogen solutions on growing corn is not recommended, as extensive leaf damage likely results if the application rate is greater than 10 pounds of nitrogen per acre.

Which Nitrogen Fertilizer?

Most of the nitrogen fertilizer materials available for use in Illinois provide nitrogen in the combined form of ammonia, ammonium, urea, and nitrate (Table 11.17). For many uses on a wide variety of soils, all forms are likely to produce about the same yield—provided that they are properly applied.

Ammonia. Nitrogen materials that contain free ammonia (NH_3), such as anhydrous ammonia and low-pressure solutions, must be injected into the soil to avoid loss of ammonia in gaseous form. Upon injection into the soil, ammonia quickly reacts with water to form ammonium (NH_4^+). In this positively charged form, the ion is not susceptible to gaseous loss because it is temporarily attached to the negative charges on clay and organic matter. Some of the ammonia reacts with organic matter to become a part of the soil humus.

On silt loam or soils with finer textures, ammonia moves about 4 inches from the point of injection. On

Table 11.17. Composition of Various Nitrogen Fertilizers

Material	Total nitrogen %	Percentage of total nitrogen as				Salting out temperature	Weight of solution per gallon
		Ammonia	Ammonium	Nitrate	Urea		
Anhydrous ammonia	82	100	—	—	—	—	5.90
Ammonium nitrate	34	—	50	50	—	—	—
Ammonium sulfate	21	—	100	—	—	—	—
Urea	46	—	—	—	100	—	—
Urea–ammonium nitrate	28	—	25	25	50	–1	10.70
Urea–ammonium nitrate	32	—	25	25	50	32	11.05

more coarsely textured soils, such as sands, ammonia may move 5 to 6 inches from the point of injection. If the depth of application is shallower than the distance of movement, some ammonia may move slowly to the soil surface and escape as a gas over several days. On coarse-textured (sandy) soils, anhydrous ammonia should be placed 8 to 10 inches deep, whereas on silt-loam soils, the depth of application should be 6 to 8 inches.

Anhydrous ammonia is lost more easily from shallow placement than is ammonia in a low-pressure solution. Nevertheless, low-pressure solutions contain free ammonia and thus need to be incorporated into the soil at a depth of 2 to 4 inches.

Ammonia should not be applied to soils having a physical condition that would prevent closure of the applicator knife track. Ammonia will escape to the atmosphere whenever there is a direct opening from the point of injection to the soil surface.

Seedlings can be damaged if proper precautions are not taken when applying nitrogen materials that contain or form free ammonia. Damage may occur if nitrogen material is injected into soils that are so wet that the knife track does not close properly. If the soil dries rapidly, this track may open. Damage can also result from applying nitrogen material to excessively dry soils, which allow the ammonia to move large distances before being absorbed. Finally, damage to seedlings can be caused by using a shallower application than that suggested in the preceding paragraph. Generally, delaying planting 3 to 5 days after applying fertilizer will cause little, if any, seedling damage. While it is extremely rare, damage from fall-applied ammonia to corn seeded the next spring has been observed. The situations where this has occurred have been characterized by application in late fall on soils that were wet enough that serious compaction resulted along the side walls of the knife track. This was followed by an extremely dry winter and spring. When the surface soils dried in the spring, the soil cracked along the knife track and allowed the ammonia to escape into the seed zone.

Because ammonia is a mixture of liquid and vapor, it is more difficult to ensure uniformity of application across a tool bar and the correct rate per acre than it is with some other nitrogen products. These problems can be minimized by using speed-control devices (radar controllers or ground-driven pumps), using heat exchangers, and taking time to ensure that the applicator is properly configured.

Don't take comfort in the fact that the scale ticket indicates that you have the correct rate per acre. Several studies have shown that ammonia flow may vary as much as three- to fourfold from knife to knife on the same tool bar. Much of the problem occurs at the manifold, and, with a bit of work, much of it can be corrected. Using the following suggestions will minimize knife-to-knife variability:

- Plug placement. If the manifold is top loading, uniformly place the plugs around the manifold (Figure 11.11). If the manifold is side loading, place the plugs directly opposite the entry of the ammonia (Figure 11.12).
- Hose placement and length. Randomly assign knives to the manifold to avoid having high (or low) rates next to each other. Cut all hoses the same length, no matter how long they need to be to reach the knife. Short hoses will have higher flow rates.

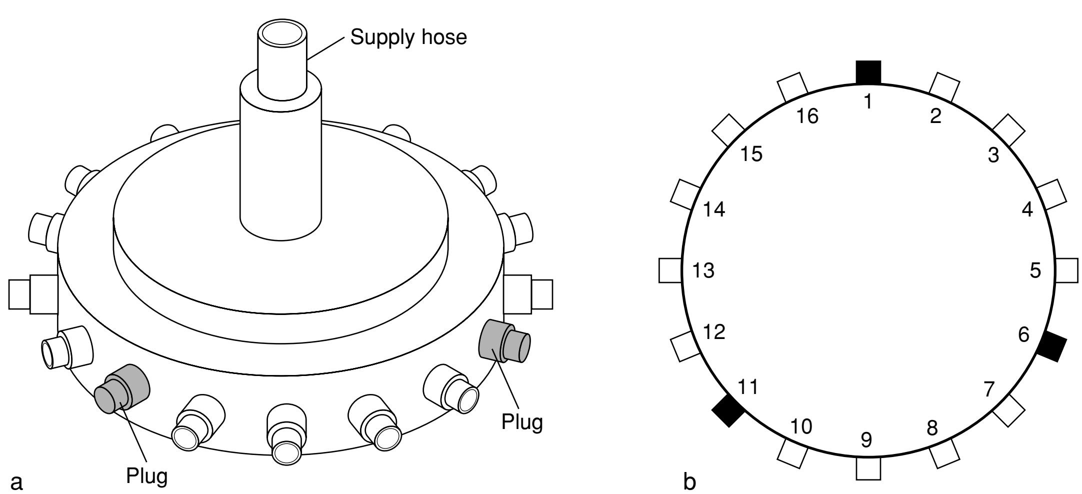


Figure 11.11. If plugs are needed on top-loading manifolds (see a), they should be placed uniformly around the manifold (see b).

- Dual manifolds. Avoid dual manifolds on tool bars with 13 or fewer knives.
- Hoses, hose barbs, and knives. Large openings allow a larger flow of ammonia than do smaller openings. This is true for hoses, hose barbs, and knives. Be sure to use the same size hose and hose barbs on all ports and the same style (openings) of knives on all shanks.

Ammonium nitrate. Half of the nitrogen contained in ammonium nitrate is in the ammonium form, and half is in the nitrate form. The part present as ammonium attaches to the negative charges on the clay and organic-matter particles and remains in that state until it is used by the plant or converted to the nitrate ions by microorganisms present in the soil. Because 50 percent of the nitrogen is present in the nitrate form, this product is more susceptible to loss from both leaching and denitrification. Thus, ammonium nitrate should not be applied to sandy soils because of the likelihood of leaching, nor should it be applied far in advance of the time when the crop needs the nitrogen because of possible loss through denitrification.

Urea. The chemical formula for urea is $CO(NH_2)_2$. In this form, it is very soluble and moves freely up and down with soil moisture. After being applied to the soil, urea is converted to ammonia, either chemically or by the enzyme urease. The speed with which this conversion occurs depends largely on temperature. Conversion is slow at low temperatures but rapid at temperatures of 55°F or higher.

If the conversion of urea occurs on the soil surface or on the surface of crop residue or leaves, some of the resulting ammonia will be lost as a gas to the atmosphere. The potential for loss is greatest when the following conditions exist:

- Temperatures are greater than 55°F. Loss is less likely with winter or early spring applications, but results show that the loss may be substantial if the materials remain on the surface of the soil for several days.
- Considerable crop residue remains on soil surface.
- Application rates are greater than 100 pounds of nitrogen per acre.
- The soil surface is moist and rapidly drying.
- Soils have a low cation-exchange capacity.
- Soils are neutral or alkaline in reaction.

Surface application of urea and urea–ammonium nitrate solutions has resulted in significantly lower no-till corn yield than surface application of ammonium nitrate, injected urea–ammonium nitrate, and injected anhydrous ammonia at both Dixon Springs Agricultural Center in Simpson, Illinois, and at Belleville, Illinois (Table 11.18). Addition of the urease inhibitor AgrotaiN resulted in increased yield compared to broadcast urea, but yields were still not as good as those obtained with injected urea–ammonium nitrate or ammonia.

