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Managing Soil pH and Crop Nutrients

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The inherent complexity of crop production systems requires integrating many factors to ensure maximum crop yields with the least risk to the environment. Assessing present- and reserved-nutrient status of the soil, understanding its nutrient-release and nutrient-holding capacity, and knowing the plant and environmental factors that impact nutrient availability are necessary to guide fertilization rates, sources, and method of application of additional nutrients. The information here is intended to provide fundamental principles to help the reader understand what to do, and why, when making management decisions related to **phosphorus** (P), **potassium** (K), **secondary macronutrients** (calcium [Ca], magnesium [Mg], and sulfur [S]), **micronutrients** (boron [B], chlorine [Cl], copper [Cu], iron [Fe], manganese [Mn], molybdenum [Mo], and zinc [Zn]), and **pH**.

Factors Impacting Plant-Nutrient Availability

Nutrient availability can be impacted by soil chemical and physical properties, including parent material and naturally occurring minerals; amount of organic matter; depth to bedrock, sand, or gravel; and permeability, water holding capacity, and drainage. In addition, environmental conditions and crop characteristics have an important impact on nutrient availability. It is not unusual for crops in fields or portions of fields to show nutrient deficiencies during periods of the growing season, even where an adequate nutrient management plan is followed. The fact that nutrients are applied does not necessarily mean they are available. Plants obtain most of their nutrients and water from the soil through their root system. Any factor that restricts root growth and activity has the potential to restrict nutrient availability. This is not because nutrients are not plant-available in the soil, but because the ability of the crop to take up those nutrients is restricted. Understanding how these factors can cause nutrient deficiency in crops is important to avoiding excessive concern about the need for additional fertilization when a sound nutrient program is already in place.

Soil compaction can limit or completely restrict root penetration and effectively reduce the volume of soil, including nutrients and water, which can be accessed by the plant. To limit soil compaction, avoid entering fields that are too wet, and minimize the weight per axle by decreasing load weight and/or increasing tire surface area in contact with the soil. Planting when soils are wet can create a compacted wall next to the seed that will prevent the seedling from developing an adequate root system. Tilling wet soils will result in clods that become hard and dry out quickly on the surface, preventing roots from accessing resources inside the clod.

Soil water content is critical not only to supply the water needs of the crop but also to dissolve nutrients and make them available to the plant. Excess water in the soil, however, depletes oxygen (O_2) and builds up carbon dioxide (CO_2) levels. While O_2 is needed by roots to grow and take up nutrients, high CO_2 levels are toxic.

Temperature is important in regulating the speed of soil chemical processes that make nutrients available. Under cool soil temperatures, chemical reactions and root activ-

ity decrease, rendering nutrients less available to the crop. Portions of the plant nutrients are taken up as roots extract soil water to replenish water lost through the leaves. Cool air temperatures can lower evapotranspiration and reduce the convective flow of water and nutrients from the soil to the root.

Light intensity is low on cloudy days. Low light intensity reduces photosynthetic rates and nutrient uptake by the crop. Since low light intensity sometimes occurs when soils are waterlogged or temperatures are cool, cloud cover can exacerbate the capacity of the crop to take nutrients.

Diseases and pests can have an important impact on crop-nutrient uptake by competing for nutrients, affecting physiological capacity (such as reduction in photosynthesis rates), and diminishing root parameters through root pruning or tissue death.

Estimating Nutrient Availability

Soil Analysis

Soil tests are not perfect, so a soil test value should be considered not a single value, but rather a value within a range. There are multiple reasons why soil tests are not perfect: a soil test represents a measurement at one point in time, while a crop takes nutrients through an extended period, and typically under very different soil-water and temperature conditions than at the time of sampling; the information generated typically comes from a sample from the plow layer, but the crop roots extract nutrients below that layer; laboratory precision is typically within 5% to 10% of the true value. Despite these imperfections, soil testing is the most important guide to profitable application of phosphorus, potassium, and lime because it provides a framework for determining the fertility status of a field. In contrast, plant tissue analysis is typically more reliable than soil testing for secondary macronutrients and micronutrients. Since crop yield response to application of these nutrients has been very limited in Illinois, there is not a large enough database to correlate and calibrate soil-test procedures. Ratings in **Table 8.1** can provide a perspective on the reliability, usefulness, and cost effectiveness of soil tests as a basis for planning a soil fertility and liming program for Illinois field crops.

Traditionally, soil testing has been used to decide how much lime and fertilizer to apply to a field. With increased emphasis on precision agriculture, economics, and the environment, soil tests are also a logical tool to determine areas where adequate or excessive fertilization has taken place. In addition, they are used to monitor the impact of past fertility practices on changes in a field's nutrient status. Of course a

Table 8.1. Ratings of soil tests.

Test	Rating[a]
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

[a]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.

soil test report can only be as accurate as the sample sent for analysis. In fact, the spatial variability of available nutrients in a field makes soil sampling the most common and greatest source of error in a soil test. To collect samples that provide a true measurement of the fertility of an area, one must determine the sampling distribution; collect samples to the proper depth; collect samples from precisely the same areas of the field that were sampled in the past; and collect samples at the proper time.

Field soil. A soil probe is the best implement for taking soil samples. An auger or a spade can also be used as long as care is taken to collect an exact depth with a constant slice thickness (**Figure 8.1**).

A soil sample, or sampling point in the field, should be a composite of at least five soil cores taken with a probe from within a 10-foot radius around the sampling point. Composite samples should be placed in bags with labels identifying the places where the samples were collected.

Sampling distribution. The number of soil samples taken from a field is a compromise between what should be done (information) and what can be done (cost). The most common mistake is taking too few samples to represent a field adequately. Shortcuts in sampling may produce unreliable results and lead to higher fertilizer costs, lower returns, or both. Determine a soil sampling strategy by first evaluating cost, equipment to be used, past fertilization practices used, and the potential response to fertilizer application. Possible strategies include sampling for the following:

● *Whole-field uniform fertilizer applications.* For this approach, sampling at the rate of one composite from each 2-1/2-acre area is suggested (see **Figure 8.2**, diagram a, for sampling directions).
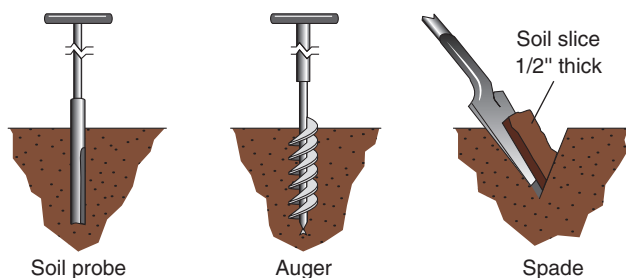
Figure 8.1. How to take soil samples with a soil probe, an auger, and a spade.

- *Site-specific applications for fields where large variations in test values over a short distance are suspected.* Under these conditions, collecting one sample from each 1.1-acre area (**Figure 8.2**, diagram b) will provide a better representation of the actual field variability. The greater 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.

- *Zones with common characteristics.* This is a directed sampling approach that is also known as "smart" or zone sampling. This method integrates information including such details as yield maps, crop canopy data, soil type or other characteristics, past management history, and the like. It defines sampling zones with common characteristics that may influence crop productivity and nutrient and water supplies. The size of such zones varies depending on field characteristics, but it seldom exceeds 10 acres.

- *Conservation tillage fields with fertilizer band applications.* There is not presently enough research data to define an accurate method for sampling these fields, so the following methods are given as suggestions. When the location of the band is known, collect the regular 7-inch depth sample 6 inches off the side of the band. Another approach would be to multiply a factor (0.67) by the distance (in inches) between bands to determine how many cores need to be collected from outside the band for each sample collected in the band. For example, in a 30-inch band distance, collect 20 cores from outside the band for each sample collected in the band. If the location of the band is not known, the best approach is to increase the number of samples (20 to 30) and to vary sampling position in relation to the row so the band does not bias test results.

Sampling depth. The proper sampling depth for pH, phosphorus, and potassium is 7 inches. This is because the fertilizer recommendation system in Illinois is based on crop response to fertility levels in the top 7 inches of the soil. For fields where conservation tillage has been used,
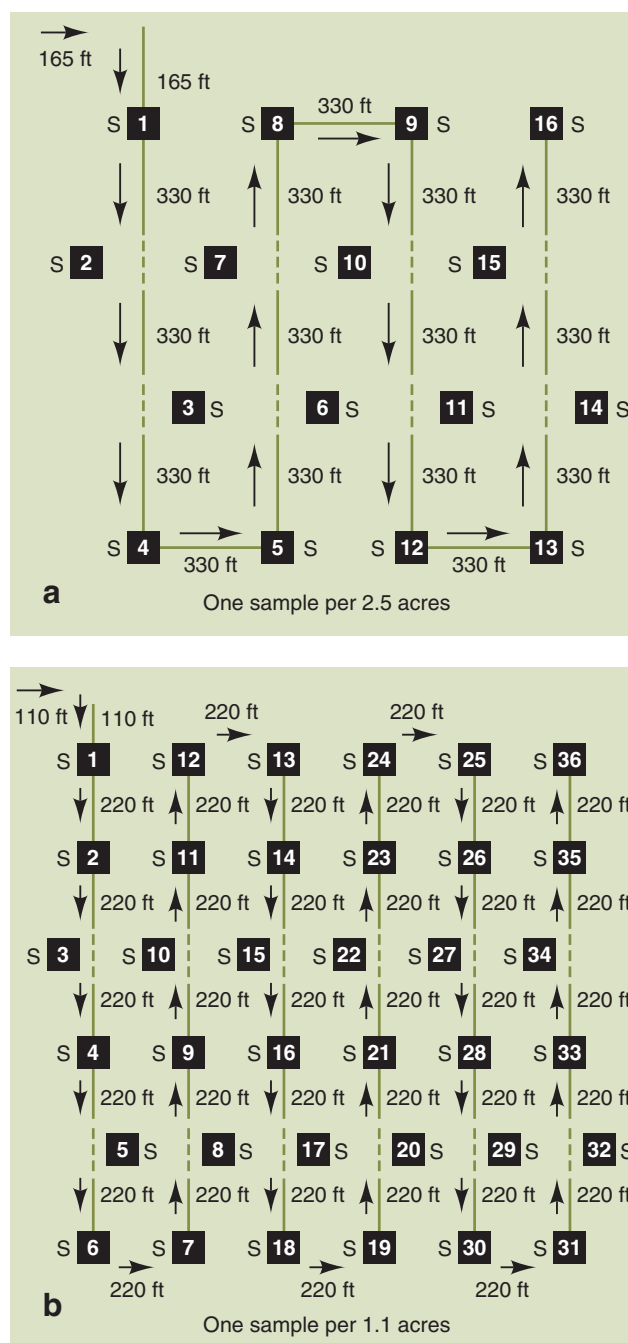

