Fertility Management

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Introduction

The purpose of developing a fertility program is to ensure that adequate levels of nutrients are available for plant uptake in support of the yield potential for the climatic, plant genetic, and soil environmental factors impacting plant growth in any given field. A regular soil sampling program is the best way to obtain the information necessary to develop such a fertility program. An occasional tissue sampling program helps augment the soil sampling program. For corn production, nutrient application most commonly involves lime for pH, as well as nitrogen (N), phosphorus (P), and potassium (K). Zinc (Zn) or magnesium (Mg) is needed occasionally. In rare cases, boron (B) may be necessary.

Soil Sampling

When you take soil test samples, keep in mind that a few ounces of soil are being tested to determine lime and fertilizer needs for millions of pounds of soil in the field. It is absolutely necessary that the soil sample you send to the laboratory accurately represent the area sampled.

Soil samples can be collected during much of the year, although September to December or February to April are the best times. There will be a small difference in soil test results depending on the time of the year of sampling. So, once a time of the year is selected, always sample in the same season.

How to Sample

A soil probe, auger, garden trowel, or a spade and knife are all the tools you need to take the individual cores that will make up the field sample. You will also need a clean, dry bucket (preferably plastic) to collect and mix the sample cores. Soil sample boxes or bags and information forms for submitting samples are available at all county Cooperative Extension services offices.

The most representative sample can be obtained from a large field by sampling smaller, more uniform areas on the basis of soil type, cropping history, erosion, or past management practices. A sample should represent no more than 20 acres except when soils, past management, and cropping history are quite uniform. When troubleshooting problem areas in fields during the growing season, take a sample from the problem area and adjacent areas with good crop growth.

Collect at least 10 soil cores in small areas and up to 30 cores in larger fields. Take the soil cores randomly throughout the area to be sampled and place in the bucket.

Tilled areas—Take soil cores to the depth of the tillage operation (usually about 6 inches).

No-tilled areas—Take soil cores to a depth of 4 inches where fertilizer or lime remains on the soil surface or is incorporated only in the surface 1 to 2 inches.

Lime and fertilizer applied continuously to the surface of no-till fields results in a build-up of immobile nutrients within the top 1 to 3 inches of the field, with little effect on increasing soil test values below this depth. This stratification of P, K, Ca, and Mg has not been a problem in no-till corn production in Kentucky, but no-till fields are sampled to a 4-inch depth because of nutrient stratification. Also, if most or all of the N is applied on the soil surface, continuous no-tillage does cause increased acidity in the top 1 to 2 inches of soil. This surface acidity reduces the activity of some herbicides, particularly the triazines. This surface acidity may need occasional monitoring with a separate 2-inch soil sampling.

Certain areas should be avoided when taking soil samples. Do not include soil from the following areas:

- Backfurrows or dead furrows.
- Old fencerows.
- Near or in rows where banded fertilizer was applied.
- Areas used for manure or hay storage or livestock feeding.
- Highly eroded areas.

Sampling for Precision Agriculture

Many farmers now sample fields to delineate soil-test variability so that they can make variable-rate applications of lime and fertilizer within the field. This is most commonly done by sampling fields on a grid. Grid sampling involves establishing some measured grid intersects within a field and then taking a composite soil sample within a small area either around the grid intersects or from the center of the grid. The question of concern is what grid size to use. A widely used method is to grid fields into 330- x 330-foot (2.5 acre) blocks and sample each block by compositing six or eight cores taken within a 60-foot radius of the center of the block. While such regimented grid sampling gives a better picture of soil-test variability within a field, it does require more intensive sampling, which increases costs. Research on grid size has shown that the smaller the grid, the more accurate the map of a field's availability. Grids on 100-foot intersects (0.23 acre per grid) are much more accurate than 330-foot intersect grids, but they require the expense of a soil test for every 0.23 acre in a field.

The expense of the large number of soil tests required by grid sampling has resulted in some farmers resorting to a procedure presently called "smart sampling." This procedure is identical to the long-standing University of Kentucky recommendation of (a) sampling fields in units no larger than

20 acres and (b) separately sampling areas known to be different within the field. Currently, "smart sampling" protocols are derived from field maps of crop yield made with yield monitors, where low-producing areas are identified and then sampled separately.

Sample Preparation

After all cores are collected and placed in the bucket, crush the soil material and mix the sample thoroughly by hand. Take about a pint volume from the bucket and allow it to air dry in an open space free from contamination. Do not dry the sample in an oven or at an abnormally high temperature.