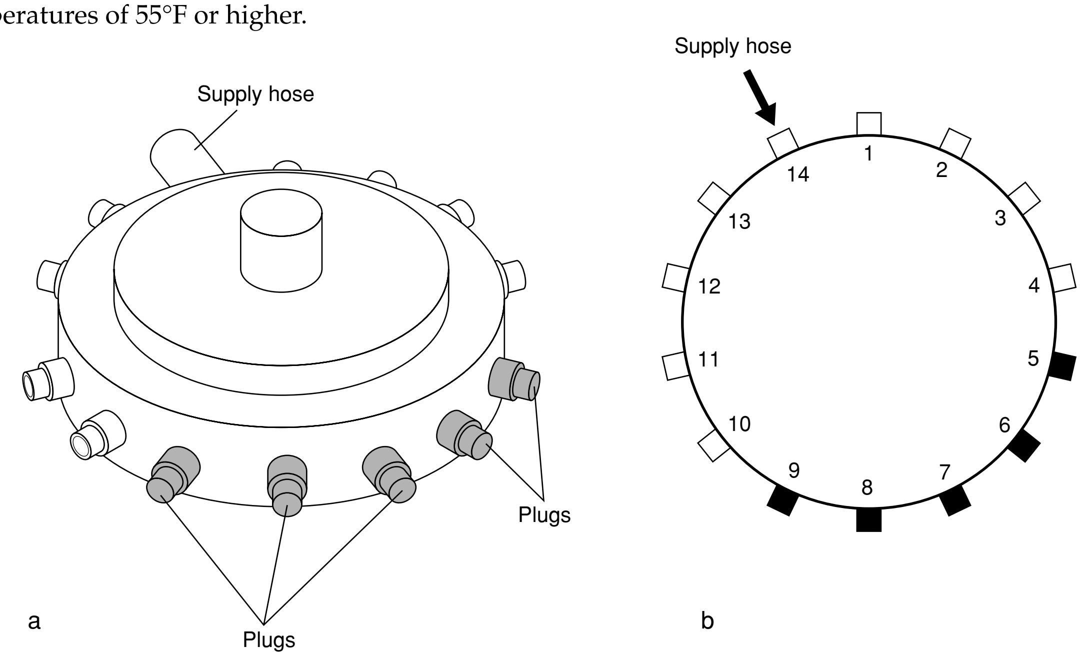


Figure 11.12. If plugs are needed on side-loading manifolds (see a), they should be placed directly across from the entry of the ammonia (see b).

Urease inhibitors. The chemical compound N-(n-butyl) thiophosphoric triamide, commonly referred to as NBPT and sold under the trade name AgrotaiN, has been shown to inhibit the urease enzyme that converts urea to ammonia. This material can be added to urea–ammonium nitrate solutions or to urea. Addition of this material will reduce the potential for volatilization of surface-applied, urea-containing products. Experimental results collected around the Corn Belt over the last several years have shown an average increase of 4.3 bushels per acre when applied with urea and 1.6 bushels per acre when applied with urea–ammonium nitrate solutions. Where nonvolatile nitrogen treatments resulted in a higher yield than unamended urea, addition of the urease inhibitor increased yield by 6.6 bushels per acre for urea and by 2.7 bushels per acre for urea–ammonium nitrate solutions. In a year characterized by a long dry period in the spring, NBPT with urea resulted in yield increases of 20 bushels per acre as compared to urea alone in related experiments in southern Illinois and Missouri (Tables 11.19 and 11.20). These results clearly show the importance of proper urea management techniques in years when precipitation is not received soon after surface application of urea.

Urease inhibitors have the greatest potential for benefit when urea-containing materials are surface-applied without incorporation at 50°F or higher. The potential is even greater if there is significant residue remaining on the soil surface. In situations where the urea-containing materials can be incorporated within 2 days after application, either with a tillage operation or with adequate rainfall, the potential for benefit from a urease inhibitor is very low.

Ammonium sulfate. The compound ammonium sulfate ($[NH_4]_2SO_4$) supplies all of the nitrogen in the ammonium form. As a result, it theoretically has a slight advantage over products that supply a portion of their nitrogen in the nitrate form, because the ammonium form is not susceptible to leaching or denitrification. However, this advantage is usually short-lived because all ammonium-based materials quickly convert to nitrate once soil temperatures are favorable for activity of soil organisms (above 50°F).

In contrast to urea, there is little risk of loss of the ammonium contained in ammonium sulfate through volatilization. As a result, it is an excellent material for surface application on fields that will be planted no-till that have high-residue levels. As with any other ammonium-based material, there is a risk associated with surface application in years in which there is inadequate precipitation to allow for adequate root activity in the fertilizer zone.

Ammonium sulfate is an excellent material for use on soils that may be deficient in both nitrogen and sulfur. However, applying the material at a rate sufficient to meet the nitrogen need will cause overapplication of sulfur. That is not of concern because sulfur is mobile and moves out of the profile quickly. Fortunately, there is no known environmental problem associated with sulfate sulfur in water supplies.

Most ammonium sulfate available in the marketplace is a by-product of the steel, textile, or lysine industry and is marketed as either a dry granulated material or a slurry.

Ammonium sulfate is more acidifying than any of the other nitrogen materials on the market. As a rough rule, ammonium sulfate requires about

Table 11.18. Effect of Source of Nitrogen on Yield for No-Till Corn

			Location			
			Dixon Springs		Belleville	
Nitrogen source	Method of application	Rate[1] (lb/acre)	Continuous corn	Corn–soybean	Continuous corn	Corn–soybean
Control	—	0	62	73	34	53
Urea	Broadcast	180/140	98	100	106	120
Urea + AgrotaiN	Broadcast	180/140	112	112	134	143
Ammonium nitrate	Broadcast	180/140	118	119	151	156
UAN	Broadcast	180/140	103	107	123	137
UAN + AgrotaiN		180/140	107	114	128	145
UAN	Injected	180/140	123	121	172	176
Anhydrous ammonia	Injected	180/140	122	130	158	166

[1] Nitrogen rate was 180 lb of nitrogen per acre for continuous corn and 140 lb of nitrogen per acre for a corn–soybean rotation.

Table 11.19. Effect of Nitrogen Source, Rate, and NBPT on No-Till Corn Yield in Southern Illinois

	Yield (bu/A) by nitrogen source		
N (lb/A)	Ammonium nitrate	Urea	Urea + NBPT
0	60	—	—
80	114	90	110
120	118	97	115
160	114	105	122

Source: Southern Illinois University, Dr. E. C. Varsa. 1992.

Table 11.20. Effect of Nitrogen Source, Rate, and NBPT on No-Till Corn Yield in Missouri

	Yield (bu/A) by nitrogen source		
N (lb/A)	Ammonium nitrate	Urea	Urea + NBPT
0	83	—	—
60	164	132	151
180	203	173	196

Source: University of Missouri.

9 pounds of lime per pound of nitrogen applied, compared to 4 pounds of lime per pound of nitrogen from ammonia or urea. The extra acidity is of no concern as long as the soil is monitored for pH every 4 years.

In areas where fall application is acceptable, ammonium sulfate could be applied in late fall (after temperatures have fallen below 50°F) or in winter on frozen ground where the slope is less than 5 percent.

Nitrogen solutions. The nonpressure nitrogen solutions that contain 28 to 32 percent nitrogen consist of a mixture of urea and ammonium nitrate. Typically, half of the nitrogen is from urea, and the other half is from ammonium nitrate. The constituents of these compounds will undergo the same reactions as described earlier for the constituents applied alone.

Experiments at DeKalb have shown a yield difference between incorporated and unincorporated nitrogen solutions that were spring-applied (Table 11.21). This difference associated with method of application is probably caused by volatilization loss of some nitrogen from the surface-applied solution containing urea.

The effect on yield of postemergence application of nitrogen solutions and atrazine when corn plants are in the three-leaf stage was evaluated in Minnesota. The results indicated that yields were generally depressed when the nitrogen rate exceeded 60 pounds per acre. Leaf burn was increased by increasing the nitrogen rate, including atrazine with the nitrogen, and by hot, clear weather conditions.

Phosphorus and Potassium

Inherent Availability

Illinois has been divided into three regions in terms of the inherent phosphorus-supplying power of the soil below the plow layer in dominant soil types (Figure 11.13).

High phosphorus-supplying power means that the soil test for available phosphorus (P_1 test) is relatively high and conditions are favorable for good root penetration and branching throughout the soil profile.

Low phosphorus-supplying power may be caused by one or more factors:

1. A low supply of available phosphorus in the soil profile because (a) the parent material was low in phosphorus; (b) phosphorus was lost in the soil-forming process; or (c) the phosphorus is made unavailable by high pH (calcareous) material.

Table 11.21. Effect of Source, Method of Application, and Rate of Spring-Applied Nitrogen on Corn Yield, DeKalb

		Yield (bu/A)		
Carrier and application method	N (lb/A)	1976	1977	Avg
None	0	66	61	64
Ammonia	80	103	138	120
28% N solution, incorporated	80	98	132	115
28% N solution, unincorporated	80	86	126	106
Ammonia	160	111	164	138
28% N solution, incorporated	160	107	157	132
28% N solution, unincorporated	160	96	155	126
Ammonia	240	112	164	138
28% N solution, incorporated	240	101	164	132
28% N solution, unincorporated	240	91	153	122
$LSD_{.10}$*		9.1	5.2	

*Differences greater than the LSD value are statistically significant.

2. Poor internal drainage that restricts root growth.
3. A dense, compact layer that inhibits root penetration or branching.
4. Shallowness to bedrock, sand, or gravel.
5. Droughtiness, strong acidity, or other conditions that restrict crop growth and reduce rooting depth.

Regional differences in phosphorus-supplying power are shown in Figure 11.13. Parent material and degree of weathering were the primary factors considered in determining the various regions.

The "high" region is in western Illinois, where the primary parent material was more than 4 to 5 feet of loess that was high in phosphorus content. The soils are leached of carbonates to a depth of more than 3½ feet, and roots can spread easily in the moderately permeable profiles.