Figure 8.2. How to collect soil samples from a 40-acre field. Each sample (diagram a) should consist of five soil cores, 1 inch in diameter, collected to a 7-inch depth from within a 10-foot radius around each point. Higher frequency sampling (diagram b) is suggested for those who can use computerized spreading techniques on fields suspected of having large variations in test values over short distances.

accurate sampling depth is especially important, as such tillage results in less thorough mixing of lime and fertilizers than a tillage system that includes a moldboard plow. This stratification has not adversely affected crop yield, but misleading soil test results may be obtained if samples are not taken to the proper depth. Shallow samples will

overestimate actual soil status, leading to underapplication of lime or fertilizers, while samples that are too deep or where some part of the top portion falls off during sampling will underestimate current soil status, causing overapplication of lime or fertilizers.

If surface soil pH is too high or too low, the efficacy of some herbicides and other chemical reactions may be affected. Thus, in addition to the regular 7-inch depth sampling, if either limestone (which raises pH) or nitrogen (which lowers pH) is applied to the soil surface and not incorporated with tillage, 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.

Precise sample locations. Variations in values are often observed across soil tests in the same field. Given the inherent variability of soils over even short distances (related to soil forming factors) and management effects for which there is no record (such as non-uniform distribution of fertilizer), it is important to collect samples from precisely the same points each time a field is tested. Sample locations can be identified using a global positioning system (GPS) unit or by accurately measuring the sample points with a device such as a measuring wheel.

When to sample. Sampling every 4 years is strongly suggested when soils are at an optimum level of fertility. When maintenance levels are not being applied in cropping systems that remove large quantities of nutrients, such as hay or corn silage, soil testing should be done every other year. To improve the consistency of results, collect samples at the same time of year and, if possible, under similar soil-water conditions. Sampling done within a few months of lime or fertilizer treatment will be more variable than after a year.

Late summer and fall are the best seasons for collecting soil samples, because K test results are most reliable then. Results of the K test tend to be cyclic, with low levels in late summer and early fall and high levels in late January and early February. Phosphorus and pH levels are typically not seasonally affected in most soils in Illinois. In coarse-textured (sandy) soils with low buffer capacity, pH levels can increase as much as one unit under wet conditions.

Sending soils for analysis. Find information about commercial testing services available in your area at www.soiltesting.org, or contact an Extension office or a fertilizer dealer.

The best fertilizer recommendations are based on both soil test results and 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 to provide adequate information with each sample.

The information needed includes cropping intentions for the next 4 years; the 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.

The following tests should be performed:

● *pH*: The water pH test.

● *Phosphorus*: The Bray P_1 test for plant-available soil P. This test has been used to measure P availability in Illinois since it was developed in the 1940s. It was not developed to test alkaline soils, so it should be restricted to soils with pH less than 7.3. The Mehlich-3 test was developed in North Carolina for routine analysis of P, K, Ca, Mg, and several micronutrients. Research in Iowa has shown that the P results obtained with this test are nearly identical to those obtained with the Bray P_1 test on neutral-to-acid soils as long as the analysis is done by the colorimetric procedure. In soils or portions of a field where pH is above 7.3, the Bray P_1 test results in high test values. Under those soil conditions, yield response to P may be better correlated with the Mehlich-3 procedure. Samples extracted by the Mehlich-3 procedure and analyzed by inductively coupled plasma emission spectroscopy (ICP) result in higher values than those analyzed by the colorimetric procedure. The values obtained from ICP analysis cannot be adjusted to colorimetric values by a numerical conversion. A third procedure, referred to as the Olsen or sodium bicarbonate test, was developed for high-pH soils in western states and should not be used for acid soils. The results obtained with this test on high-pH soils are lower than those obtained with the Mehlich-3 procedure.

● *Potassium:* The ammonium acetate test has been the recommended test. Research in Iowa has shown that results from the Mehlich-3 extractable K test are similar to the ammonium acetate test.

● *Secondary nutrients and micronutrients:* Tests are available for most secondary nutrients and micronutrients, but interpretation is less reliable than with tests for lime, P, and K. 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. First is troubleshooting, or diagnosing symptoms of abnormal growth; paired samples representing areas of good and poor growth are needed for analyses. Second

is "hidden-hunger checkup," or 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.

Interpreting soil test results and formulating soil treatment programs. A soil pH test reports soil reaction as pH units; phosphorus and K tests are typically reported in pounds of element per acre. Formulate a soil treatment program by preparing field soil test maps to observe areas of similar test levels that will benefit from similar applications. Areas with differences in soil test pH of 0.2 unit, P test of 10 pounds of P per acre, and K test of 30 pounds of K per acre are reasonable to designate for separate treatment. See page 96 for suggested pH goals, page 100 for P information, and page 103 for K information.

Spatial variability in soil test results. When soil test values vary across a field, there are two patterns and two possible ways to address the issue:

- *A definite pattern* of distinct high- and low-test values in different parts of the field. This likely indicates different soil types or different past management practices. Split the fertilizer or lime application to treat each area differently to meet the specific needs.

- *No consistent pattern* of high- and low-test values. Select the median test (the one that falls in the middle of a ranking 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), Ca, Mg, K, ammonium (NH_4), Fe, Mn, Zn, and Cu exist as cations. The same is true for non-plant nutrients such as sodium (Na), barium (Ba), and metals of environmental concern, including mercury (Hg), cadmium (Cd), chromium (Cr), and others. Cation exchange capacity (CEC) is a measure of the amount of attraction for the soil with these chemical elements.

In soil, a high CEC is desirable, but not necessary, for high crop yields, as it is not a direct determining factor for yield. CEC facilitates retention of positively charged chemical elements from leaching, yet it gives nutrients to a growing plant root by an exchange of H. Cation exchange capacity in soil arises from negatively charged electrostatic charges in minerals and organic matter. The CEC of organic residues is low but increases as the residues convert to humus, which requires from 5 years to centuries. Thus, farming practices that reduce soil erosion and maintain soil humus favor the maintenance of

CEC. It is influenced very little by fertilization, slightly decreased with soil acidification, and slightly increased with liming.

Depending on the amount of clay and humus, soil types have the following characteristic amounts of cation exchange (in units of milliequivalent per 100 grams of soil):

- Sandy soils: less than 4
- Light-colored silt-loam soils: 8 to 12
- Dark-colored silt-loam soils: 15 to 22
- Clay soils: 18 to 30

Plant Analysis

Plant analyses can be useful in diagnosing nutrient problems, identifying hidden hunger, and determining whether current fertility programs are adequate. Critical tissue-nutrient level (below which deficiency occurs) is the concentration needed for a crop to complete its life cycle. These concentrations are largely independent of soil or growing conditions, so the values typically apply across environments and provide a more reliable measurement for micronutrients and secondary nutrients than do soil tests.

How to sample. When diagnosing a fertility problem through plant analysis, select paired samples of comparable plant parts representing the abnormal and normal plants. Abnormal plants selected should represent the first stages of a problem. Samples taken at stages other than those described in **Table 8.2** might not correlate with the suggested critical nutrient levels.

After collecting the samples, deliver them immediately to the laboratory. Samples should be air-dried if they cannot be delivered immediately or if they are going to be shipped. Soil factors (fertility status, temperature, and moisture) and plant factors (cultivar and development stage) may complicate the interpretation of plant analysis data. The more information provided concerning a particular field, the more reliable the interpretation will be.

Soil pH

Effect of Soil Acidity on Plant Growth

Soil pH is a measure of the acidity or alkalinity of soil. Since pH is measured using a logarithmic scale, a decrease of 1 unit of pH means that the acidity increases by a factor of 10, so small changes in pH values can have important consequences. For most of Illinois, soil acidification is a concern, as acidity is created by removal of bases by harvested crops, leaching, and an acid residual left in the soil from N fertilizers. If surface soil pH is too high or too low, the efficacy of some herbicides and other chemical reactions may be affected. Also, soil acidity affects plant

Table 8.2. Suggested critical plant nutrient levels for various crops and stages of sampling.

Crop	Plant part	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)
Alfalfa	Upper 6 in. at early bloom	—	0.25	2.00	1.00	0.25	0.22	15	25	20	7	25
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
Soybean	Fully developed leaf and petiole at early podding	—	0.25	2.00	0.40	0.25	0.15	15	30	20	5	25
Wheat	Entire aboveground portion at tillering	4.7	0.22	3.20	0.36	0.12	0.15	15	25	25	5	10

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

growth in several ways. Whenever soil pH is low (and acidity is high), several situations may exist:

- The concentration of soluble metals, especially aluminum and Mn, may be toxic.

- Populations and the activity of the organisms responsible to transform N, S, and P to plant-available forms may be reduced.

- Calcium may be deficient. Usually this occurs only when the CEC of the soil is extremely low.

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

- Acidic soils—particularly those low in organic matter—are poorly aggregated and have poor tilth.

- The availability of mineral elements to plants may be affected. **Figure 8.3** shows the relationship between soil pH and nutrient availability (the wider the dark bar, the greater the nutrient availability). For example, the availability of P is greatest in the pH range between 5.5 and 7.5, dropping off below 5.5. In other words, for a given soil, if P is applied at pH 6, there will be more of it available than if the same amount is applied when the soil pH is below 5.5. Because the availability of Mo is increased greatly as soil acidity is decreased, Mo deficiencies usually can be corrected by liming.