Soil Testing

Extractants. Soil pH is nearly always measured on a slurry of soil and distilled water or a buffer solution, but nutrient measurements are made after their extraction from the soil. Different laboratories may use different extractants or extraction procedures. The most commonly used extractants are:

1. Mehlich-3—used by the UK Soil Testing Lab and widely used by other testing labs.
2. Mehlich-1—widely used in the Southeast.
3. Bray-1 and neutral, normal, ammonium acetate—widely used in the Midwest.

The ultimate concern is that fertilizer nutrients be recommended on the basis of crop response that has been correlated with, and calibrated for, each specific extractant. For example, UK's fertilizer recommendations are correlated and calibrated for soil test values determined with the Mehlich-3 extractant. Using UK's recommendations for soil test values determined with the Mehlich-1 extractant would be totally invalid and might result in fertilizer rate recommendations that are much greater than needed.

Soil Test Results—Units

Some laboratories report results in parts per million (ppm), while others report in pounds per acre. If there is need to convert from one to the other, use the following formulas to estimate this comparison:

ppm x 2 = lbs per acre
lbs per acre ÷ 2 = ppm

Fertilizer Recommendations

It is not uncommon for a farmer to receive vastly different fertilizer recommendations after splitting a soil sample and sending half to different labs. Such differences are due to the differing philosophies used in interpreting soil test values and making fertilizer recommendations.

Several different philosophies are used in Kentucky, depending on who is making the recommendation. Farm supply dealers, agricultural consultants, and soil test laboratories use different approaches. Philosophies commonly used in making recommendations are discussed below. Each of these philosophies is based on different assumptions about crop needs and how crops respond to applied nutrition at different soil test levels and to different amounts and ratios of available nutrients. For any of these philosophies to have value in Kentucky, they must be correlated to the soil types and climatic conditions of Kentucky.

Crop Sufficiency

The crop response is the focus of this philosophy. The expected response of the crop at any given soil test level is what determines the fertilizer rate recommended for each nutrient. The amount of fertilizer recommended is determined from many field trials on different soils over many years. The approach is based on research data that adequately predict a crop response under normal to good conditions.

Nutrient Balance

The theory behind this philosophy is that the correct nutrient balance results in maximum crop response. This approach is often adopted when wide extremes in soil type are encountered or when the research base for the soil types encountered is limited.

Maintenance Fertilization

According to this philosophy, the nutrients removed at harvest should always be replaced. This approach is used especially on soils that test medium to high in P and K. This method is often used in combination with a recommendation made by either the nutrient balance or crop sufficiency approaches, which use a soil test as a basis for recommendation. A yield response to this extra maintenance fertilizer is usually not expected, but the fertilizer is added to maintain soil test levels over time.

Secondary Nutrients and Micronutrients by Soil Testing

This concept is based on testing the soil for secondary nutrients and micronutrients, and recommendations are made based only on this information, regardless of whether the correlation and calibration research base exists. Using a soil test in this way greatly increases the chance of adding a nutrient where it may not be needed. This is significantly different from making recommendations for these nutrients when both tissue and soil tests are used to determine deficiency or when an area or soil type is known to have a consistent secondary nutrient or micronutrient problem.

Combination of Philosophies

Normally recommendations are made from a combination of these philosophies. The philosophy that usually stands alone is the crop sufficiency philosophy. The maintenance philosophy frequently is used with either the sufficiency or the nutrient balance approaches. The philosophy of recommending micronutrients based only on a soil test is sometimes used with all approaches but is most commonly used with the maintenance and nutrient balance philosophies.

Summary of Fertilizer Recommendation Philosophies

All of these philosophies or combinations of philosophies have been evaluated in Kentucky. All resulted in excellent crop yields when the weather conditions were good. In almost all cases, there was no real difference in yields. However, there were always fairly large differences in the amount and kinds of fertilizer recommended. This resulted in large differences in the costs, with very high fertilizer costs giving no yield advantage. Fertilizer rates based on the crop sufficiency philosophy usually cost the least and produce yields equivalent to the more costly recommendations derived from the other philosophies tested. Soil tests taken a few years following the application of the various recommendations indicated that surplus fertilizer was being stored in the soil.

Liming

Causes of Acidity

Greater soil acidity is the result of naturally occurring processes, mostly the decomposition of soil organic matter and plant residues and the removal of bases from the soil. Acid-forming fertilizers accelerate the formation of acidity, and the "salt" effect from fertilizer use also increases soil acidity.

The commonly used N fertilizers are the most usual source of acid-forming fertilizers. When used at high rates for a number of years, these N fertilizers cause the soil pH to drop rapidly. Table 1 shows the amounts of lime needed to neutralize acidity from various N fertilizers.