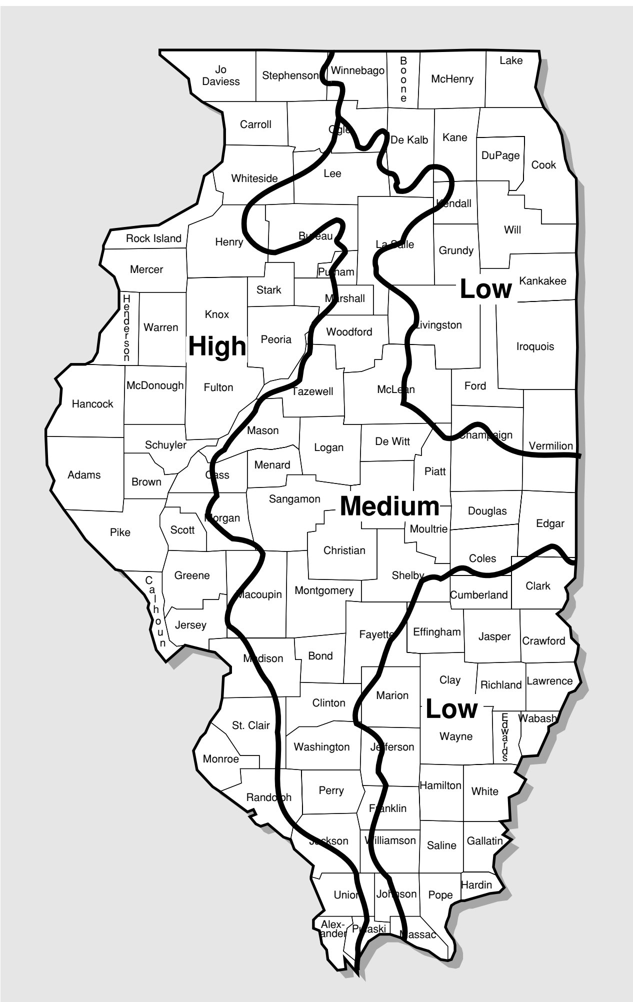


Figure 11.13. Subsoil phosphorus-supplying power in Illinois.

The "medium" region is in central Illinois, with arms extending into northern and southern Illinois. The primary parent material was more than 3 feet of loess over glacial till, glacial drift, or outwash. Some sandy areas with low phosphorus-supplying power occur in the region. In comparison with the high-phosphorus region, more of the soils are poorly drained and have less available phosphorus in the subsoil and substratum horizons. Carbonates are likely to occur at shallower depths than in the "high" region. The soils in the northern and central areas are generally free of root restrictions, whereas soils in the southern arm are more likely to have root-restricting layers within the profile. The phosphorus-supplying power of soils of the region is likely to vary with natural drainage. Soils with good internal drainage are likely to have higher levels of available phosphorus in the subsoil and substratum. If internal drainage is fair or poor, phosphorus levels in the subsoil and substratum are likely to be low or medium.

In the "low" region in southeastern Illinois, the soils were formed from 2½ to 7 feet of loess over weathered Illinoisan till. The profiles are more highly weathered than in the other regions and are slowly or very slowly permeable. Root development is more restricted than in the "high" or "medium" regions. Subsoil levels of phosphorus may be rather high by soil test in some soils of the region, but this is partially offset by conditions that restrict rooting.

In the "low" region in northeastern Illinois, the soils were formed from thin loess (less than 3 feet) over glacial till. The glacial till, generally low in available phosphorus, ranges in texture from gravelly loam to clay in various soil associations of the region. In addition, shallow carbonates further reduce the phosphorus-supplying power of the soils of the region. Further, high bulk density and slow permeability in the subsoil and substratum restrict rooting in many soils of the region.

The three regions are delineated to show broad differences among them. Parent material, degree of weathering, native vegetation, and natural drainage vary within a region and cause variation in the soil's phosphorus-supplying power. It appears, for example, that soils developed under forest cover have more available subsoil phosphorus than those developed under grass.

Illinois is divided into two general regions for potassium, based on cation-exchange capacity (Figure 11.14). Important differences exist, however, among soils within these general regions because of differences in these factors:

1. The amount of clay and organic matter, which influences the exchange capacity of the soil.
2. The degree of weathering of the soil material, which affects the amount of potassium that has been leached out.

3. The kind of clay mineral.
4. Drainage and aeration, which influence uptake of potassium.
5. The parent material from which the soil was formed.

Soils with a cation-exchange capacity less than 12 meq/100 grams are classified as having low capacity. These soils include the sandy soils because minerals from which they were developed are inherently low in potassium. Sandy soils also have very low cation-exchange capacities and thus do not hold much reserve potassium.

Silt-loam soils in the "low" area in southern Illinois (claypans) are relatively older in terms of soil development; consequently, much more of the potassium has been leached out of the rooting zone. Furthermore, wetness and a platy structure between the surface and subsoil may interfere with rooting and with potassium uptake early in the growing period, even though roots are present.

Rate of Fertilizer Application

Minimum soil-test levels required to produce optimal crop yields vary depending on the crop to be grown and the soil type (Figures 11.15 and 11.16). Near-maximal yields of corn and soybeans are obtained when levels of available phosphorus are maintained at 30, 40, and 45 pounds per acre for soils in the high, medium, and low phosphorus-supplying regions, respectively. Potassium soil-test levels at which optimal yields of these two crops are attained are 260 and 300 pounds of exchangeable potassium per acre for soils in the low and high cation-exchange capacity regions, respectively. Because phosphorus, and on most soils also potassium, will not be lost from the soil system other than through crop removal or soil erosion and because these are minimum values required for optimal yields, it is recommended that soil-test levels be built up to 40, 45, and 50 pounds per acre of phosphorus for soils in the high, medium, and low phosphorus-supplying regions, respectively.

Depending on the soil-test level, the amount of fertilizer recommended may be buildup plus maintenance, maintenance, or no fertilizer. The buildup is the amount of material required to increase the soil test to the desired level. The maintenance addition is the amount required to replace the amount that will be removed by the crop to be grown.

Buildup plus maintenance. When soil-test levels are below the desired values, it is suggested that enough fertilizer be added to build the test to the desired goal and to replace what the crop will remove. At these test levels, the yield of the crop will be affected by the amount of fertilizer applied that year.

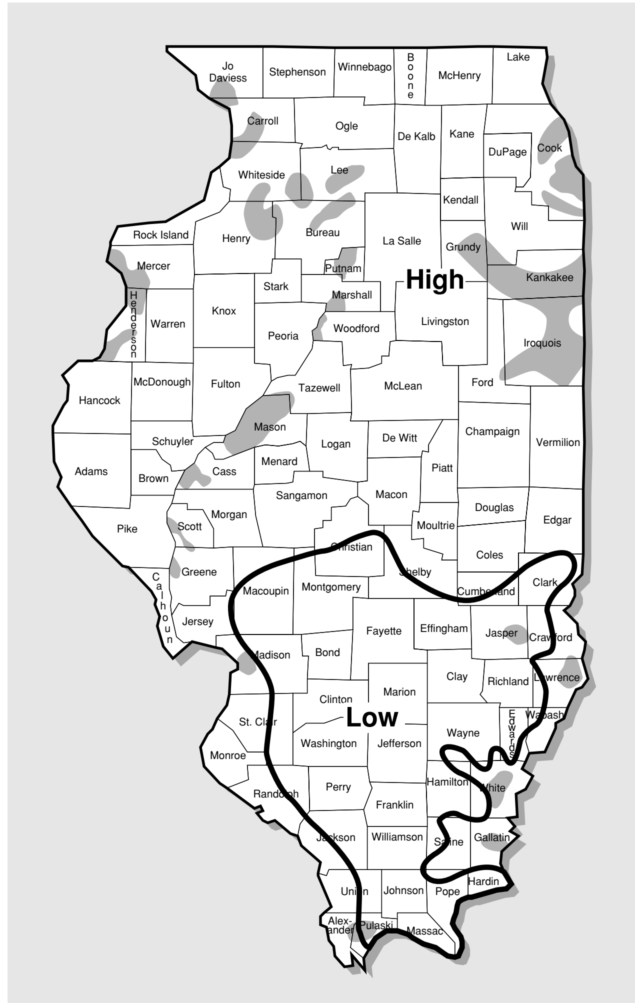


Figure 11.14. Cation-exchange capacity of Illinois soils. The shaded areas are sands with low cation-exchange capacity.

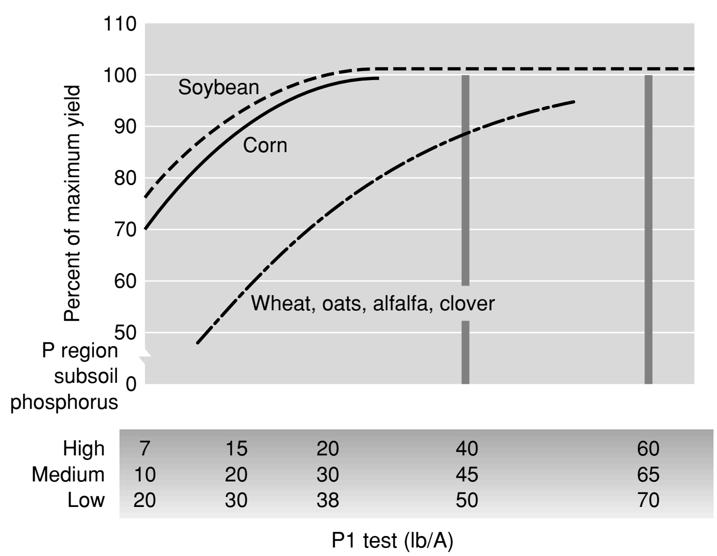


Figure 11.15. Relationship between expected yield and soil-test phosphorus.