Suggested pH goals. A soil test every 4 years is the best way to check pH levels. For cash grain systems and pasture grasses (not 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. In contrast, a profitable yield response from raising the pH above 6.5 in cash grain systems is unlikely.

For cropping systems with alfalfa, clover, or lespedeza, 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 probably will not be necessary to apply limestone.

Raising soil pH (liming). In addition to soil test value and cropping system, liming rates are determined based on soil type, depth of tillage, and limestone quality. Suggested limestone rates for different soil types in **Table 8.3** are based on typical limestone quality and a tillage depth of 9 inches. For details on adjusting rates to specific conditions, see table footnotes.

Limestone quality is defined by its effective neutralizing value (ENV), a measurement of the neutralizing value and the fineness of grind. The neutralizing value of limestone is determined by its calcium carbonate ($CaCO_3$) equiva-
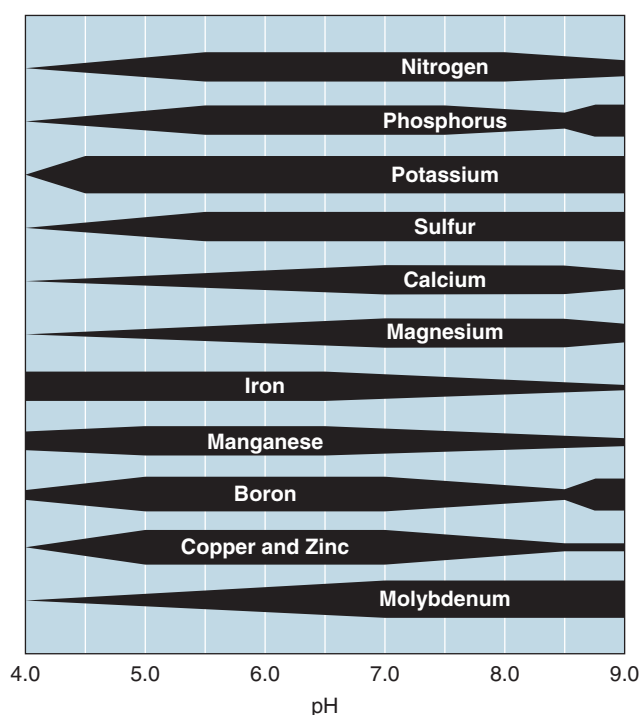

Figure 8.3. Available nutrients in relation to pH.

Table 8.3. Suggested limestone rates based on soil type, pH, cropping system, and 9-inch depth of tillage.

Soil type[a]	Soil pH value																					
	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	7.0
Tons of typical limestone[b] to apply to grain farming systems																						
A	8.0	8.0	8.0	8.0	8.0	8.0	7.8	7.0	6.3	5.5	4.8	4.0	3.3	2.5	1.8	1.0	Optional					
B	8.0	8.0	7.5	7.0	6.5	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	Optional					
C	6.6	6.3	5.9	5.5	5.1	4.8	4.4	4.0	3.6	3.3	2.9	2.5	2.1	1.8	1.4	1.0	Optional					
D	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	Optional					
E	4.0	3.6	3.2	2.8	2.4	2.0																
Tons of typical limestone[b] to apply to forage farming systems (alfalfa, clover, lespedeza)																						
A	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.3	9.6	8.9	8.1	7.4	6.7	6.0	5.3	4.6	3.9	3.1	2.4	1.7	1.0	Optional
B	11.0	11.0	11.0	10.4	9.9	9.3	8.8	8.2	7.7	7.1	6.6	6.0	5.4	4.9	4.3	3.8	3.2	2.7	2.1	1.6	1.0	Optional
C	10.0	9.6	9.1	8.7	8.2	7.8	7.3	6.9	6.4	6.0	5.5	5.1	4.6	4.2	3.7	3.3	2.8	2.4	1.9	1.5	1.0	Optional
D	6.0	5.8	5.5	5.3	5.0	4.8	4.5	4.3	4.0	3.8	3.5	3.3	3.0	2.8	2.5	2.3	2.0	1.8	1.5	1.3	1.0	Optional
E	6.0	5.4	4.9	4.3	3.8	3.2	2.7	2.1	1.6	1.0												

Note: If plowing is less than 9 in., reduce the amount; if it is more than 9 in., increase it. A chisel plow, disk, or field cultivator rather than a mold-board plow may not mix limestone deeper than 4 to 5 in.; for no-till or pasture systems, use the equivalent of a 3-in. tillage depth (one-third of the amount suggested).

[a]Soil A: Dark-colored silty clays and silty clay loams (CEC > 24). Soil B: Light- and medium-colored silty clays and silty clay loams; dark-colored silt and clay loams (CEC 15–24). Soil C: Light- and medium-colored silt and clay loams; dark- and medium-colored loams; dark-colored sandy loams (CEC 8–15). Soil D: Light-colored loams; light- and medium-colored sandy loams; sands (CEC < 8). Soil E: Muck and peat. Soil color is usually related to organic matter. Light-colored soils <2.5% organic matter; medium-colored soils 2.5–4.5% organic matter; dark-colored soils >4.5% organic matter.

[b]Typical limestone: 10% of the particles are greater than 8-mesh; 30% pass an 8-mesh and are held on 30-mesh; 30% pass a 30-mesh and are held on 60-mesh; and 30% pass a 60-mesh. A calcium carbonate equivalent (total neutralizing power) of 90%. Effective neutralizing value (ENV) of this material is 46.35 for 1 year after application, and 67.5 for 4 years after application. To correct the rate of application based on the ENV of the material available, follow calculations in the worksheet on page 98.

lent: the higher this value, the greater the limestone's ability to neutralize soil acidity. The fineness of grind determines the rate of reaction: finer limestone will neutralize soil acidity faster. Relative efficiency factors have been determined for various particle sizes (**Table 8.4**). 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 ENV can be calculated for any liming material by using the efficiency factors in **Table 8.4** and the $CaCO_3$ equivalent for the limestone in question. 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, Bureau of Agricultural Products Inspection, P.O. Box 19281, Springfield, IL 62794-9281, in the annual publication *Illinois Voluntary Limestone Program Producer Information.* To calculate the ENV and the correction factor needed to determine rate of application for materials not reported in that publication, obtain the analysis of the material in question from the

Table 8.4. Efficiency factors for various limestone particle sizes.

Particle sizes	Efficiency factor	
	1 yr after application	4 yr 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

supplier and use the worksheet for lime-rate calculation on page 98 (or online at iah.ipm.illinois.edu/limestone_rate).

Examples of Rate Calculation

As an example, consider a limestone that has a $CaCO_3$ equivalent of 86.88% and a sample with 13.1% of the particles greater than 8-mesh, 40.4% that pass 8-mesh and are held on 30-mesh, 14.9% that pass 30-mesh and are held on 60-mesh, and 31.6% that pass 60-mesh. Assume that 3 tons of typical limestone are needed per acre (according to **Table 8.3**). The amounts of limestone with these characteristics that would be needed to meet the 3-ton recommendation would be 3.36 and 3.51 tons on a 1- and

Worksheet for Lime-Rate Calculation Based on ENV of Material

AFTER 1 YEAR

Formulas	Completed Examples

1

% of particles greater than 8-mesh $= \dfrac{}{100}$ x 5 =.. ☐

$\dfrac{13.1\%}{100}$ x 5 =.............................. 0.65

% of particles that pass 8-mesh and are held on 30-mesh $= \dfrac{}{100}$ x 20 =........... + ☐

$\dfrac{40.4\%}{100}$ x 20 =......................... + 8.08

% of particles that pass 30-mesh and are held on 60-mesh $= \dfrac{}{100}$ x 50 = ... + ☐

$\dfrac{14.9\%}{100}$ x 50 =......................... + 7.45

% of particles that pass 60-mesh $= \dfrac{}{100}$ x 100 =............................... + ☐

$\dfrac{31.6\%}{100}$ x 100 =....................... + 31.60

Total fineness efficiency................ ☐

Total fineness efficiency......... 47.78

2

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

ENV = 47.78 x $\dfrac{86.88}{100}$ = 41.51

3

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

$\dfrac{46.35}{41.51}$ = 1.12

4

Correction factor x limestone requirement (from Table 8.3) = _____ tons of sampled limestone needed per acre

1.12 x 3 = 3.4 tons per acre

AFTER 4 YEARS

Formulas	Completed Examples

1

% of particles greater than 8-mesh $= \dfrac{}{100}$ x 15 =.. ☐

$\dfrac{13.1\%}{100}$ x 15 =.............................. 1.96

% of particles that pass 8-mesh and are held on 30-mesh $= \dfrac{}{100}$ x 45 =........... + ☐

$\dfrac{40.4\%}{100}$ x 45 =......................... + 18.18

% of particles that pass 30-mesh and are held on 60-mesh $= \dfrac{}{100}$ x 100 = ... + ☐

$\dfrac{14.9\%}{100}$ x 100 =....................... + 14.90

% of particles that pass 60-mesh $= \dfrac{}{100}$ x 100 =................................... + ☐

$\dfrac{31.6\%}{100}$ x 100 =....................... + 31.60

Total fineness efficiency............... ☐

Total fineness efficiency......... 66.64

2

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

ENV = 66.64 x $\dfrac{86.88}{100}$ = 57.9

3

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

$\dfrac{67.5}{57.9}$ = 1.17

4

Correction factor x limestone requirement (from Table 8.3) = _____ tons of sampled limestone needed per acre

1.17 x 3 = 3.5 tons per acre

4-year basis, respectively (see the sample calculation in the worksheet).

How to apply limestone. Since limestone does not react with acidic soil very far from the particle, adjust application rates proportionally to the depth of tillage as explained in the footnote of **Table 8.3**. For pastures and no-till systems, when lime is broadcast on the soil surface, apply one-third of the needed rate to avoid creating extremely high pH at the soil surface. Consequently, liming may be required more often (but at lower rates) in these systems than in cultivated fields.