Measuring Acidity

Soils that contain higher levels of active hydrogen and aluminum or both in relation to Ca and Mg are acidic. The degree of acidity is expressed in terms of pH. A pH of 7 is neutral; pH values below 7 are acidic, and those above 7 are alkaline. Each pH unit represents a 10-fold change in acidity. For example, a soil with pH 5 has 10 times more active acidity than one with pH 6. Most crops grow best at soil pH values between 6 and 7.

Table 1. Approximate pounds of ag lime needed to neutralize the acidity generated by nitrogen fertilizers.

		Lime needed for 1 lb of actual N added	
Pure product	**% N**	**100% pure fine lime**	**Normal ag lime**
Ammonium Nitrate	34	1.8	2.7
Urea	46	1.8	2.7
Anhydrous Ammonia	82.5	1.8	2.7
N Solutions	28-32	1.8	2.7
Ammonium Sulfate	21	5.3	7.9
Diammonium Phosphate	18	1.8	2.7

The pH of the soil is a measurement made on a slurry of soil and water. It is a measure of the acidity in the soil solution that is in contact with plant roots. The soil buffer pH is a measure of reserve soil acidity that is held on the surface of soil mineral and organic particles and that must also be neutralized in order to increase the soil pH. In the soil buffer test, a buffer solution is mixed with soil, and the pH of the slurry is measured. The result from the buffer test is reported as buffer pH. The buffer pH is used only to determine lime requirements. The buffer pH and the soil pH together can be used to determine the lime required to change soil pH to some desired level.

Symptoms of Acidity and Benefits of Liming

Lime neutralizes soil acidity, raises soil pH, and adds Ca and Mg to the soil. The range in soil pH for optimal nutrient availability is generally between 6 and 7, with a target pH of about 6.5. Outside this range, one or more nutrients may become deficient. Liming acid soils also improves the environment for beneficial soil microorganisms and promotes a more rapid breakdown of soil organic matter, releasing nutrients for growing plants.

Corn is somewhat less sensitive to acid soils than wheat and soybean with which it is usually rotated. Nevertheless, at very low pH, corn suffers from both manganese and aluminum toxicity. Manganese toxicity causes striped leaves and stunted growth, and many times there is a string of necrotic spots on the interveins of the leaves. Aluminum toxicity results in poor root growth that causes short thick roots with few fine roots, which results in drought injury. Both symptoms are common in soils with pH values of 4 to 5.2; yields are often greatly reduced, and many nutrients are rendered much less available for plant uptake. This is especially true for phosphorus but also the availability of calcium, magnesium, nitrogen, sulfur, potassium, and molybdenum (see Figure 1).

Between pH 5 and 5.5, no visual symptoms are likely, and plant growth may appear normal, but yield will probably be reduced by 10 percent or more. The nutrients listed above are more available than at a pH below 5 but are still reduced in availability. The efficiency of most added fertilizers, especially P, will be reduced. Fertilizer P efficiency will probably be reduced by 25 percent or more when compared to pH 6.5.

Corn grows well with little or no yield reduction between pH 5.5 and 6.0, but fertilizer efficiency is still reduced. The reduction in the availability of P will be in the 0 to 25 percent range when compared to pH 6.5.

Although corn can tolerate moderately acid soils, growers need to keep two points in mind. First, adding ammonical N fertilizer to corn greatly accelerates soil acidification. Second, in no-till corn fields where most of the

Figure 1. Symptoms of corn growing in low pH soils.

N is added to the soil surface, the soil surface can become very acid (below pH 5) within three to four years. Once this happens, toxic amounts of aluminum and manganese are produced, and the triazine herbicides (atrazine and simazine) are rapidly degraded and do not provide adequate weed control.

At pH 7.0 or above, manganese and zinc may become deficient. For example, zinc deficiency of corn has been observed in Kentucky soils at these pH levels, especially when available P is also high.

The best liming program for corn involves a soil test every two years and lime applied according to soil test recommendations. On the average, one can expect the need for about one-half ton of lime per acre per year, but this is usually added at a rate of 2 to 3 tons per acre every three to six years.

Lime Sources

The most important source of lime for agricultural use is ground limestone called agricultural lime. The quality of agricultural lime is determined by its purity and fineness of grind. The Kentucky lime law specifies that agricultural lime must be 80 percent pure (calcium carbonate equivalence) and must be ground fine enough that 90 percent will pass a 10-mesh screen and at least 35 percent will pass a 50-mesh screen. This is a minimum standard for the lime to be effective in neutralizing soil acidity.