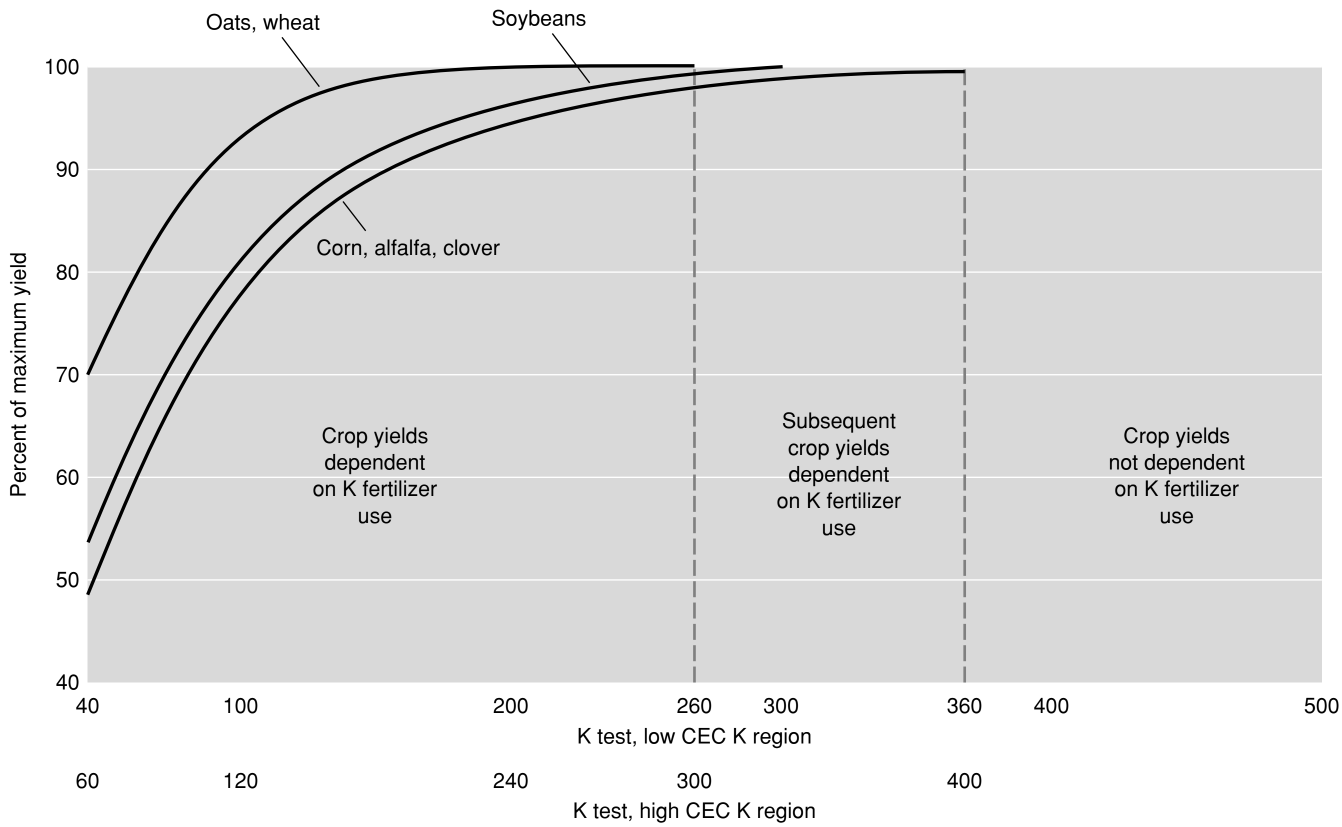


Figure 11.16. Relationship between expected yield and soil-test potassium.

Maintenance. When the soil-test levels are between the minimum and 20 pounds above the minimum for phosphorus (that is, 40 to 60, 45 to 65, or 50 to 70) or between the minimum and 100 pounds above the minimum for potassium (260 to 360 or 300 to 400), apply enough to replace what the crop to be grown is expected to remove. The yield of the current crop may not be affected by the fertilizer addition, but the yield of subsequent crops will be adversely affected if the materials are not applied to maintain soil-test levels.

No fertilizer. Although it is recommended that soil-test levels be maintained slightly above the level at which optimal yield would be expected, it would not be economical to attempt to maintain excessively high values. *Therefore, it is suggested that no phosphorus be applied if P_1 values are higher than 60, 65, and 70 for soils in the high, medium, and low phosphorus-supplying regions, respectively. No potassium is suggested if test levels are above 360 and 400 for the low and high cation-exchange capacity regions, unless crops that remove large amounts of potassium (such as alfalfa or corn silage) are being grown.* When soil-test levels are between 400 and 600 pounds per acre of potassium and corn silage or alfalfa is being grown, the soil should be tested every 2 years instead of every 4, or maintenance levels of potassium should be added to ensure that soil-test levels do not fall below the point of optimal yields.

Consequences of omitting fertilizer. The impact of eliminating phosphorus or potassium fertilizer on yield and soil-test level will depend on the initial soil test and the number of years that applications are omitted. In a recent Iowa study, elimination of phosphorus application for 9 years decreased soil-test levels from 136 to 52 pounds per acre, but yields were not adversely affected in any year as compared to plots where soil-test levels were maintained (Figure 11.17). In the same study, elimination of phosphorus for the 9 years when the initial soil test was 29 resulted in a decrease in soil-test level to 14 and a decrease in yield to 70 percent of the yield obtained when adequate fertility was supplied. Elimination of phosphorus at an intermediate soil-test level had little impact on yield but decreased the soil-test level from 67 to 26 pounds per acre over the 9 years. These as well as similar Illinois results indicate little if any potential for a yield decrease if phosphorus application was eliminated for 4 years on soils that have a phosphorus test of 60 pounds per acre or higher.

Phosphorus

Phosphorus soil-test procedures. The Bray P_1 test has been used to measure phosphorus availability in Illinois since it was developed in the 1940s. Research has

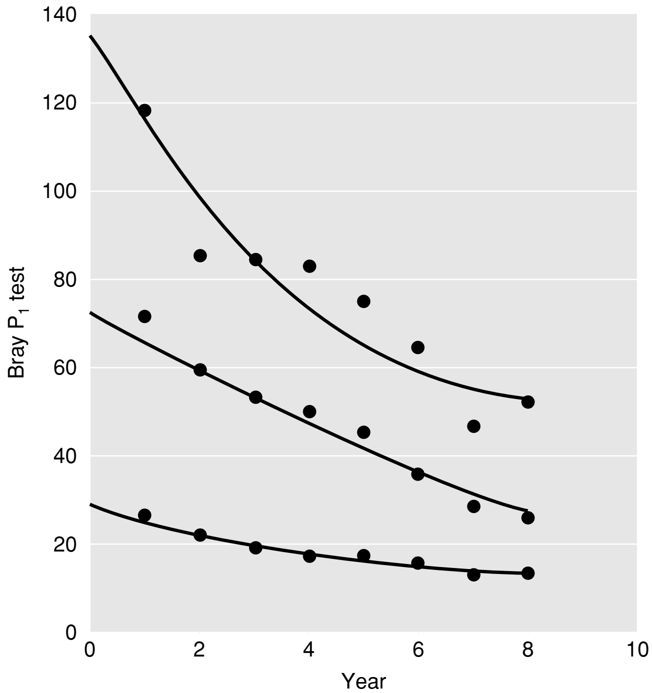


Figure 11.17. Effect of elimination of P fertilizer on P_1 soil test.

shown this test to be highly correlated to yield response on neutral to acid soils but not well correlated on calcareous (pH > 7.3) soils. While high-pH soil acreage is not extensive in Illinois, it does occur, often within a field that has neutral-to-acid pH levels.

The Mehlich-3 test was developed in North Carolina for routine analysis of phosphorus, potassium, calcium, magnesium, and several micronutrients. Research in Iowa has shown that the phosphorus results obtained from this test are nearly identical to those obtained with the Bray P_1 test on neutral-to-acid soils, but higher values result with this test on high-pH soils. The correlation between soil-test phosphorus results and yield response to applied phosphorus may be better on high-pH soils with the Mehlich-3 than the Bray P_1 procedure.

Based on the results generated in Iowa, it is suggested that the recommendations given in Tables 11.22 and 11.23 be used for results obtained on neutral-to-acid soils with either the Bray P_1 or Mehlich-3 procedure and on high-pH soils for soil test results obtained from the Mehlich-3 procedure. Results obtained with the Bray P_1 procedure are not very reliable on high-pH soils.

A third procedure, referred to as the Olsen or sodium bicarbonate test, was developed for high-pH soils in the western states. While it works well on those soils, it is not very effective on acid soils. The results obtained with this test on high-pH soils are lower than those obtained with the Mehlich-3. Therefore, one must not use the information provided in Table 11.22 when determining fertilizer rates based on Olsen test results.

Buildup. Research has shown that, as an average for Illinois soils, 9 pounds of P_2O_5 per acre are required to increase the P_1 soil test by 1 pound. The recommended rate of buildup phosphorus is thus nine times the difference between the soil-test goal and the actual soil-test value. The amount of phosphorus recommended for buildup over 4 years for various soil-test levels is presented in Table 11.22.

Because the 9-pound rate is an average for Illinois soils, some soils will fail to reach the desired goal in 4 years with P_2O_5 applied at this rate, and others will exceed the goal. It is recommended that each field be retested every 4 years.