Similarly to a broadcast application of nutrients, make sure limestone is spread evenly throughout the soil surface by avoiding overlaps. If a mistake was made and very high rates were applied, scraping the material out of the field or increasing the amount of mixing by tillage would be a practical way to reduce negative effects. Limestone can be applied at any time, but fall applications are preferred to avoid soil compaction and concerns about spring planting delays. Fall application also allows more time for limestone to neutralize soil acidity.

If high initial cost is not a deterrent, rates up to 6 tons per acre 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.

In no-till fields where lime is not incorporated in the soil, surface applications eventually neutralize acidity below the surface. However, this process is slow, so it is recommended to always maintain surface pH levels at adequate ranges. If pH levels in the surface are allowed to drop, lime applications will take a long time to start to neutralize acidity below the soil surface.

For hay and pastures, apply limestone several months ahead of seeding to allow time for the acidity to be neutralized. If rate requirements exceed 5 tons per acre, apply half the rate before the primary or intensive tillage and half before the secondary tillage (harrowing or disking).

For rates of less than 5 tons, make a single application, preferably after primary tillage.

Fluid lime suspensions (liquid lime). Liquid lime products are created by suspending very finely ground limestone in water. Several industrial byproducts with liming properties also are being land-applied as suspensions, either because they are too fine to be spread dry or because they are already in suspension. These byproducts 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% water.

The chemistry of liquid liming materials is the same as that of dry materials. The rate of reaction and the neutralizing power for liquid lime are the same as for dry materials when particle sizes are the same. Application of liquid lime during the first few months after application 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. The rate of application calculated by using the equation below is adequate to maintain soil pH for at least 4 years at the same level as typical lime.

As an example, assume a lime need of 3 tons per acre (based on **Table 8.3**) and liquid lime that is 50% dry-matter and has a $CaCO_3$ equivalent of 97% on a dry-matter basis. The rate of liquid lime needed would be calculated as shown in the sample below.

Lowering Soil pH (Acidifying)

While soils with high pH (>7.4) result in reduced availability of several nutrients, particularly P, Zn, Fe, and Mn, decreasing soil pH has not been shown to be economical for producing agronomic crops. Acidifying soils to produce crops such as blueberries and cranberries is essential if the pH is high. Acidification can be accomplished by applying elemental S, aluminum sulfate, or iron sulfate. The amount of elemental S needed to reduce soil pH depends on the initial pH and the desired pH (see **Table 8.5**).

Calculating the Application Rate for Liquid Lime

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

Sample calculation:

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

Table 8.5. Amount of elemental sulfur needed to reduce soil pH.

Soil pH	Soil group[a]			
	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
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

[a]Soil A: Dark-colored silty clays and silty clay loams (CEC > 24). Soil B: Light- and medium-colored silty clays and silty clay loams; dark-colored silt and clay loams (CEC 15–24). Soil C: Light- and medium-colored silt and clay loams; dark- and medium-colored loams; dark-colored sandy loams (CEC 8–15). Soil D: Light-colored loams; light- and medium-colored sandy loams; sands (CEC < 8).

Calcium–Magnesium Balance in Illinois Soils

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

On the other hand, concern is justified over a soil Mg 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 producing forage than grain. Very high K levels (more than 500 pounds per acre) combined with low soil Mg levels contribute to low-Mg grass forages. Research data to establish critical Mg levels are very limited, but levels of soil Mg less than 60 pounds per acre on sands and 150 pounds per acre on silt-loams are considered low.

Ca and Mg levels of agricultural limestone vary among quarries in the state. Dolomitic limestone (material with appreciable Mg content, as high as 21.7% MgO or 46.5% $MgCO_3$) 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 Ca), although it is not uncommon for it to contain 1% to 3% $MgCO_3$.

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

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

Phosphorus

Regional differences in P-supplying power shown in **Figure 8.4** were broadly defined primarily by parent material and degree of weathering factors. Within a region, variability in parent material, degree of weathering, native vegetation, and natural drainage cause differences in the soil's P-supplying power. For example, soils developed under forest cover appear to have more available subsoil P than those developed under grass.

High supplying power. 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 P content. The soils are leached of carbonates to a depth of more than 3-1/2 feet, and roots can spread easily in the moderately permeable profiles.

Medium supplying power. 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 P-supplying power occur. In comparison with the high-P region, more soils are poorly drained and have less available P 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 in the profile. The P-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 P in the subsoil and substratum. If
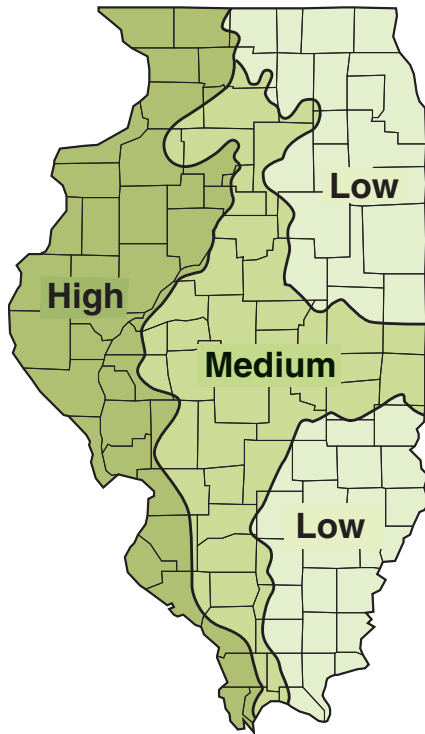
Illinois Agronomy Handbook

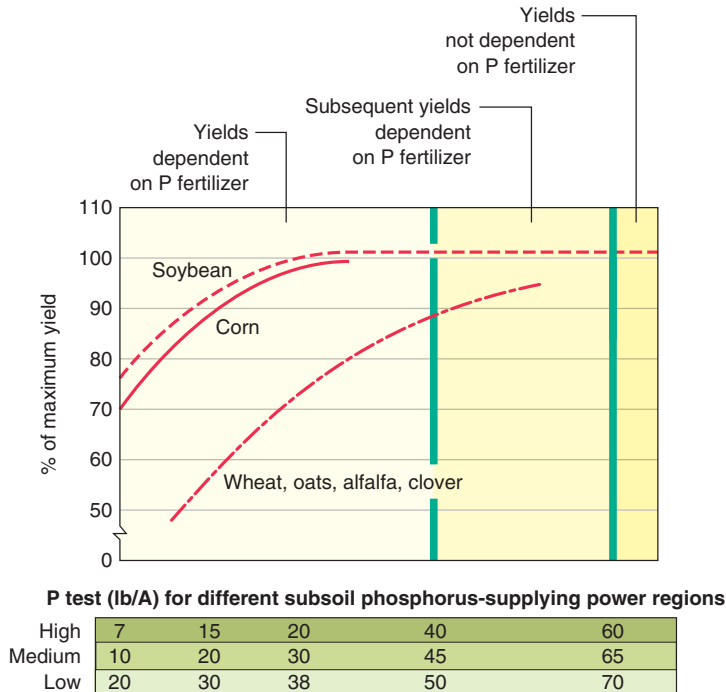**Figure 8.4.** Subsoil phosphorus-supplying power in Illinois.

Figure 8.5. Relationship between expected yield and soil P, measured colorimetrically by the Bray P_I or Mehlich-3 procedures on neutral-to-acid soils, or by the Mehlich-3 procedure on soils with pH > 7.3. These values should not be used for the Olsen (soil bicarbonate) test or for Mehlich-3 extractions analyzed by inductively coupled plasma emission spectroscopy (ICP).

internal drainage is fair or poor, P levels in the subsoil and substratum are likely to be low or medium.

Low supplying power. Soils in the "low" region in southeastern Illinois were formed from 2-1/2 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 P may be rather high by soil test in some soils of the region, but this is partially offset by conditions that restrict rooting.

Soils in the low region in northeastern Illinois were formed from thin loess (less than 3 feet) over glacial till. The glacial till, generally low in available P, ranges in texture from gravelly loam to clay in various soil associations of the region. In addition, shallow carbonates further reduce the P-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.

Phosphorus Recommendations

Minimum soil test levels required to produce optimal crop yields vary depending on the crop to be grown and the soil's P-supplying power (**Figure 8.5**). Near-maximal yields of corn and soybeans are obtained when levels of available P are maintained at 30, 40, and 45 pounds per acre for soils in the high, medium, and low P-supplying regions, respectively. Since these are minimal values, to ensure soil P availability will not restrict crop yield it is recommended that soil test results be built up to 40, 45, and 50 pounds per acre for soils in the high, medium, and low P-supplying regions, respectively. This is a practical approach because P is not easily lost from the soil, other than through crop removal or soil erosion.

Phosphorus soil test level required for optimal yields of wheat and oats is considerably higher than that required for corn and soybean yields (**Figure 8.5**), partly because of difference in uptake patterns. Wheat requires a large amount of readily available P 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 P is more important in interpreting the P test for corn than for wheat. To compensate for the higher P requirements of wheat and oats, it is suggested that 1.5 times the amount of expected P 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 8.6**.

No fertilization needed. There is no agronomic advantage in applying P when P_1 values are higher than 60, 65, and 70 for soils in the high, medium, and low P-supplying regions, respectively.

Maintenance fertilization needed. When soil test levels are between the minimum and 20 pounds above the minimum (40 to 60, 45 to 65, and 50 to 70 for the high, medium, and low P-supplying regions, respectively), apply enough to replace expected removal by the crop (and 1.5 times the removal for wheat and oats) using values from **Table 8.6**. At this test level, 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 P is not applied to maintain soil test levels.

Buildup plus maintenance fertilization needed. When soil test levels are below the desired values (40, 45, and 50 for the high, medium, and low P-supplying regions, respectively), it is suggested that enough fertilizer be added to build the test to the desired goal and to replace what the crop will remove (as described in the previous paragraph). At this test level, the yield of the crop will be affected by the amount of P applied that year.