Relative neutralizing value (RNV) estimates the percent of agricultural lime that will dissolve in a three- to four-year period. The higher the RNV, the higher the lime's quality. Lime whose RNV is 80 will require a smaller amount to reach a desired pH than one whose RNV is 60. The average RNV in Kentucky is about 67, and this is the basis for University o f Kentucky's lime rate recommendations. County Extension agents have information on the RNV levels for sources of agricultural lime being sold in Kentucky.

Other liming materials are sometimes available in an area. These are usually by-products of industry or are liquid suspensions of finely ground limestone. Use of these materials should be based on their purity (expressed as percent $CaCO_3$) and fineness. With suspensions, the actual amount of lime in the mix determines the liming value. For example, a ton of lime suspension may contain only 1,000 pounds of lime. The rest is water and suspension agent. Specialty products like bagged, finely ground limestone, pelletized lime, hydrated lime, ground oyster shells, and others are available. These are usually more expensive but are convenient to use on small areas. Be careful in using these products so that an area is not over-limed.

Lime Rates

When cornfields are limed, enough should be used to raise the soil pH to the mid-6 range (pH 6.2 to 6.4 is suggested by the University of Kentucky). The exact amount needed is largely due to the amount of reserve acidity that is held on the soil particle surface as measured by the buffer pH. By knowing the buffer pH together with water pH, the amount of ag lime necessary to raise the soil to pH 6.4 can be determined. The rates can be found in the Extension publication *Lime and Fertilizer Recommendations* (AGR-1).

The adjustment of soil pH by lime is affected by five factors:

1. Thoroughness of mixing into the soil.
2. Depth of mixing into soil (top 6 inches is assumed except in no-till soils).
3. Time of reaction (four years is needed for complete reaction of agricultural lime, but the reaction time for hydrated lime is much shorter).
4. Quality of agricultural lime (an RNV of 67 is assumed).
5. Continued use of acid-forming N fertilizers, which can lower the final soil pH obtained.

When applying lime rates greater than 4 tons per acre, the lime should be thoroughly mixed in the plow layer by applying one-half the recommended rate before plowing and the other half after plowing, followed by disking.

When to Lime

Lime can be applied at any time. With adequate soil incorporation and moisture, a measurable pH change can occur within 4 weeks. However, it takes six to 12 months for a significant amount of the lime to dissolve and make the desired change in soil pH. For this reason, lime should be applied at least six months before the target crop is to be planted. Fall is a good time to apply lime so dissolution can occur during the winter. Also, fall weather is usually better for getting on the land with spreading equipment.

Nitrogen

Importance of N

Nitrogen is the fertilizer element required in the largest amounts, and at the greatest cost, for corn production. Each bushel of grain harvested will contain almost a pound of N. Properly fertilized silage corn removes slightly more than 10 pounds of N for each 1,000 pounds of dry matter. Availability of N in most soils is too low to supply all the N required for optimal corn production without fertilizer N. Recommended rates take into account that only one-third to two-thirds of the fertilizer N added is recovered in the harvested corn.

Nitrogen recovery is variable and largely unpredictable. This is primarily due to the powerful effect of weather on the release of native soil N and on the fate of fertilizer N. This makes it impossible to precisely predict the quantity of N required for maximum yield or maximum economic return and is the reason that meaningful soil tests for N availability are not very useful for most situations in Kentucky.

Neither the amount of organic matter nor the amount of soil nitrate has proven to be a reliable indicator of the available N for field crops grown under Kentucky conditions. For this reason, N recommendations for field crops are based on past cropping history, soil management, and soil properties.

Deficiency Symptoms

Young corn plants show a general chlorosis or yellowing of the entire plant when N is limiting. Under severe early growth deficiency, the bottom leaves may "fire" and desiccate. If N supply becomes limiting after stalk elongation begins, through the remainder of the growing season N is translocated from the most mature leaves at the lower stalk positions to the newer leaves or the ear. This causes the lower leaves to show a characteristic "V"-shaped yellowing extending from the leaf tip along the midrib toward the stalk, with the open end of the "V" at the leaf tip. The effect on growth and grain yield can range from stunted, chlorotic plants, which may not even form an ear, to normal-appearing plants with ears that do not have fully formed kernels toward the tips of the ears (see Figure 2).

Time of Rapid N Uptake and Partitioning

The absolute amount of N needed during the first few weeks of growth is small and uptake is slow. Uptake progressively increases as the plant becomes larger with rapid uptake of N beginning about 3 weeks before tasseling. Most of the N taken up will be held in the leaves until grain formation begins. After grain formation begins, there is translocation of much N from other plant parts to the ear. About half the total N uptake occurs by the time of pollination.