In addition to the supplying power of the soil, the crop to be grown influences the optimal soil-test value. For example, the phosphorus soil-test level required for optimal yields of wheat and oats (Figure 11.15) is considerably higher than that required for corn and soybean yields, partly because wheat and corn have different phosphorus uptake patterns. Wheat requires a large amount of readily available phosphorus in the fall, when the root system is feeding primarily from the upper soil surface. Phosphorus is taken up by corn until the grain is fully developed, so subsoil phosphorus is more important in interpreting the phosphorus test for corn than for wheat. *To compensate for the higher phosphorus requirements of wheat and oats, it is suggested that 1.5 times the amount of expected phosphorus removal be applied prior to seeding these crops. This correction has already been included in the maintenance values listed for wheat and oats in Table 11.23.*

Maintenance. In addition to adding fertilizer to build up the soil test, add sufficient fertilizer each year to maintain a specified soil-test level. The amount of fertilizer required to maintain the soil-test value is the amount removed by the harvested portion of the crop (Table 11.23). The only exception to this guideline is that the maintenance value for wheat and oats is 1.5 times the amount of phosphorus (P_2O_5) removed by the grain. This correction has already been accounted for in the maintenance values given in Table 11.23.

Potassium

As indicated, phosphorus usually remains in the soil unless it is removed by a growing crop or by erosion; thus, soil levels can be built up as described. Experience during recent years indicates that on most soils potassium tends to follow the buildup pattern of phosphorus, but on other soils, soil-test levels do not

Table 11.22. Amount of Phosphorus (P_2O_5) Required to Build Up the Soil

P_1 test (lb/A)	Lb/A of P_2O_5 to apply each year for soils with supplying power rated: Low	Medium	High
4	103	92	81
6	99	88	76
8	94	83	72
10	90	79	68
12	86	74	63
14	81	70	58
16	76	65	54
18	72	61	50
20	68	56	45
22	63	52	40
24	58	47	36
26	54	43	32
28	50	38	27
30	45	34	22
32	40	29	18
34	36	25	14
36	32	20	9
38	27	16	4
40	22	11	0
42	18	7	0
44	14	2	0
45	11	0	0
46	9	0	0
48	4	0	0
50	0	0	0

NOTE: Amounts are based on buildup over 4 years. Nine pounds of P_2O_5 per acre are required to change the P_1 soil test 1 pound.

build up as expected. Because of this, options for both buildup plus maintenance and annual application are provided.

Producers whose soils have one or more of the following conditions should consider annual application:

1. Soils for which past records indicate that soil-test potassium does not increase when buildup applications are applied.
2. Sandy soils that do not have a capacity large enough to hold adequate amounts of potassium.
3. Agricultural lands having an unknown or a very short tenure arrangement.

On all other fields, buildup plus maintenance is suggested.

Examples of how to figure phosphorus and potassium fertilizer recommendations follow.

Example 1. Continuous corn with a yield goal of 140 bushels per acre:

(a) *Soil-test results* / *Soil region*

Soil-test results	*Soil region*
P_1 30	High
K 250	High

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
Buildup	22 (Table 11.22)	50 (Table 11.24)
Maintenance	60 (Table 11.23)	39 (Table 11.23)
Total	82	89

Example 2. Corn–soybean rotation with a yield goal of 140 bushels per acre for corn and 40 bushels per acre for soybeans:

(a) *Soil-test resultsSoil region*

P_1 20	Low
K 200	Low

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
	Corn	
Buildup	68	60
Maintenance	60	39
Total	128	99
	Soybeans	
Buildup	68	60
Maintenance	34	52
Total	102	112

Note that buildup recommendations are independent of the crop to be grown, but maintenance recommendations are directly related to the crop to be grown and the yield goal for the particular crop.

Example 3. Continuous corn with a yield goal of 150 bushels per acre:

(a)

Soil-test results	*Soil region*
P_1 90	Low
K 420	Low

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
Buildup	0	0
Maintenance	0	0
Total	0	0

Note that soil-test values are higher than those suggested; thus, no fertilizer is recommended. Retest the soil after 4 years to determine fertility needs.

Example 4. Corn–soybean rotation with a yield goal of 120 bushels per acre for corn and 35 bushels per acre for soybeans:

(a)

Soil-test results	*Soil region*
P_1 20	Low
K 180	Low (soil test does not increase as expected)

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
	Corn	
Buildup	68	. . .
Maintenance	52	. . .
Total	120	51 (34 x 1.5)
	Soybeans	
Buildup	68	. . .
Maintenance	30	. . .
Total	98	69 (46 x 1.5)

Rate of Fertilizer Application

Buildup. The only significant loss of soil-applied potassium is through crop removal or soil erosion. It is thus recommended that soil-test potassium be built up to values of 260 and 300 pounds of exchangeable potassium for soils in the low and high cation-exchange capacity region, respectively. These values are slightly higher than that required for maximum yield, but as in the recommendations for phosphorus, this will ensure that potassium availability will not limit crop yields (Figure 11.16).

Research has shown that 4 pounds of K_2O is required on average to increase the soil test by 1 pound. Therefore, the recommended rate of potassium application for increasing the soil-test value to the desired goal is four times the difference between the soil-test goal and the actual value of the soil test.

Tests on soil samples that are taken before May 1 or after September 30 should be adjusted downward as follows: subtract 30 for the dark-colored soils in central and northern Illinois; subtract 45 for the light-colored soils in central and northern Illinois and for fine-textured bottomland soils; subtract 60 for the medium- and light-colored soils in southern Illinois. Annual rates of buildup of potassium application recommended for a 4-year period for various soil-test values are presented in Table 11.24.

Wheat is not very responsive to potassium unless the soil-test value is less than 100. Because wheat is usually grown in rotation with corn and soybeans, it is suggested that the soils be maintained at the optimal available potassium level for corn and soybeans.

Maintenance. As with phosphorus, the amount of fertilizer required to maintain the soil-test value equals the amount removed by the harvested portion of the crop (Table 11.23).

Annual application. If soil-test levels are below the desired buildup goal, apply potassium fertilizer annually at an amount 1.5 times the potassium content in the harvested portion of the expected yield. If levels are only slightly below desired buildup levels, so that buildup and maintenance are less than 1.5 times removal, add the lesser amount. Continue to monitor the soil-test potassium level every 4 years.

If soil-test levels are within a range from the desired goal to 100 pounds above the desired potassium goal, apply enough potassium fertilizer to replace what the harvested yield will remove.

Buildup plus maintenance and annual application each has advantages and disadvantages. In the short run, the annual option will likely be less costly. In the long run, the buildup approach may be more economical. In years of high income, tax benefits may be obtained by applying high rates of fertilizer. Also, in periods of low fertilizer prices, the soil can be built to higher levels that in essence bank the materials in the soil for use at a later date when fertilizer prices are higher. Producers using the buildup system are insured against yield loss that may occur in years when weather conditions prevent fertilizer application or in years

Table 11.23. Maintenance Fertilizer Required for Various Crop Yields

Yield per acre	P_2O_5 (lb/A)	K_2O[a] (lb/A)
Corn grain (bu)		
90	39	25
100	43	28
110	47	31
120	52	34
130	56	36
140	60	39
150	64	42
160	69	45
170	73	48
180	77	50
190	82	53
200	86	56
Oats (bu)		
50	19[b]	10
60	23	12
70	27	14
80	30	16
90	34	18
100	38	20
110	42	22
120	46	24
130	49	26
140	53	28
150	57	30
Soybeans (bu)		
30	26	39
40	34	52
50	42	65
60	51	78
70	60	91
80	68	104
90	76	117
100	85	130
Grain sorghum (bu)		
80	34	17
100	42	21
120	50	25
140	59	29

Yield per acre	P_2O_5 (lb/A)	K_2O[a] (lb/A)
Corn silage (bu; tons)		
90; 18	48	126
100; 20	53	140
110; 22	58	154
120; 24	64	168
130; 26	69	182
140; 28	74	196
150; 30	80	210
Wheat (bu)		
30	27[b]	9
40	36	12
50	45	15
60	54	18
70	63	21
80	72	24
90	81	27
100	90	30
110	99	33
Alfalfa, grass, or alfalfa-grass mixtures (tons)		
2	24	100
3	36	150
4	48	200
5	60	250
6	72	300
7	84	350
8	96	400
9	108	450
10	120	500

[a] If annual application is chosen, potassium application will be 1.5 times the values shown.
[b] Values given are 1.5 times actual P_2O_5 removal for wheat and oats.

when fertilizer supplies are not adequate. The primary advantage of the buildup concept is the slightly lower risk of potential yield reduction that may result from lower annual fertilizer rates. This is especially true in years of exceptionally favorable growing conditions. The primary disadvantage of the buildup option is the high cost of fertilizer in the initial buildup years.

For farmers planning to double-crop soybeans after wheat, it is suggested that phosphorus and potassium fertilizer required for both the wheat and soybeans be applied before seeding the wheat. This practice reduces the number of field operations at planting time and hastens the planting operation.

The maintenance recommendations for phosphorus and potassium in a double-crop wheat and soybean system are presented in Tables 11.25 and 11.26, respectively. Assuming a wheat yield of 50 bushels per acre followed by a soybean yield of 30 bushels per acre, the maintenance recommendation would be 71 pounds of P_2O_5 and 54 pounds of K_2O per acre.

Table 11.24. Amount of Potassium (K_2O) Required to Build Up the Soil

	Lb/A of K_2O to apply each year for soils with cation-exchange capacity rated	
K test* (lb/A)	Low (< 12 meq/100 g soil)	High (≥ 12 meq/100 g soil)
50	210	250
60	200	240
70	190	230
80	180	220
90	170	210
100	160	200
110	150	190
120	140	180
130	130	170
140	120	160
150	110	150
160	100	140
170	90	130
180	80	120
190	70	110
200	60	100
210	50	90
220	40	80
230	30	70
240	20	60
250	10	50
260	0	40
270	0	30
280	0	20
290	0	10
300	0	0

NOTE: Amounts are based on buildup over 4 years. Four pounds of K_2O per acre are required to change the potassium test 1 pound.