For perennial forage crops, broadcast and incorporate all of the buildup and as much of the maintenance as economically feasible after primary tillage and before seeding. On soils with low fertility, reserve 30 pounds of P_2O_5 per acre for band seeding. Warm-season perennial grasses prefer fertile soils but grow well in moderate fertility conditions.

For establishment, fertilize with 24 to 30 pounds of P_2O_5. For these cropping systems, P rates beyond the year of establishment follow the regular maintenance or buildup plus maintenance program already described.

On average, Illinois soils require 9 pounds of P_2O_5 per acre to increase the P_1 soil test by 1 pound. The recommended rate of buildup for P is thus nine times the difference between the soil test goal and the actual soil test value. For a typical 4-year buildup program, divide the rate by 4 to determine the annual rate. 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.

Consequences of omitting fertilizer. The impact on yield and soil test level of eliminating P fertilizer will depend on the initial soil test and the number of years that applications are omitted. In a study in Iowa, eliminating P 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 8.6**). In the same study, eliminating P 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% of that obtained when adequate fertility was supplied. Eliminating P 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 P application was eliminated for 4 years on soils that have a P test of 60 pounds per acre or higher.
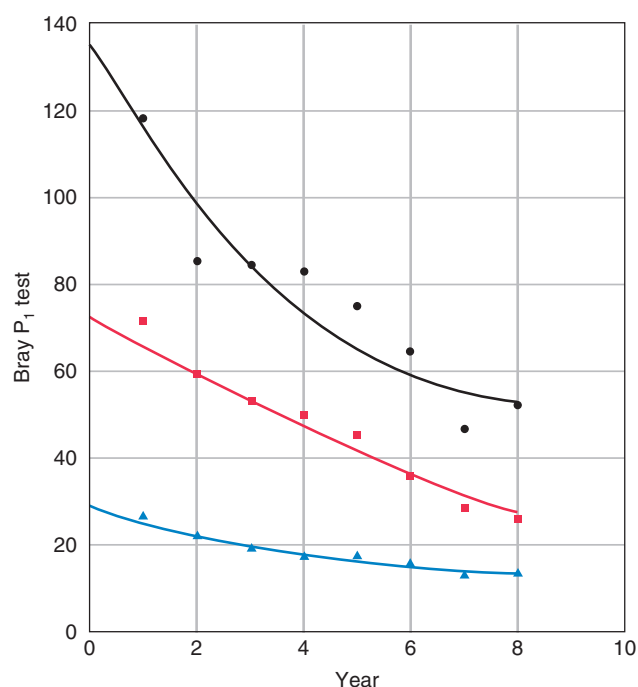
Table 8.6. Maintenance fertilizer required for various crops.

	P_2O_5	K_2O
Grains		
Corn	0.43 lb/bu	0.28 lb/bu
Oats	0.38 lb/bu[a]	0.20 lb/bu
Soybean	0.85 lb/bu	1.30 lb/bu
Grain sorghum	0.42 lb/bu	0.21 lb/bu
Wheat	0.90 lb/bu[a]	0.30 lb/bu
Biomass		
Alfalfa, grass, or alfalfa–grass mixes	12.0 lb/ton	50.0 lb/ton
Corn silage	2.7 (0.53)[b] lb/ton	7.0 (1.4)[b] lb/ton
Corn stover	7.0 lb/ton	30 lb/ton[c]
Wheat straw	4.0 lb/ton	30 lb/ton[c]

To obtain total nutrient removal by the crop (maintenance rate), multiply value by the expected yield.
[a]Values given are 1.5 times actual P_2O_5 removal for oats and wheat.
[b]Values in parentheses correspond to pounds per bushel.
[c]Value will vary depending on amount of precipitation received between the time of physiological maturity and the time the material was baled and by the potassium fertility level of the soil.

Figure 8.6. Effect of elimination of P fertilizer on P_1 soil test.

Potassium

Illinois is divided into two general regions for K, based on CEC (**Figure 8.7**). Soils with a CEC less than 12 milliequivalents per 100 grams are classified as having low capacity, while soils with values equal to or greater than 12 milliequivalents per 100 grams are considered to have high capacity. Important differences exist, however, among soils within these general regions because of differences in these factors:

● The amounts of clay and organic matter, which influence the exchange capacity of the soil.

● The degree of weathering of the soil material, which affects the amount of K that has been leached out.

● The kind of clay mineral.

● Drainage and aeration, which influence uptake of K.

● The parent material from which the soil was formed.

Low capacity includes sandy soils, because minerals from which they were developed are inherently low in K. Sandy soils also have very low cation exchange capacities and thus do not hold much reserve K.

Silt-loam soils in the "low" area in southern Illinois (claypans) are relatively older in terms of soil development; consequently, much more of the K 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 K uptake early in the growing period, even though roots are present.

Potassium Recommendations

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.

Minimum soil test levels required to produce optimal crop yields vary depending on the crop to be grown and the soil's CEC (**Figure 8.8**). As with P, the only significant loss of soil-applied K is through crop removal or soil erosion, so to ensure that K availability will not limit crop yields it is recommended that soil test levels be slightly higher than that required for maximum yield. For corn and soybean it is recommended to have 260 and 300 pounds of exchangeable K per acre for soils in the low and high CEC regions, respectively.

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

No fertilization needed. No K additions are suggested if test levels are above 360 and 400 for the low and high CEC regions, unless crops that remove large amounts of K (such as alfalfa or corn silage) are being grown. When soil test levels are between 400 and 600 pounds of K per acre and corn silage or alfalfa is being grown, the soil should be tested every 2 years instead of every 4, or maintenance levels of K should be added to ensure that soil test levels do not fall below the point of optimal yields. Having adequate K in these systems is important to producing high-quality forage (K is important for the conversion of N to protein) and maintaining a vigorous stand (winter survival of legumes and stand longevity in grass-legume stands).

Maintenance fertilization needed. When soil test levels are between the minimum and 100 pounds above the minimum (260 to 360 and 300 to 400 for the low and high capacity, respectively), apply enough to replace what the crop to be grown is expected to remove using values from **Table 8.6**. At this test level 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 K is not applied to maintain soil test levels.

Buildup plus maintenance fertilization needed. When soil test levels are below the desired values (260 and 300 for the low and high capacity, respectively), it is suggested that enough fertilizer be added to build the test to the desired goal and to replace what the crop will remove (as described in the previous paragraph). At this test level, the yield of the crop will be affected by the amount of K applied that year.

For perennial forage crops, broadcast and incorporate all of the buildup and as much of the maintenance as economically feasible before seeding. On soils with low fertility, it is safe to apply a maximum of 30 to 40 pounds of K_2O per acre along with the P band. Up to 600 pounds of K_2O per acre can be safely broadcast in the seedbed without damaging seedlings. Warm-season perennial grasses prefer fertile soils but grow well in moderate fertility conditions. For establishment, fertilize with 40 to 60 pounds of K_2O per acre. For these cropping systems, K rates beyond the year of establishment follow the regular maintenance or buildup plus maintenance program already described.

On average most Illinois soils require 4 pounds of K_2O per acre to increase the K exchangeable soil test by 1 pound. The recommended rate of buildup for K is thus 4 times the difference between the soil test goal and the actual soil test value. For a typical 4-year buildup program, divide the rate by 4 to determine the annual rate. In some soils, soil

Figure 8.7. Cation-exchange capacity of Illinois soils. The darkest areas are sands with low capacity.

test levels do not build up as expected. Under the following conditions, an annual application approach (rather than buildup and maintenance) should be used:

- Soils for which past records indicate that soil test K does not increase when buildup applications are applied.

- Sandy soils that do not have a capacity large enough to hold adequate amounts of K.

Annual applications. When one of these conditions exists, or the land's expected tenure is short or unknown, continued monitoring of the level of K through soil testing every 4 years is recommended, along with the following:

- If soil test levels are below the desired buildup goal, multiply the maintenance value (K content in the harvested portion of the expected yield calculated from **Table 8.6**) by 1.5 and apply that rate annually.

- If levels are within the maintenance range, or only slightly below desired buildup levels (buildup and maintenance are less than 1.5 times removal), apply K maintenance amounts for the expected yield (**Table 8.6**).

There are advantages and disadvantages to buildup plus maintenance vs. annual application. 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
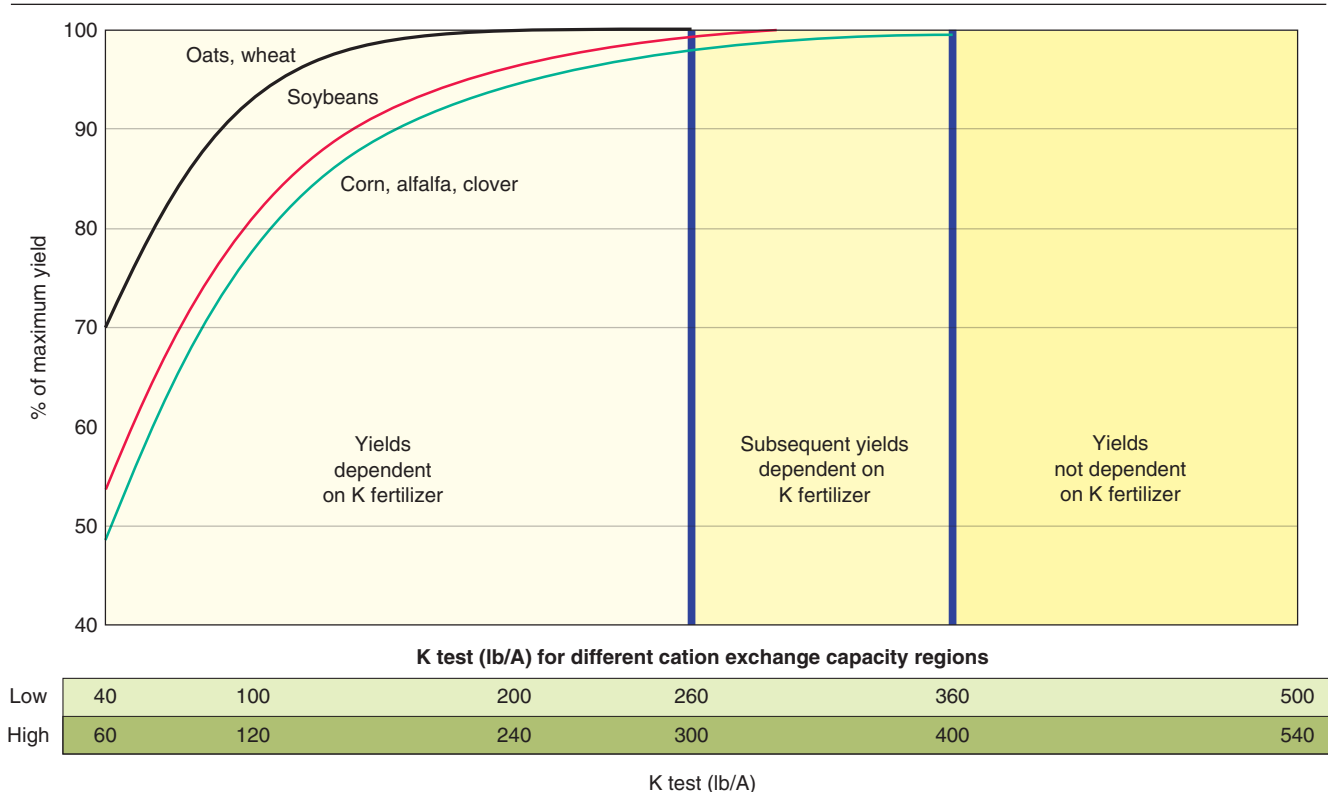