Factors Affecting Nitrogen Availability

Organic soil N is found in large quantities in virtually all soils. A soil that has 3 percent organic matter contains more than 3,000 pounds of organic N per acre. However, only a small part of this, 1 to 5 percent each season, is broken down to inorganic N forms that are available to plants. A greater rate of N release can be expected from fresh plant residues and from plowed-down or killed grass and legume sods. For this reason, cropping history is an important consideration when estimating fertilizer requirements. Inorganic ammonium (NH_4^+) is either released by organic matter decomposition or added as fertilizer. Ammonium is a relatively immobile ion, and it is not susceptible to leaching or denitrification as is nitrate

Figure 2. Corn leaf with nitrogen deficiency symptoms (right) and a normal leaf.

(NO_3^-). Corn takes up NH_4^+ less readily than NO_3^-. In most Kentucky soils suitable for corn production, NH_4^+ is rapidly converted to NO_3^- in a process called nitrification. This reaction is largely completed shortly or within 30 days after fertilization.

Nitrate is a highly mobile ion because its solubility in water is essentially unlimited. It is readily available to plants but also is susceptible to leaching below the root zone, mainly in well-drained soils subjected to long-lasting or very intense rainfall. Denitrification loss of nitrate N is a microbiological transformation that can proceed very rapidly when soils become saturated with water. Therefore, it is most important in soils with impaired drainage.

Some nitrate is lost almost every year in all Kentucky soils, but such losses become serious when heavy rains or flooding occur within a month after fertilizer application. These losses result in more N fertilizer being needed on poorly drained soils. The tillage system also influences these processes. Denitrification, leaching, and immobilization can all be greater in no-till soils, so N rates should generally be slightly increased when using the no-till system.

Organic Source

A winter legume cover crop can also provide a substantial amount of N for corn, either with no-tillage or conventional tillage. Research conducted by the University of Kentucky indicates that some legume cover crops can provide yield advantages beyond N. Benefits from hairy vetch have been greater than from crimson clover or big flower vetch.

Nitrogen Fertilizers

Mixed Fertilizers

Most of the mixed fertilizers used in Kentucky contain some N, with the amounts varying depending on the grade. The first number in the guaranteed analysis of a fertilizer refers to the percentage of N. An 18-46-0 grade is 18 percent N and contains 18 pounds of N in each 100 pounds. Most of the N in mixed fertilizer is in the ammonium form. Diammonium phosphate and monammonium phosphate are also commonly available N-containing fertilizers in which all the N is in the ammonium form.

Nitrogen Materials

Fertilizers that contain only N are sometimes referred to as straight N fertilizers. They are marketed in both solid and liquid forms. Nitrogen materials commonly sold in Kentucky are discussed below.

Ammonium Nitrate (NH_4NO_3) is a solid N fertilizer that contains 33.5 to 34.5 percent N. One-half of the N is in the ammonium form, and one-half is in the nitrate form. Ammonium nitrate dissolves rapidly in the soil and is an excellent source of nitrogen, especially for surface-applied N on no-till corn.

Urea ($CO(NH_2)_2$) contains 45 to 46 percent N in the solid form. When applied to the soil, the enzyme urease quickly converts urea N to ammonium. Consequently, urea N behavior in soil is essentially the same as that of ammonium except for the volatilization loss of NH_3. The soil near the urea granule becomes alkaline, which favors the formation of NH_3 gas from NH_4^+. A large fraction of the N sometimes can be volatilized as NH_3 and lost to the air. Some of the factors that affect the amount of loss are temperature, tillage, vegetative cover, moisture, and soil pH.

If the urea is moved into the soil by a rain (0.25 inch is enough) or by tillage within two days after application, the volatilization loss is little or none. When the urea is applied before May 1, the loss is little to none, even without tillage or a rain within two days. However, after May 1 the volatilization N loss is about 5 percent or less if urea is applied to the surface of a tilled soil, although it can be higher if the soil pH is near 7 or above. If the urea is applied to the surface of a no-till field after May 1, the losses can range from 0 to 25 percent, but the average is about 10 percent. The higher losses come with a soil pH of 7 or above or if the soil is warm and moist but drying due to a good breeze. Surface application of urea to no-till corn after May 1 is risky.

Volatilization loss from urea can be greatly reduced or almost eliminated by the use of urease inhibitors with the fertilizer. Urease inhibitors are very effective, but their use is best justified economically with surface application of urea to no-till corn after May 1.