*Tests on soil samples taken before May 1 or after September 30 should be adjusted downward:

Subtract 30 pounds for dark-colored soils in central and northern Illinois.

Subtract 45 pounds for light-colored soils in central and northern Illinois and for fine-textured bottomland soils.

Subtract 60 pounds for medium- and light-colored soils in southern Illinois.

Table 11.25. Maintenance Phosphorus Required for Wheat–Soybean Double-Crop System

Wheat yield (bu/A)	Lb/A of P_2O_5 required for desired soybean yield (bu/A)				
	20	30	40	50	60
30	44	53	61	69	78
40	53	62	70	78	87
50	62	71	79	87	96
60	71	80	88	96	105
70	80	89	97	105	114
80	89	98	106	114	123

Table 11.26. Maintenance Potassium Required for Wheat–Soybean Double-Crop System

Wheat yield (bu/A)	Lb/A of K_2O required for desired soybean yield (bu/A)				
	20	30	40	50	60
30	35	48	61	74	87
40	38	51	64	77	90
50	41	54	67	80	93
60	44	57	70	83	96
70	47	60	73	86	99
80	50	63	76	89	102

Computerized Recommendations

Soil fertility recommendations have been incorporated into a microcomputer program that utilizes the soil-test information, soil type and characteristics, cropping and management history, cropping plans, and yield goals to develop recommendations for lime, nitrogen, phosphorus, and potassium. This program, called *Soil Plan*, groups similar fertilizer recommendations and provides a map showing where each recommendation should be implemented within the field. The user can alter the map to show the desired spread pattern. The program also indicates the potential impact of altering the recommendation on crop yield. This program is available at http://web.aces.uiuc.edu/iah.

Further information about this program may be obtained from the Department of Crop Sciences, N-305 Turner Hall, 1102 S. Goodwin Avenue, Urbana, IL 61801.

Time of Application

Although the fertilizer rates for buildup and maintenance in Tables 11.22 to 11.24 are for an annual application, producers may apply enough nutrients in any 1 year to meet the needs of the crops to be grown in the succeeding 2 to 3 years.

Phosphorus and potassium fertilizers may be applied in the fall to fields that will not be fall-tilled, provided that the slope is less than 5 percent. Do not fall-apply fertilizer to fields that are subject to rapid runoff. When the probability of runoff loss is low, soybean stubble need not be tilled solely for the purpose of incorporating fertilizer. *This statement holds true when ammoniated phosphate materials are used as well because the potential for volatilization of nitrogen from ammoniated phosphate materials is insignificant.*

For perennial forage crops, broadcast and incorporate all of the buildup and as much of the maintenance phosphorus as economically feasible before seeding. On soils with low fertility, apply 30 pounds of phosphate (P_2O_5) per acre using a band seeder. Using a band seeder, it is safe to apply a maximum of 30 to 40 pounds of potash (K_2O) per acre in the band with the phosphorus. Up to 600 pounds of K_2O per acre can be safely broadcast in the seedbed without damaging seedlings.

Applications of phosphorus and potassium topdressed on perennial forage crops may be made at any convenient time. Usually this will be after the first harvest or in September.

High Water Solubility of Phosphorus

The water solubility of the P_2O_5 listed as available on the fertilizer label is of little importance under typical field crop and soil conditions on soils with medium to high levels of available phosphorus when recommended rates of application and broadcast placement are used. Due to rapid interaction of phosphorus fertilizer with iron and aluminum, phosphorus is tightly bound in the soil such that water solubility does not imply great movement or leaching.

Table 11.27. Water Solubility of Some Common Processed-Phosphate Materials

Material	Percent P_2O_5	Percent water-soluble
Ordinary superphosphate 0-20-0	16–22	78
Triple superphosphate	44–47	84
Mono-ammonium phosphate 11-48-0	46–48	100
Diammonium phosphate 18-46-0	46	100
Ammonium polyphosphate 10-34-0, 11-37-0	34–37	100

For some situations, water solubility is important:

1. For band placement of a small amount of fertilizer to stimulate early growth, at least 40 percent of the phosphorus should be water-soluble for application to acidic soils and, preferably, 80 percent for calcareous soils. As shown in Table 11.27, the phosphorus in nearly all fertilizers commonly sold in Illinois is highly water-soluble. Phosphate water solubility above 80 percent has not been shown to increase yield any further than water solubility of at least 50 percent.
2. For calcareous soils, a high degree of solubility in water is desirable, especially on soils that are shown by soil test to be low in available phosphorus.

Phosphorus and the Environment

Phosphorus has been identified as an important pollutant to surface waters. At very low concentrations, it can increase eutrophication of lakes and streams, which leads to problems with their use for fisheries, recreation, industry, and drinking water. Although eutrophication is the natural aging process of lakes and streams, human activities can accelerate this process by increasing the concentration of nutrients flowing into water systems. Since phosphorus is the element most often limiting eutrophication in natural water bodies, controlling its input into lakes and streams is very important. The United States Environmental Protection Agency is in the process of developing a strategy to adopt nutrient criteria as part of state water quality standards.

There are concerns that agricultural runoff and erosion from soils may be major contributors to eutrophication. While this loss may not be of economic significance to farmers, it may create economic impacts on water quality. Even though phosphorus loss from agricultural fields may not be of economic significance, it is in the best interest of all in agriculture to minimize the amount of phosphorus loss. While additional research will likely lead to new and better ways to minimize phosphorus loss, the following practices are already known to help:

1. Do not maintain excessively high phosphorus soil-test levels. Research has demonstrated that the higher the soil-test level, the greater the loss of dissolved phosphorus (Figure 11.18). This relationship does vary somewhat depending on soil type. Environmental decisions regarding phosphorus applications should not be made solely on phosphorus soil-test levels. Rather, the decision should also include such factors as distance from a significant lake or stream, infiltration rate, slope, and residue cover. Additional work is being done to develop a system that more accurately predicts the vulnerability

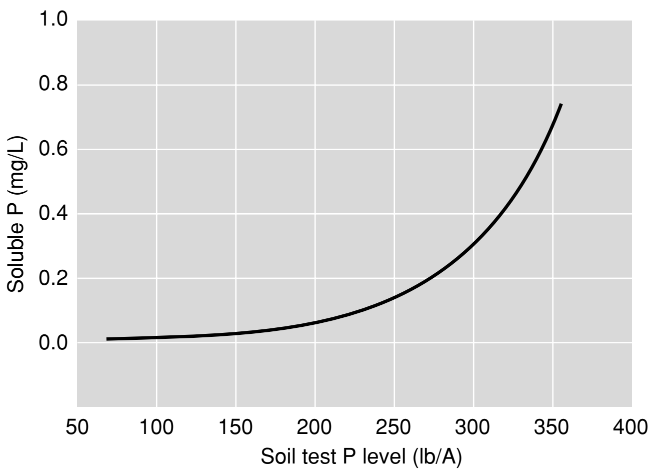


Figure 11.18. Relationship between soil-test value and dissolved phosphorus.

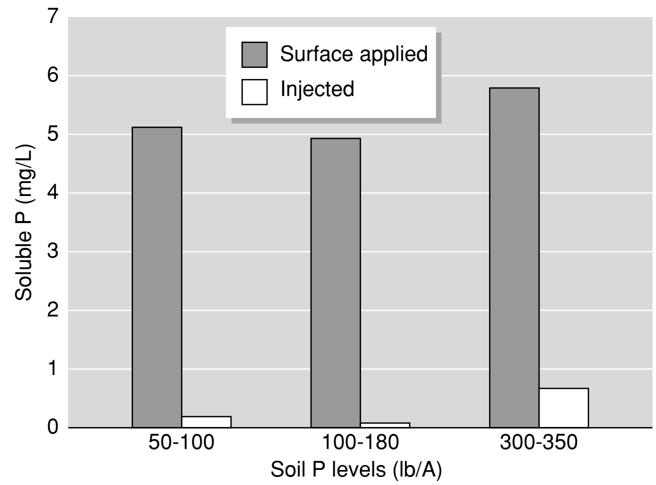


Figure 11.19. Injection of the manure markedly reduces soluble phosphorus runoff at all soil-test levels.

to phosphorus loss on a field-by-field basis. At this time, the research database is inadequate to establish a soil-test level that can be used for environmental purposes. Soil-test procedures were designed to predict where phosphorus was needed; they were not designed to predict environmental problems. One possible problem with using soil-test values to predict environmental problems is in sample depth. Normally samples are collected to a 7-inch depth for prediction of nutritional needs. For environmental purposes, it would often be better to collect the samples from a 1- or 2-inch depth, which is the depth that will influence phosphorus runoff. Another potential problem is within field soil-test level variability in relation to the dominant runoff and sediment-producing zones.

2. Maintain buffer strips at the point where water leaves the field.
3. Minimize erosion. Although this may not reduce the potential for loss of dissolved phosphorus, it will reduce the potential for loss of total phosphorus.
4. Inject manure. This practice not only reduces the potential for phosphorus runoff (Figure 11.19), it also reduces the potential for nitrogen volatilization and reduces odor.
5. Match nutrient applications to crop needs. This will minimize the potential for excessive buildup of phosphorus soil tests and reallocate phosphorus sources to fields or areas where they can produce agronomic benefits.
6. Where possible, grow high-yielding, high-phosphorus-removing crops on fields that have excessively high soil-test phosphorus levels. Even when this is done, it may take several years to reduce very high soil-test levels to medium to high tests.