K test (lb/A) for different cation exchange capacity regions					
Low	40	100	200	260	360	500
High	60	120	240	300	400	540

K test (lb/A)

Figure 8.8. Relationship between expected yield and soil K, measured by the ammonium acetate or Mehlich-3 extractable K tests.

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 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.

Consequences of omitting fertilizer. The impact of eliminating K fertilizer on yield and soil test level will depend on the initial soil test and the number of years that applications are omitted. Although test levels tend to decline more rapidly for K than for P, there is little potential, if any, for a yield decrease if K application is eliminated for 4 years on soils that have a K test of at least 360 pounds per acre.

Applications of Phosphorus and Potassium

The following are examples of how to calculate P and K fertilizer rates for a 4-year program.

Example 1: Buildup plus maintenance needed

Continuous corn with a yield goal of 180 bushels per acre grown in a region of soils with high P-supplying power and high CEC. The soil test levels were 32 pounds of P and 250 pounds of K.

● Step 1: Calculate buildup rate.

Phosphorus:

The soil is 8 pounds below the desired level of 40 pounds per acre (**Figure 8.5**) (40 – 32 = 8).

It takes 9 pounds of P_2O_5 to build the soil test level by 1 pound. 8 x 9 = 72 pounds of P_2O_5 over 4 years to bring soil P to the desired level, or 72 ÷ 4 = **18 pounds of P_2O_5** per year.

Potassium:

The soil is 50 pounds below the desired level of 300 pounds per acre (**Figure 8.8**) (300 – 250 = 50).

It takes 4 pounds of K_2O to build the soil test level by 1 pound. 50 x 4 = 200 pounds of K_2O over 4 years to bring soil K to the desired level, or 200 ÷ 4 = **50 pounds of K_2O** per year.

● Step 2: Calculate maintenance (from **Table 8.6**).

Phosphorus:

0.43 pounds of P_2O_5 per bushel of corn x 180 bushels = **77 pounds of P_2O_5** per year.

Potassium:

0.28 pounds of K_2O per bushel of corn x 180 bushels = **50 pounds of K_2O** per year.

● Step 3: Sum buildup and maintenance values to determine yearly application rate.

Phosphorus: 18 + 77 = **95 pounds of P_2O_5**

Potassium: 50 + 50 = **100 pounds of K_2O**

Example 2: Maintenance-only needed

Corn and soybean with a yield goal of 180 bushels of corn per acre and 50 bushels of soybean per acre grown in a region of soils with medium P-supplying power and low CEC. The soil test levels were 55 pounds of P and 320 pounds of K.

● Step 1: Calculate maintenance (from **Table 8.6**).

Phosphorus:

0.43 pounds of P_2O_5 per bushels of corn x 180 bushels = **77 pounds of P_2O_5** for corn year.

0.85 pounds of P_2O_5 per bushels of soybean x 50 bushels = **43 pounds of P_2O_5** for soybean year.

Potassium:

0.28 pounds of K_2O per bushel of corn x 180 bushels = **50 pounds of K_2O** for corn year.

1.30 pounds of K_2O per bushel of soybean x 50 bushels = **65 pounds of K_2O** for soybean year.

If a biennial application is preferred, sum the P and K rates for both crops to determine the rate of application.

Example 3: No fertilization needed

Corn and soybean with a yield goal of 180 bushels of corn per acre and 50 bushels of soybean per acre grown in a region of soils with high P-supplying power and high CEC. Soil test levels were 90 pounds of P and 450 pounds of K.

Example 4: Annual application

Corn and soybean with a yield goal of 160 bushels of corn per acre and 40 bushels of soybean per acre grown in a region of soils with low P-supplying power and low CEC. The soil test levels were 75 pounds of P and 180 pounds of K. The K test levels fail to increase as expected.

Since P levels are high, there is no need to apply P. The soil does not respond to buildup rates, so following an annual application approach is recommended.

● Step 1: Calculate maintenance (from **Table 8.6**).

0.28 pounds of K_2O per bushel of corn x 160 bushels = **45 pounds of K_2O** for corn year.

1.30 pounds of K_2O per bushel of soybean x 40 bushels = **52 pounds of K_2O** for soybean year.

● Step 2: Adjust for annual application approach.

45 pounds of K_2O x 1.5 = **68 pounds of K_2O** for corn year.

52 pounds of K_2O x 1.5 = **78 pounds of K_2O** for soybean year.

Determining Removal in Forage Systems

As mentioned, P and K needs are assessed by soil testing. If testing is not being done in a pasture system, the second best option is to apply what is removed by the crop using values from **Table 9.6**. Very productive pastures yield 5 to 6 tons of dry matter per acre, moderately productive pastures 3 to 5 tons, and less productive pastures 1 to 3 tons. Recycling of nutrients from urine and manure reduces the total nutrients removed from a pasture by 60% to 80%, varying with the intensity of grazing management (continuous vs. rotational vs. management-intensive) and the resulting distribution of manure. Managed grazing improves the distribution and utilization of P and K. Thus, usually less of these two nutrients is needed on pastures than on hay fields. It is important to test soil every 4 years to monitor changes in the fertility status of pastures.

Determining Removal by Baled Stover or Straw

Baling corn stover and wheat straw has a direct impact on P and K removal from the field. This removal needs to be included in fertilization plans for the following crop. The best method to determining nutrient removal is by directly measuring tons of residue baled and chemically analyzing samples collected from those bales.

If that method is not feasible, follow these guidelines to determine nutrient removal through an indirect approach: The amount of residue produced depends on several factors, but for corn and wheat typically a general value is 1 pound of residue per pound of grain produced (dry weight basis). The amount of actual removal will depend on harvest method. Traditional harvest methods remove anywhere from 50% to 80% of the total residue. To determine the amount of P and K removed with the residue, multiply the values in **Table 8.6** by the tons of residue removed.

The actual amount of nutrients present in the residue can vary significantly from the table values dependent on several factors such as growing-season conditions, hybrid, and general fertility of the soil. Further, while P has low mobility because it is present in organic forms, K is present in a highly soluble inorganic form. Thus, K amounts can be largely influenced by the amount and frequency of precipitation in the time elapsed since the crop reached maturity and the time the residue was removed from the field.

In determining nutrient removal and the actual value of crop residue, it is important to realize that there are components in addition to P and K. Crop residue also includes N, secondary macronutrients, and micronutrients, as well as organic carbon. The impacts of increased removal of these nutrients and organic carbon from residue removal are not as obvious in the short term as for P and K, but they will definitely carry consequences in the long term. While secondary macronutrients and micronutrients are not typically provided through fertilization in Illinois, greater removal can accelerate deficiency of these nutrients in the soil. Removal of basic cations (such as K, Ca, and Mg) can lead to an increase in the need to lime soils to maintain adequate pH levels. Nitrogen reserves, as well as organic matter depletions, can lead to less crop availability of N through the process of mineralization (conversion of organic N to inorganic forms). Diminishing organic carbon contents can also result in negative impacts on soil physical, chemical, and biological properties. Thus, all factors, including nutrient removal and soil resources, should be carefully considered when estimating the actual cost of crop residue removal.

Fertilizer Sources

MAP vs. DAP. Monoammonium phosphate (MAP) and diammonium phosphate (DAP) are the most common P sources. The main difference between these two products is the amount of P and N present in the fertilizer and the initial chemical reaction that takes place in the soil when they are applied. Both products are made by ammoniation of phosphoric acid. The grade for MAP varies (11-51-0, 10-50-0, 11-55-0, etc.) because the phosphoric acid quality for MAP is lower than for DAP (which can be sold only as 18-46-0). As phosphate rock quality declines in the mines, MAP production is favored. When applied in the soil, MAP produces an acidifying reaction that can prevent the formation of toxic levels of ammonia, while DAP produces an alkaline reaction and the formation of ammonia. However, these initial differences diminish within a month or two, and no agronomic differences are typically observed between the two P sources.

Solubility of phosphorus. The water solubility of the P_2O_5 listed as available on the fertilizer label is of little impor-

tance under typical field crop and soil conditions on soils with medium to high levels of available P when recommended rates of application and broadcast placement are used. Due to rapid interaction of P fertilizer with iron and aluminum, P is tightly bound in the soil, so water solubility does not imply great movement or leaching.