Nitrogen solutions contain N that range from 28 to 32 percent; 28 percent N solution is used in Kentucky because of its low salt-out potential. In N solutions most commonly used for direct soil application, one-half of the N is from ammonium nitrate, and one-half is from urea. Each gallon of 28 percent, 30 percent, and 32 percent N solution contains 2.98, 3.25, and 3.54 pounds of N, respectively. The volatilization losses of N from surface-applied N solutions are much smaller than from urea even though one-half of the fertilizer is in the urea form.

Anhydrous Ammonia (NH_3) is the highest analysis N fertilizer available, containing about 82 percent N. At ordinary temperatures and pressure, it is a gas and must be kept under pressure to be stored as a liquid.

When anhydrous ammonia is released from pressure during application, the liquid immediately changes to a gas. For this reason, anhydrous ammonia must be injected 6 or more inches deep into the soil and then covered immediately to prevent loss of ammonia gas to the atmosphere. To prevent losses in no-tillage, extra sealing devices must be used. A winged or beaver-tail-shaped piece of steel on the injection knife is very helpful, but many times an additional device, such as a solid or spoked closing wheel or an inverted disc, is needed to close the knife opening. When injected into the soil, the ammonia molecule (NH_3) reacts with water and becomes ammonium (NH_4^+). The positively charged ammonium ion is then held by soil particles until it is either converted to nitrate N by nitrification over a period of several weeks or is absorbed directly by plant roots or soil microorganisms.

The N in the injection band moves very little laterally, so the roots must grow to the vicinity of the injection band to come in contact with the N. Therefore, the plants may be N-deficient early in the growing season if root growth is slowed by cool and wet conditions or sidewall compaction. If some N is broadcast before planting or applied as in-row fertilizer, the potential for temporary N deficiency is often relieved.

Anhydrous ammonia can also be applied as a supercooled liquid. In this process, anhydrous ammonia is released and depressurized in a specially built converter that keeps 70 to 85 percent of it as a liquid during application. In this state, the anhydrous ammonia can be metered and calibrated much more accurately.

Ammonium sulfate $(NH_4)_2SO_4$ contains about 21 percent N and 24 percent sulfur. All the N is in the ammonium form, which is temporarily absorbed by the clay and organic matter of the soil until it is nitrified to nitrate N or used by plants or microorganisms. Ammonium sulfate acidifies the soil much more quickly than other sources of N. It is not subject to volatilization loss.

Nitrate of Soda ($NaNO_3$) contains 16 percent N, all of which is in the nitrate form and readily soluble in the soil solution.

Nitrogen Losses on Wet Soils

The amount of N loss on wet soils depends on the source of N used, the time between N application and the onset of waterlogging, and the number of days the soil is saturated. Nitrogen can only be lost, due to excessive water, when the N is in the nitrate form and is leached or lost by denitrification. Denitrification is the more common cause of loss in Kentucky soils. The expected N loss from periods of heavy rains is found below.

Upland Soils Wet from Constant Rains

These soils probably have not lost much N because it takes two to three days of saturated conditions to begin the denitrification process and these soils usually do not remain saturated between rains. There may be some exceptions here.

Lower Soils with Short Periods of Flooding (One to Two Days)

These soils stay saturated longer for several reasons, and the corn usually looks bad. The amount of N loss is still not as great as one might assume. A N rate of 50 pounds per acre probably would be the most a grower could justify adding to replace lost N in these situations. Replicated trials by the University of Kentucky in 1993 showed increased corn yields of 11 bushels per acre from sidedressing N under these conditions.

Flooded Soils

Since only nitrate is lost, we must first estimate the amount of applied N that was in the nitrate form at the time of flooding. Below are estimates of fertilizer in the nitrate form at 0, 3, and 6 weeks after application. It is estimated that 3 to 4 percent of the NO_3-N in the soil will be lost by denitrification for each day the soil is saturated.

The NO_3-N in a flooded sandy soil is leached more rapidly than other soils, and the nitrate level would be expected to be very low after the water recedes.

	Week after application		
	0	3	6
N source	% Fertilizer as NO_3^{-N}		
Anhydrous Ammonia (AA)	0	20	65
AA with N-Serve*	0	10	50
Urea	0	50	75
Urea with N-Serve*	0	30	70
UAN	25	60	80
Ammonium Nitrate	50	80	90

* Nitrification inhibitor that slows transformation of ammonium to nitrate.

Nitrogen Soil Test

An additional tool for determining NO_3-N in the soil after flooding is a NO_3-N soil test. The sample should be taken down to 12 inches deep, and several samples should be taken in each field of both the low and higher ground. If the NO_3-N is 0 to 10 ppm, a full rate of N for the crop potential should be added as a supplemental application. At 25 ppm, no additional N would be needed. One would extrapolate between these two figures, keeping in mind the amount of NH_4 left in the soil from the first application.