Secondary Nutrients

The elements classified as secondary nutrients include calcium, magnesium, and sulfur. Crop yield response to application of these three nutrients has been observed on a very limited basis in Illinois. The database necessary to correlate and calibrate soil-test procedures is thus limited, and the reliability of the suggested soil-test levels for the secondary nutrients presented in Table 11.28 is low.

Deficiency of calcium has not been seen in Illinois where soil pH is 5.5 or higher. Calcium deficiency associated with acidic soils should be corrected by using limestone that is adequate to correct the soil pH.

Magnesium deficiency has been recognized in isolated situations in Illinois. Although the deficiency is usually associated with acidic soils, in some instances low magnesium has been reported on sandy soils that were not excessively acidic. The soils most likely to be deficient in magnesium include sandy soils throughout Illinois and low exchange-capacity soils of southern Illinois. Deficiency will be more likely where calcitic rather than dolomitic limestone has been used.

Table 11.28. Suggested Soil-Test Levels for Secondary Nutrients

	Levels adequate for crop production (lb/A)			
Soil type	Calcium	Magnesium	Rating	Sulfur (lb/A)
Sandy	400	60–75	Very low	0–12
Silt loam	800	150–200	Low	12–22
			Response unlikely	22

Sulfur deficiency has been reported with increasing frequency throughout the Midwest. Deficiencies probably are occurring because of (1) increased use of sulfur-free fertilizer; (2) decreased use of sulfur as a fungicide and insecticide; (3) increased crop yields, resulting in increased requirements for all of the essential plant nutrients; and (4) decreased atmospheric sulfur supply. Early season sulfur symptoms may disappear as rainfall contributes some sulfur and as root systems develop to exploit greater soil volume.

Organic matter is the primary source of sulfur in soils, so soils low in organic matter are more likely to be deficient than soils high in organic matter. Because sulfur is very mobile and can be readily leached, deficiency is more likely on sandy soils than on finer-textured soils.

A yield response to sulfur application was observed at 5 of 85 locations in Illinois (Table 11.29). Two of these responding sites, one an eroded silt loam and one a sandy soil, were found in northwestern Illinois (Whiteside and Lee counties); one site, a silty clay loam, was in central Illinois (Sangamon County); and two sites, one a silt loam and one a sandy loam, were in southern Illinois (Richland and White counties).

At the responding sites, sulfur treatments resulted in corn yields that averaged 11.2 bushels per acre more than yields from the untreated plots. At the non-responding sites, yields from the sulfur-treated plots averaged only 0.6 bushel per acre more than those from the untreated plots (Table 11.29). If only the responding sites are considered, the sulfur soil test predicts with good reliability which sites will respond to sulfur applications. Of the five responding sites, one had only 12 pounds of sulfur per acre, less than the amount considered necessary for normal plant growth, and three had marginal sulfur concentration (from 12 to 20 pounds of sulfur per acre). Sulfur tests on the 80 nonresponding sites showed 14 to be deficient and 29 to have a sulfur level considered marginal for normal plant growth. Sulfur applications, however, produced no significant positive responses in these plots. The correlation between yield increases and measured sulfur levels in the soil was very low, indicating that the sulfur soil test did not reliably predict sulfur need.

Table 11.29. Average Yields at Responding and Nonresponding Zinc and Sulfur Test Sites, 1977–1979

	Sites	Yield from untreated plots (bu/A)	Yield from zinc-treated plots (bu/A)	Yield from sulfur-treated plots (bu/A)
Responding sites				
Low-sulfur soil	5	140.0	. . .	151.2
Low-zinc soil	3	150.6	164.7	. . .
Nonresponding sites	80	147.6	146.2	148.2

Experiments were conducted over 2 years on a Cisne silt loam and a Grantsburg silt loam in southern Illinois to evaluate the effect of sulfur application on wheat production. Even though increasing rates of sulfur application increased the sulfur concentration of the flag leaf and the whole plant, it did not increase grain yield at either location in either year. Based on these studies, routine application of sulfur fertilizer for wheat production does not appear warranted.

In addition to evaluating soil-test values, consider organic-matter level, potential atmospheric sulfur contributions, subsoil sulfur content, and moisture conditions just before soil sampling in determining whether a sulfur response is likely. If organic matter exceeds 2.5 percent or if the field in question is downwind from industrial operations where significant sulfur is emitted, use sulfur only on a trial basis even when the soil-test reading is low. Because sulfur is a mobile nutrient supplied principally by organic-matter oxidation, abnormal precipitation (either high or low) could adversely affect the sulfur status of samples taken from the soil surface. If precipitation has been high just before sampling, some samples may have a low reading due to leaching. If precipitation were low and temperatures warm, some soils might have a high reading when, in fact, the soil is not capable of supplying adequate sulfur throughout the growing season.

Micronutrients

The elements classified as essential micronutrients include zinc, iron, manganese, copper, boron, molybdenum, and chlorine. These elements are classified as micronutrients because they are required in small (micro) amounts. Confirmed deficiencies of any of these micronutrients in Illinois have been limited to boron deficiency of alfalfa, zinc deficiency of corn, and iron and manganese deficiencies of soybeans.

Similar to the tests for secondary nutrients, micronutrient tests have very low reliability and usefulness because of the limited database available to correlate and calibrate the tests. Suggested levels for each test are provided in Table 11.30. In most cases, micronutrient plant analysis will probably provide a better estimate of micronutrient needs than the soil test.

Manganese deficiency (stunted plants with green veins in yellow or whitish leaves) is common on high-pH (alkaline) sandy soils, especially during cool, wet weather in late May and June. Suggested treatment is to spray either manganese sulfate or an organic manganese formulation onto the leaves soon after the symptoms first appear. Broadcast application on the soil is ineffective because the manganese becomes unavailable in soils with a high pH.

Foliar application of MnEDTA at rates as low as 0.15 pound Mn per acre in mid-June to beans planted in early May provided a significant yield increase (Table 11.31). Delaying application until early July provided a slightly higher yield than did the mid-June application. In some cases, multiple applications may be necessary to optimize yield.

Wayne and Hark soybean varieties or lines developed from them often show iron deficiency on soils with a very high pH (usually 7.4 to 8.0). The symptoms are similar to those shown with manganese deficiency. Most of the observed deficiencies have been on Harpster, a "shelly" soil that occurs in low spots in some fields in central and northern Illinois.

Table 11.30. Suggested Soil-Test Levels for Micronutrients

Micronutrient and procedure	Soil-test level (lb/A)		
	Very low	Low	Adequate
Boron			
(hot-water soluble)	0.5	1	2
Iron (DTPA)	. . .	< 4	> 4
Manganese (DTPA)	. . .	< 2	> 2
Manganese (H_3PO_4)	. . .	< 10	> 10
Zinc (.1N HCl)	. . .	< 7	> 7
Zinc (DTPA)	. . .	< 1	> 1

Table 11.31. Effect of Time of Application of Manganese on Soybean Yield

Treatment			Yield (bu/A)
Manganese (lb/A/application)	Application		
	Times	Dates	
0	—	—	56
0.15	1	6–19	63
0.15	1	7–2	66
0.15	1	7–17	66
0.15	2	6–19, 7–2	69
0.15	3	6–19, 7–2, 7–19	71

Soybeans often outgrow the stunted, yellow appearance of iron shortage. As a result, it has been difficult to measure yield losses or decide whether or how to treat affected areas. Sampling by U.S. Department of Agriculture scientists indicated yield reductions of 30 to 50 percent in the center of severely affected spots. The yield loss may have been caused by other soil factors associated with a very high pH and poor drainage rather than by the iron deficiency itself.

Research in Minnesota has shown that time of iron application is critical to attaining a response. Researchers recommend that 0.15 pound of iron as iron chelate be applied per acre to leaves within 3 to 7 days after chlorosis symptoms develop (usually in the second-trifoliate stage of growth). Waiting for soybeans to grow to the fourth- or fifth-trifoliate stage before applying iron resulted in no yield increase. Because iron applied to the soil surface between rows does not help, applications directed over the soybean plants were preferred.

A significant yield response to zinc applications was observed at 3 of 85 sites evaluated in Illinois (Table 11.29). The use of zinc at the responding sites produced a corn yield that averaged 14.1 bushels per acre more than the check plots. Two sites were Fayette silt loams in Whiteside County, and one was a Green river sand in Lee County.

At two of the three responding sites, tests showed that the soil was low or marginal in available zinc. The soil of the third had a very high zinc level but was deficient in available zinc, probably because of the excessively high phosphorus level also found.

The zinc soil-test procedures accurately predicted results for two-thirds of the responding sites. The same tests, however, incorrectly predicted that 19 other sites would also respond. These results suggest that the soil test for available zinc can indicate where zinc deficiencies are found but does not indicate reliably whether the addition of zinc will increase yields.

To identify areas before micronutrient deficiencies become important, continually observe the most sensitive crops in soil situations in which the elements are likely to be deficient (Table 11.32).

In general, deficiencies of most micronutrients are accentuated by one of five situations: (1) strongly weathered soils; (2) coarse-textured soils; (3) high-pH soils; (4) organic soils; and (5) soils that are inherently low in organic matter or are low in organic matter because erosion or land-shaping processes have removed the topsoil.