For some situations, water solubility is important:

- For band placement of a small amount of fertilizer to stimulate early growth, at least 40% of the P should be water-soluble for application to acidic soils, and preferably 80% for calcareous soils. As shown in **Table 8.7**, the P in nearly all fertilizers commonly sold in Illinois is highly water-soluble. Phosphate water solubility above 80% has not been shown to increase yield any further than water solubility of at least 50%.

- 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 P.

White vs. red potash. Both red and white potash are muriate of potash (potassium chloride, or KCl). When the ore is mined it is reddish in color due to iron impurities. Depending on the processing and recovery method, the iron impurities are either removed or are left on the final product. Red potash is produced by grinding and flotation, while white potash is produced by dissolution and recrystallization in which iron is removed from the final product. Red potash is 0-0-60, and white potash is slightly more pure 0-0-62. Both forms are highly soluble and contain approximately 47% chloride. The difference in the amount of sodium is significant enough to produce any differences in the crops. Red potash contains approximately 4% sodium and white potash about 1%; there are no agronomic differences between the two products.

Noncommercial fertilizer sources. Livestock manure, sewage sludge, and some industrial waste materials are effective sources of plant nutrients. Since many of the nutrients in these materials are in the organic form and since the ratio of N to P is often not in the same proportion as removed by the plants, these materials require special management to ensure that an adequate supply of plant

Table 8.7. Water solubility of some common processed-phosphate materials.

Material	% P$_2$O$_5$	% water-soluble
Ordinary superphosphate 0-20-0	16–22	78
Triple superphosphate	44–47	84
Mono-ammonium phosphate 11-48-0	46–48	100
Di-ammonium phosphate 18-46-0	46	100
Ammonium polyphosphate 10-34-0, 11-37-0	34–37	100

nutrients will be available. Whenever possible, the allocation of these products should be based on P, not N, needs of the crop to minimize the potential for long-term buildup of P in the soil. The amount of nutrients present in these products is animal- and management-specific. In order to apply adequate nutrient rates, the quantities contained in these materials need to be determined through chemical analysis, if details are not already provided by the supplier. Table 9.6 (p. 132) shows average nutrient values that can be used as a general reference for different materials. In equivalent bases of commercial fertilizer, P and K availability from these sources is normally 80% and 85%, respectively. A large percentage of both P and K will be available the first year after application, and approximately 10% of the original amount will be available the second year.

Placement of Fertilizers

Selecting the proper application technique for a particular field depends at least in part on 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, method of placement is often irrelevant. In contrast, on low-testing soils and in soils with high P- and K-fixing capacity, placement of the fertilizer within a concentrated band can be beneficial, 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. Finally, there is no evidence suggesting that fertility levels can be maintained if fertilizer rates are reduced in a band application.

Broadcast fertilization. Broadcast and incorporation by plow or disk is an effective method to apply buildup and maintenance rates of P and K on soils with adequate fertility. 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 high fixation ability. Fortunately, most Illinois soils do not have high fixation rates for P or K.

Relatively immobile materials such as limestone, P, and K move slowly in most soils unless they are physically mixed by tillage operations. Broadcast applications of these materials in no-till or other forms of conservation tillage (including chisel plow) cause vertical stratification of nutrients, with higher concentrations developing near the surface. Such stratification has not been shown to reduce yields of corn or soybeans in Illinois. Among other fac-

tors, this is likely because crops develop more roots near the soil surface in conservation tillage systems, due apparently to both the improved soil-water conditions caused by the surface mulch of crop residues and the higher levels of available nutrients.

When doing a broadcast application it is important to maintain uniformity across the application width, do the correct amount of overlap, and have an applicator control system that maintains application rate per unit of soil surface constant independent of ground speed. When using dry bulk blends, ensure that materials are as uniform as possible in size, density, and distribution in the fertilizer bin. For liquids, maintain solution well mixed in the tank, and check nozzles for clogging.

Starter or row fertilization. This is an application below and to the side of the seed (typically 2 inches below and 2 inches to the side, also known as 2x2 placement). Other techniques to attain a starter response include application in direct contact with the seed ("pop-up" fertilization, described later) and placement on the soil surface near the seed row. These methods have not shown the consistency of crop response observed for the 2x2 technique. On soils of low fertility, 2x2 placement of fertilizer has been shown to be an efficient method of application, especially when 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 row fertilization are the additional time and labor required at planting time, limited contact between roots and fertilizer, and inadequate rate of application to increase soil levels for future crops.

Wet and cool soil conditions early in the season can limit plant growth and nutrient uptake. This is typically a greater concern in no-till fields where the high surface residue content has a mulching effect. Row fertilization promotes rapid and uniform corn growth when cool and wet soil conditions are present, even in soils with high fertility. At high soil test levels, the early growth response to starter seldom results in increased yield at harvest. This early growth response to starter occurs because the fertilizer band provides a high nutrient concentration when uptake demands are high relative to the small size of a root system with reduced growth and nutrient uptake capacity due to unfavorable soil conditions. For this reason, even when a large amount of fertilizer is being added by broadcast, starter applications are recommended on soils with low to medium fertility to ensure adequate nutrient supply to corn seedlings.

The greatest response to starter in corn is given by N, followed by P. Potassium produces the smallest response, and typically only when K test levels are low or when soil conditions are limiting nutrient uptake. Nitrogen in the band can increase P uptake by maintaining this nutrient in a more available form. Also, roots proliferate in response to N and P, so a band containing these two nutrients can increase nutrient availability by producing more roots to absorb the nutrients. The use of urea in the band, however, is not recommended since its hydrolysis produces ammonia, which inhibits root growth and thus negatively impacts P uptake. Since salt content can also injure roots, it is recommended not to exceed 75 and 100 pounds of salt (N plus K_2O) per acre in a starter application for soybean and corn, respectively. However, research has shown that under some conditions as much as 200 pounds of N per acre can be applied in a 2x2 placement without injuring corn. Although rarely done, a 2x2 placement can supply all the P and K maintenance for one crop.

In contrast to corn, soybean response to starter is unlikely if soil fertility is medium to high or if an adequate broadcast application of P and K was done in a low-testing soil. The difference is likely related to the distinct root system of both crops and the fact that soybeans are planted later, when soil conditions are less limiting for nutrient uptake.

Seed placed, or "pop-up," fertilization. With this method a small amount of fertilizer is applied directly with the seed. The term "pop-up" is misleading. Corn does not emerge sooner; in fact, it may be delayed a few days with this kind of application. While corn may grow more rapidly during the first 1 to 2 weeks after emergence, seldom will there be a yield difference compared to a 2x2 placement.

Some advantages for this placement method include lower equipment cost, faster planting (fewer fertilizer fill-up stops during planting), and the possibility for early cultivation for weed control due to faster growth of the crop. However, seed-placed fertilization is a risky operation. Under normal moisture conditions, the maximum safe amount of salt (N plus K_2O) for pop-up placement is about 10 or 12 pounds per acre. In excessively dry springs, or sandy soils with very low CEC (less than 8), even these low rates may result in damage to seedlings and/or reduction in germination. Urea or urea-containing fertilizers as well as micronutrients should not be used in direct contact with the seed.

Soybean is more sensitive to salt than is corn, so pop-up fertilization is not recommended for soybean.

Wheat is very responsive to P, especially under low-test levels. Because of narrow rows in wheat, there are fewer options for starter fertilizers than in corn. For this reason, starter P (normally 10-34-0, 18-46-0, or 11-52-0) is often placed with the seed. The small amount of N in the fertilizer can also help the crop when no pre-plant N was applied or when little carryover N is available from the previous crop.

For perennial forage crops, 30 pounds of P_2O_5 and up to 30 to 40 pounds of K_2O per acre can be applied safely when using a band seeder. This large amount of K is safe because the rate per acre is distributed over more rows (less fertilizer in direct contact with the seed) compared to a wider 30-inch row planter.

Strip application. With this technique, P, K, 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 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 any combination of N, P, and K can be injected at a depth of 4 to 8 inches. The knife spacing varies, but generally it is 15 to 18 inches apart for close-grown crops such as wheat and 30 inches for row crops. This placement technique is often used in combination with strip-tillage operations. With this tillage system, greater early growth and increase in corn yield, compared to a no-till system, often is the result of tillage in strip-till and not the method of nutrient placement. Under low-testing soils, when surface soil conditions are dry and subsurface water content is still adequate, subsurface placement (especially for K) can be advantageous for corn in reduced tillage systems. However, the small yield increase that can be expected is not cost-effective in light of the added cost of deep placement. It is important to realize that if the application is deep, it takes a longer time for the roots to reach the fertilizer. This can be a problem in years when growing conditions limit root development. If a deep placement is chosen in low-fertility soils, applying a starter fertilizer is recommended. Another situation in which subsurface applications may be beneficial (as long as the subsurface band application does not create a channel for water and soil movement) is when the potential for surface water runoff is high.

Site-specific or variable-rate application. This application method uses several remote sensing technologies, yield monitors, global positioning systems (GPS), geographical information systems (GIS), and variable-rate technology (VRT). These technologies can improve the efficacy of fertilization and promote more environmentally sound placement of fertilizer compared to single-rate applications derived from the conventional practice of collecting a composite soil sample to represent a large area of the field. Research has shown that this technology often reduces the amount of fertilizer applied over an entire field. However, one of the drawbacks of this placement method is the expense associated with these technologies. Also, VRT can only be as accurate as the soil test information used to guide the application rate. At this point, due to the inherent high variability in soil testing over small distances and the fact that most soils where these technologies are being used have been managed to have reserved P and K levels, the technology has seldom produced significant yield increases.

Foliar fertilization. It is well known that plant leaves absorb and utilize nutrients sprayed on them. Foliar fertilization can be effective for nutrients required in small amounts by plants. Nutrients required in large amounts, such as N, P, and K, are recommended to be soil-applied rather than foliar-applied. Foliar applications can only supply very small amounts of the total nutrients needed by crops. Because it would take many applications to supply the needed amounts without burning leaves, foliar application of major nutrients is neither practical nor cost-effective.