Nitrogen Inhibitors

There are two types of inhibitors. They are unrelated and are helpful in two totally different situations.

Nitrification Inhibitors: Nitrification inhibitors protect from loss of N due to excessively wet soils. They are most effective on N fertilizers that are mainly in the ammonium form, such as anhydrous ammonia, urea, and N solutions. When N in the ammonium form is added to soil, it is rapidly transformed to nitrate. Nitrification inhibitors slow the transformation for about 4 weeks. This keeps N as ammonium longer so that it is not likely to leach or be lost by denitrification due to excessive wetness. Economic benefits are more likely on poorly drained soils that usually remain wet during spring. The economics of the use of a nitrification inhibitor must be weighed against other methods, such as adding more N to offset the loss (about 35 pounds per acre) or sidedressing at least one-half of the nitrogen when the corn is 6 to 12 inches high.

Urease Inhibitors: Urease inhibitors protect against losses of N from urea-based N sources to the atmosphere (volatilization). The losses are greatest for surface applied urea on no-till corn. See the urea section for discussion of this.

Timing N Applications: Probably the most practical and effective method of increasing N recovery by corn is to delay or split the N application. This practice works because young corn plants (up to 4 to 6 weeks) require very little N, and in Kentucky most of that can be supplied by the soil. Also, soils are typically wettest and most prone to N losses early in the season. Delayed N is most beneficial where the potential for denitrification and leaching losses are greatest, particularly on poorly, somewhat poorly, and moderately well-drained soils. As a general guideline for these soils, if two-thirds or more of the N is applied 4 to 6 weeks after planting, the total N can be reduced by 25 to 50 pounds per acre. Fall application of N for corn is never recommended in Kentucky, and use of nitrification inhibitors with fall-applied N does not eliminate the sizeable overwinter N loss likely in Kentucky.

Placement of N Fertilizer: The application of N below the soil surface improves efficiency of N use in no-till corn but has very little benefit with tilled corn. When the N fertilizer is placed below the residue layer of no-till corn, the N is less likely to be immobilized in the residue layer as happens when fertilizer N is broadcast on the surface. Subsurface application reduces the amount of N required by 10 to 15 percent when compared to surface broadcasting under no-till conditions. More is discussed later under row fertilizers.

Recommended Rates of Nitrogen: Amounts of fertilizer N recommended in Kentucky are affected by cropping history, type of tillage, internal soil drainage, irrigation, and time of application. Recommended rates can be found in the University of Kentucky publication *Lime and Fertilizer Recommendations* (AGR-1).

Phosphorus and Potassium

Both phosphorus (P) and potassium (K) are required in large quantities for good corn growth and yield. A good yielding crop will take up to 50 to 70 pounds of phosphate (P_2O_5) and 130 to 170 pounds of potash (K_2O) per acre (see Nutrient Content and Removal section). Of this total uptake, about three-fourths of the phosphate and about one-third of the potash is in the grain. The remainder is in leaves, stalk, roots, husks, and cob. So for a grain production system where all crop residues are left on the field, 40 to 50 pounds P_2O_5 and 40 to 50 pounds K_2O per acre are removed from the soil each year. In silage production, all P_2O_5 and K_2O taken up by the plant, except for that in the roots and stubble, are removed from the soil.

It is particularly important that adequate P_2O_5 and K_2O be available for plant uptake during the first half of the season. By the time kernels start filling rapidly (70 to 75 days after seedling emergence and 10 to 15 days after silking), the plant will have taken up about 70 percent of its P_2O_5 requirements and nearly 90 percent of its K_2O requirements.

Availability from Soil: Both P and K are considered immobile elements in the soil since they react with the soil in ways that minimize their movement with soil water. This is particularly true for P since, once in the soil, it forms compounds with calcium, iron, aluminum, manganese, and zinc, which are less soluble than the P compounds in the fertilizer. If soil pH is in the range of 6.0 to 6.5, much of the fertilizer P will react to form calcium phosphates, which are more soluble than the iron, aluminum, and manganese phosphates that form at lower pH levels. Therefore, greater P availability is one benefit of good liming practices. Potassium is retained on clays and organic matter by cation exchange. Except for very sandy soils, soil cation exchange capacity is great enough to hold an adequate reservoir of readily available K^+. For these reasons, leaching of P and K from Kentucky soils is of little importance. By comparison, loss of P and K by erosion of topsoil is of much greater concern.

Corn grown on fields being rotated from a tilled sod may respond less to P fertilization than expected from the soil test results. This is because P will be released as organic residues from the sod as it decomposes.