The use of micronutrient fertilizers should be limited to areas of known deficiency, and only the deficient nutrient should be applied. An exception to this guideline would be situations in which farmers

Table 11.32. Soil Situations and Crops Susceptible to Micronutrient Deficiency

Micronutrient	Sensitive crop	Susceptible soil situations	Conditions favoring deficiency
Zinc (Zn)	Young corn	1. Low in organic matter, either inherently or because of erosion or land shaping 2. High pH (> 7.3) 3. Very high phosphorus 4. Restricted root zone 5. Coarse-textured (sandy) soils 6. Organic soils	Cool, wet
Iron (Fe)	Soybeans, grain sorghum	High pH	Cool, wet
Manganese (Mn)	Soybeans, oats	1. High pH 2. Restricted root zone 3. Organic soils	Cool, wet
Boron (B)	Alfalfa	1. Low organic matter 2. High pH 3. Strongly weathered soils in south-central Illinois 4. Coarse-textured (sandy) soils	Drought
Copper (Cu)	Corn, wheat	1. Infertile sand 2. Organic soils	Unknown
Molybdenum (Mo)	Soybeans	Acidic, strongly weathered soils in south-central Illinois	Unknown
Chlorine (Cl)	Unknown	Coarse-textured soils	Excessive leaching by low-Cl water

already in the highest yield bracket try micronutrients experimentally in fields that are yielding less than would be expected under good management, which includes an adequate nitrogen, phosphorus, and potassium fertility program and a favorable pH.

Method of Fertilizer Application

With the advent of new equipment, producers have a number of options for placement of fertilizer. These options range from traditional broadcast application to injection of the materials at varying depths in the soil. Selecting the proper application technique for a particular field depends at least in part upon the inherent fertility level, the crop to be grown, the land tenure, and the tillage system.

On fields where the fertility level is at or above the desired goal, there is little research evidence to show any significant difference in yield that is associated with method of application. In contrast, on low-testing soils and in soils that "fix" phosphorus, placement of the fertilizer within a concentrated band has been shown to result in higher yields, particularly at low rates of application. On higher-testing soils, plant recovery of applied fertilizer in the year of application is usually greater from a band than a broadcast application, though yield differences are unlikely.

Broadcast fertilization. On highly fertile soils, both maintenance and buildup phosphorus and potassium are efficiently utilized when broadcast and then plowed or disked in. This system, particularly when the tillage system includes a moldboard plow every few years, distributes nutrients uniformly throughout the entire plow depth. As a result, roots growing within that zone have access to high levels of fertility. Because the nutrients are intimately mixed with a large volume of soil, opportunity exists for increased nutrient fixation on soils having a high fixation ability. Fortunately, most Illinois soils do not have high fixation rates for phosphorus or potassium.

Row fertilization. On soils of low fertility, placement of fertilizer in a concentrated band below and to the side of the seed has been shown to be an efficient method of application, especially in situations for which the rate of application is markedly less than that needed to build the soil to the desired level. Producers who are not assured of having long-term tenure on the land may wish to consider this option. The major disadvantages of this technique are (1) the additional time and labor required at planting time; (2) limited contact between roots and fertilizer; and (3) inadequate rate of application to increase soil levels for future crops.

For information on the use of starter fertilizer for no-till, see the description of fertilizer management related to tillage systems.

Strip application. With this technique, phosphorus, potassium, or both are applied in narrow bands on approximately 30-inch centers on the soil surface, in the same direction as the primary tillage. The theory behind this technique is that, after moldboard plowing, the fertilizer will be distributed in a narrow vertical band throughout the plow zone. This system reduces the amount of soil-to-fertilizer contact as compared with a broadcast application, and thus it reduces the potential for nutrient fixation. Because the fertilizer is distributed through a larger soil volume than with a band application, the opportunity for root-fertilizer contact is greater.

Deep fertilizer placement. Several terms have been used to define this technique, including root-zone banding, dual placement, knife injection, and deep placement. With this system, a mixture of nitrogen-phosphorus or nitrogen-phosphorus-potassium is injected at a depth from 4 to 8 inches. The knife spacings may vary by crop to be grown, but generally they are 15 to 18 inches apart for close-grown crops such as wheat and 30 inches for row crops. This technique provided a significantly higher wheat yield as compared with a broadcast application of the same rate of nutrients in some, but not all, experiments conducted in Kansas. Wisconsin research showed the effect of this technique to be equivalent to a band application for corn on a soil testing high in phosphorus but inferior to a band application for corn on a soil testing low in phosphorus. If this system is used on low-testing soils, it is advisable to apply a portion of the phosphorus fertilizer in a band with the planter.

Dribble fertilizer. This technique applies urea–ammonium nitrate solutions in concentrated bands on 30-inch spacings on the soil surface. Results from several states have shown that this system reduces the potential for nitrogen loss of these materials, as compared with an unincorporated broadcast application. However, it has not been shown to be superior to an injected or an incorporated application of urea–ammonium nitrate solution.

"Pop-up" fertilization. The term "pop-up" is a misnomer. The corn does not emerge sooner with this kind of application, and it may come up 1 or 2 days later. The corn may, however, grow more rapidly during the first 1 to 2 weeks after emergence. Pop-up fertilizer will make corn look very good early in the season and may aid in early cultivation for weed control. But no substantial difference in yield is likely in most years due to a pop-up application as compared to fertilizer that is placed in a band to the side and below the seed. Seldom will there be a difference of more than a few days in the time the root system intercepts fertilizer placed with the seed as compared to that placed below and to the side of the seed.

Under normal moisture conditions, the maximum safe amount of N plus K_2O for pop-up placement is about 10 or 12 pounds per acre in 40-inch rows and correspondingly more in 30- and 20-inch rows. In excessively dry springs, even these low rates may result in damage to seedlings, reduction in germination, or both. Pop-up fertilizer is unsafe for soybeans. In research conducted at Dixon Springs, a stand was reduced to one-half by applying 50 pounds of 7-28-14 and reduced to one-fifth with 100 pounds of 7-28-14.

Site-specific application. Equipment has recently been developed that uses computer technology to alter the rate of fertilizer application as the truck passes across the field. This approach offers the potential to improve yield while minimizing the possibility of overfertilization. Yield improvement results from applying the correct rate (not a rate based on average soil test) to the low-testing portions of the field. Overfertilization is reduced by applying the correct rate (in many cases zero) to high-testing areas of the field. The combination of improved yield and reduced output results in improved profit.

Foliar fertilization. Researchers have known for many years that plant leaves absorb and utilize nutrients sprayed on them. Foliar fertilization has been used successfully for certain crops and nutrients. This method of application has had the greatest use with nutrients required in only small amounts by plants. Nutrients required in large amounts, such as nitrogen, phosphorus, and potassium, have usually been applied to the soil rather than the foliage.

The possible benefit of foliar-applied nitrogen fertilizer was researched at the University of Illinois in the 1950s. Foliar-applied nitrogen increased corn and wheat yield, provided that the soil was deficient in nitrogen. Where adequate nitrogen was applied to the soil, additional yield increases were not obtained from foliar fertilization.

Research in Illinois on foliar application of nitrogen to soybeans attempted to supply additional nitrogen to soybeans without decreasing nitrogen that was symbiotically fixed. It was thought that if nitrogen application were delayed until after nodules were well established, perhaps symbiotic fixation would remain active. Neither single nor multiple applications of nitrogen solution to foliage increased soybean yields. Damage to vegetation occurred in some cases because of leaf "burn" caused by the nitrogen fertilizer.

Although considerable research in foliar fertilization had been conducted in Illinois already, new studies were done in 1976 and 1977. This research was prompted by a report from a neighboring state that soybean yields had recently been increased by as much as 20 bushels per acre in some trials. Research in that state differed from earlier work on soybeans in that, in addition to nitrogen, the foliar fertilizer increased yield only if phosphorus, potassium, and sulfur were also included. Researchers there thought that soybean leaves become deficient in nutrients as nutrients are translocated from vegetative parts to the grain during grain development. They reasoned that foliar fertilization, which would prevent leaf deficiencies, should result in increased photosynthesis that would be expressed in higher grain yields.

Foliar fertilization research was conducted at several locations in Illinois during 1976 and 1977, ranging from Dixon Springs in the south to DeKalb in the north. None of the experiments gave economical yield increases. In some cases there were yield reductions, attributed to leaf damage caused by the fertilizer. Table 11.33 contains data from a study at Urbana in which soybeans were sprayed four times with various fertilizer solutions. Yields were not increased by foliar fertilization.

Table 11.33. Yields of Corsoy and Amsoy Soybeans After Fertilizer Treatments Were Sprayed on the Foliage Four Times at Urbana

Treatment per spraying (lb/A)				Yield (bu/A)	
N	P_2O_5	K_2O	S	Corsoy	Amsoy
0	0	0	0	61	56
20	0	0	0	54	53
0	5	8	1	58	56
10	5	8	1	56	58
20	5	8	1	55	52
30	7.5	12	1.5	52	46

Nontraditional Products

In this day of better-informed farmers, it seems hard to believe that letters, calls, and promotional leaflets about nontraditional products are increasing. The claim made is usually that "Product X" either replaces fertilizers and costs less, makes nutrients in the soil more available, supplies micronutrients, or is a natural product without strong acids that kill soil bacteria and earthworms.

The strongest position that agronomists can take is to challenge these peddlers to produce unbiased research results in support of their claims. Testimonials by farmers are no substitute for research.

Extension specialists at the University of Illinois are ready to give unbiased advice when asked about purchasing new products or accepting a sales agency for them.

In addition, each Extension office has the publication *Compendium of Research Reports on the Use of Nontraditional Materials for Crop Production*, which contains data on a number of nontraditional products that have been tested in the Midwest. Check with the nearest Extension office for this information.