Environmental Considerations

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 the process by increasing the concentration of nutrients flowing into water systems. Since P is the element most often limiting eutrophication in natural water bodies, controlling its input into lakes and streams is very important.

There are concerns that agricultural soils may be important contributors to eutrophication. Normally about 5% of the soil P is soluble or easily soluble (labile) and can be lost in surface water runoff; the remaining 95% is tightly bound to soil particles. When the soil particles end up in the water, chemical equilibrium reactions release some of the absorbed P into the water. Thus, erosion control and reduction of P levels in the very surface of the soil are the best ways to minimize P loss. The following practices can help minimize P loss from agricultural fields:

1. Do not maintain excessively high-P soil test levels. While soil test procedures were designed to predict where P was needed, not to predict environmental problems, the likelihood of P loss increases with high-P

test levels. Of course, environmental decisions regarding P applications should not be made solely on P soil test levels. Rather, decisions should also include such factors as distance from a significant lake or stream, infiltration rate, slope, and residue cover. 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 predicting 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 P runoff. Another potential problem is variability in soil test levels within fields in relation to the dominant runoff and sediment-producing zones.

2. Maintain buffer strips (grassy waterways, vegetative filter strips, or constructed wetlands) at the point where water leaves the field.

3. Minimize soil erosion and surface water runoff by protecting soils with residue cover, conservation tillage, the use of cover crops, farming on contours and having contour buffer strips, reducing soil compaction and increasing soil-water permeability, and maintaining subsurface drainage systems, which allow excess water to move out of the field in the tiles and not on the surface. Although some of these practices may not reduce the potential for loss of dissolved P, they will reduce the potential for loss of total P.

4. Do not leave manure or P fertilizers on the soil surface. Incorporating or injecting these products not only reduces the potential for P runoff, it also reduces the potential for N volatilization and reduces odor of manure applications.

5. Match nutrient applications to crop needs. This will minimize the potential for excessive buildup of P soil tests and reallocate P sources to fields or areas where they can produce agronomic benefits.

6. Where possible, grow high-yielding, high-P-removing crops on fields that have excessively high-P soil test levels. Even when this is done, it may take several years to lower very high levels.

Time of Application

While an annual application of P and K in a corn–soybean rotation is effective, it is possible to apply enough nutrients in any one year to meet the needs of the crops to be grown in the succeeding 2 to 3 years. Biennial applications are often preferred to reduce application costs. With biennial applications, it is recommended that you apply the fertilizer required for both crops before the corn crop and make soybean a residual feeder in the rotation.

P and K fertilizers may be applied in the fall to fields that will not be fall-tilled, provided that the slope is less than 5%. Do not apply fertilizer in fall 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 N from ammoniated phosphate materials is insignificant. P and K applications are preferred in the fall because normally there is more time available than during the spring planting season, and soil conditions tend to be less conducive to compaction. One drawback of fall P application is that the small amounts of N accompanying ammoniated phosphate fertilizers are subject to nitrification and potential loss. A three-year study in Urbana showed total N recoveries at the end of May to be 17% and 45%, respectively, for fall- and spring-applied ammoniated phosphates (MAP and DAP).

For double-crop soybeans after wheat, it is suggested that P and K fertilizer required for both crops be applied before seeding wheat. This practice reduces the number of field operations at planting time and hastens soybean planting. Also, wheat can benefit by having abundant P available during early establishment.

For perennial forage crops, broadcast and incorporate all of the P and K buildup and as much of the maintenance as economically feasible before seeding. After establishment, top-dressed applications of P and K may be made at any convenient time. Usually this will be after the first harvest or in September.

Secondary Nutrients

As previously mentioned, since response to application of secondary nutrients is uncommon in Illinois, there is not a large database to correlate and calibrate soil test procedures; thus, low confidence can be placed in the suggested soil test levels offered in **Table 8.8**.

Calcium deficiencies in Illinois have not been observed for soils with pH at or above 5.5. Calcium deficiency associated with acidic soils can be corrected by adjusting soil pH with limestone.

Table 8.8. Suggested soil-test levels for secondary nutrients.

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

Magnesium deficiency has been recognized in isolated situations in Illinois. The soils most likely to be deficient in Mg include acidic and sandy soils throughout Illinois and low CEC soils in southern Illinois. Deficiency is more likely where calcitic limestone ($CaCO_3$) rather than dolomitic limestone ($CaMg[CO_3]_2$) has been used.

The number of incidents with sulfur-deficient crops in the Midwest has increased, probably the result of increased use of S-free fertilizer; decreased use of S as a fungicide and insecticide; increased crop yields, resulting in increased requirements for all of the essential plant nutrients; and decreased atmospheric S supply. Despite the increasing frequency of S deficiency reports, crop responses to S applications in Illinois have been inconsistent. Routine application of S fertilizer is thus not recommended.

If an S soil test is performed, evaluate whether an S response is likely by also considering organic matter level, potential atmospheric S contributions, subsoil S content, and soil-water conditions just before soil samples were taken. Since soil organic matter is the primary source of S, soils low in organic matter are more likely to be deficient than soils with higher organic matter (>2.5%). Early-season S symptoms may disappear as rainfall contributes some S (especially downwind from industries emitting significant S amounts) and as root systems develop to exploit greater soil volume. Sulfur is also a very mobile nutrient. In sandy soils under excess precipitation, leaching may result in low test values of samples collected from the soil surface. Conversely, if the soil surface is dry and hot at the time of sampling, test results can overestimate the capacity of the soil to supply this nutrient during the entire growing season. For these reasons, if a soil test is unexpectedly low, use S only on a trial basis.

Micronutrients

Boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) are the seven essential micronutrients (also known as minor or trace elements). Although these nutrients are required only in small (micro) amounts, if any of them is deficient, it can result in severe yield reduction. Deficiencies of these nutrients are not common, making it challenging to study and to correlate and calibrate soil tests. Micronutrient tests thus have very low reliability and usefulness. Suggested levels for each test are provided in **Table 8.9**. In most cases, however, plant analysis will provide a better estimate of micronutrient needs than the soil test. **Table 8.2** shows critical plant-nutrient levels for various crops.

In general, deficiencies of most micronutrients are accentuated by one of five situations: strongly weathered soils, coarse-textured soils, high-pH soils, organic soils, and soils low in organic matter, either inherently or 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 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 N, P, and K fertility program and a favorable pH.

Confirmed deficiencies of micronutrients in Illinois have been limited to B deficiency of alfalfa, Zn deficiency of corn, and Fe and Mn deficiencies of soybean. 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 8.10**).

Boron deficiency in alfalfa results in shorter internodes and bunching of top leaves that are typically yellow-reddish. Some plants might not flower, and under severe deficiency, growing points may die. Deficiency symptoms typically appear on the second and third cuttings of alfalfa and are especially pronounced during droughty periods in some areas of Illinois. Application of B on soils with less than 2% organic matter is recommended for areas of high alfalfa production. If you suspect B deficiency, a simple test is to apply 30 pounds per acre of household borax (3.3 lb of B) to a strip. To make application easier, B can be added to the P–K fertilizer. Generally 1 to 2 pounds of B per acre can be applied yearly to sandy soil. On finer-textured soils, 3 to 4 pounds of B per acre can be applied in the first hay year to correct the deficiency for a few years. Oats are sensitive to B. If oats accompany alfalfa during the establishing year, it is better to apply B after the first year. Foliar applications of 0.1 to 0.3 pounds of B per acre are recommended for severely deficient fields. Do not apply B to alfalfa the year before corn. Both corn and soybean have

Table 8.9. 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 8.10. Soil situations and crops susceptible to micronutrient deficiency.

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

low requirements for B and can suffer toxicity if the previous alfalfa crop received heavy or repeated B applications.

Zinc deficiency in corn is characterized by interveinal light green to whitish bands from the base to the tip of new leaves. Normally the edge of the leaf, including the tip, and the midrib area stay green, but in cases of severe deficiency the new leaves can be completely white. Also, corn plants will look stunted and have shorter internodes. Applications of 5 and 10 pounds of Zn per acre are recommended for band and broadcast applications, respectively. If a chelated product is used, follow the manufacturer's directions.

Iron deficiency in soybean appears in new leaves, typically at early stages of development. The entire leaf blade turns yellow except for the veins, which remain green. The growth is often stunted. Foliar applications are more effective in restoring green color. Typically 1 to 2 pounds of Fe per acre are recommended. When using chelated products, follow the manufacturer's directions. Research in Minnesota has shown that for soybean, time of Fe application is critical to attaining a response. Apply 0.15 pounds of Fe as Fe chelate 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 Fe would result in no yield increase.

Manganese deficiency in soybean causes stunted plants with green veins in yellow or whitish newer leaves and typically occurs in late May and June if the weather turns cool and wet. To correct Mn deficiency in soybean, spray either manganese sulfate or an organic Mn formulation onto the leaves after the symptoms appear. Broadcast applications on the soil are not recommended; band applications of 5 to 8 pounds of Mn per acre can be effective. Foliar applications of 0.5 pounds of Mn per acre are recommended. For chelated products, follow the manufacturer's directions. Foliar applications of MnEDTA at rates as low as 0.15 pounds of Mn per acre in mid-June to soybean planted in early May have shown significant yield increases. Similarly, multiple applications or delaying applications to early July have been beneficial.

Nontraditional Products

Many products circulate the fertilizer market claiming to replace fertilizers and to cost less, to make nutrients in the soil more available, to supply micronutrients, or to be a natural product. Those promoting the products typically use testimonials by farmers and present data from suspect sources. The best approach that producers can take is to challenge these peddlers to produce unbiased research results in support of their claims.

Extension specialists at the University of Illinois are ready to give unbiased advice when asked about new products. An additional resource entitled *Compendium of Research Reports on Use of Non-traditional Materials for Crop Production* contains searchable data on a number of nontraditional products that have been tested by university researchers in the U.S. The publication can be accessed at extension.agron.iastate.edu/compendium.