Requirements: The amount of P and K fertilizer required for good corn growth is directly related to the amount of plant-available P and K already in the soil. Using a reliable soil testing laboratory that makes fertilizer recommendations based on field-tested procedures is the best way to determine levels of plant-available soil P and K. The annual amount of P and K taken up by the plant from fertilizer is not likely to exceed 15 to 20 percent of the P or 25 to 40 percent of the K applied.

Sources: Commercial fertilizer is the most widely used source of P and K for corn production. The sources of P most commonly used are triple superphosphate (0-46-0), diammonium phosphate (18-46-0), monoammonium phosphate (11-48-0), and a wide array of other ammoniated phosphates, both liquid and dry. Most commonly used sources of fertilizer P are considered equally effective for agronomic purposes when used at recommended rates and properly applied. Solid and liquid forms of P are also considered equally effective.

Almost all K fertilizer used for corn is muriate of potash (0-0-60). Other available sources are sulfate of potash (0-0-50) and sulfate of potash magnesia (0-0-18, 11 S, 18 Mg). All are considered equally effective.

Organic sources of P and K such as animal manures and sewage sludge may also be used. Since their nutrient content varies, analysis is necessary to determine appropriate rates. It is important to know the content of heavy metals (nickel, cadmium, and chromium) in municipal and industrial sludges in order to prevent toxic build-up.

Placement: Broadcasting P and K is the most convenient method of application, although at low to very low soil test levels, large amounts are required. Banded applications (2 inches to the side and 2 inches below the seed) can increase agronomic efficiency of P and K, making it possible to decrease the usual rate by one-third to one-half. A “starter” effect (improved initial growth) is likely to result from band placement. This may appear very significant during the early growing season, but in Kentucky it rarely increases yield, provided that broadcast P and K fertilizers are used at recommended rates.

Rates: Rates of phosphate and potash recommended by the University of Kentucky can be found in the AGR-1 publication.

Secondary Nutrients and Micronutrients

Magnesium

Magnesium levels in soils range from high (chiefly the loess-derived soils) to low (primarily some sandstone-derived soils). Soil test levels and recommended Mg rates can be found in AGR-1. Deficiency of Mg is rare in Kentucky and is most likely to be found on sandy soils.

Calcium and Sulfur

Calcium deficiency of corn has never been documented in Kentucky. Despite concerns about reduced atmospheric sulfur fallout, no verified sulfur deficiency on corn has been recorded. University of Kentucky tests of sulfur application to corn during the 1990s and before did not show a yield response to its use. If deficiency occurs, it is most likely to be found on sandy soils.

Zinc

Zinc deficiencies in corn are common in Kentucky in limestone soils, particularly when soil pH is above 6.5. The deficiency symptom most commonly noticed are broad whitish streaks down the leaves of young corn seedlings (see Figure 3). If corn plants are carefully removed from the soil and the stalk is carefully split all the way to the bottom tip of the plant, the presence of a purplish discoloration at the lower nodes is another distinctive indicator of zinc deficiency. If the deficiency is severe, seedlings may die. In mild cases, internode growth is limited, stunting plant height. Leaves may also show purplish edges, and ears may cup to one side and not fill completely. Where zinc deficiency of corn is suspected or has occurred previously, a zinc soil test is helpful in determining if zinc should be applied. A table found in AGR-1 lists soil test zinc levels at various soil pH ranges and soil test P levels below which a response to zinc fertilization is likely to occur. However, many other factors, including weather conditions, affect availability of soil zinc to corn, making it difficult to predict a response to added zinc for a specific growing season. Zinc fertilizer recommendations can be found in AGR-1.

Boron

Boron deficiencies in corn have been documented in Kentucky, but they are not common. Plant tissue analysis is the best way to test for this deficiency. If the ear leaf sample contains less than 5 parts per million (ppm) and the soil test value is less than one ppm, an application of 2 pounds of boron per acre might be beneficial.

Figure 3. Corn leaf with zinc deficiency (left) and a normal leaf.

Other Nutrients

Deficiencies of other nutrients such as manganese, iron, copper, molybdenum, chlorine, and cobalt are extremely unlikely for corn in Kentucky. If a problem is suspected, tissue analysis is recommended.

Row Fertilizers

The use of row fertilizer and its potential benefits vary with conditions. The efficiency of fertilizer is greatly increased by banding fertilizer and is helpful on soils with a low soil test. In such cases, the rate of P and K can be reduced by one-third to one-half. For soils testing medium or high, a sufficient amount of P and K nutrients exists in the soil such that additional fertilizer applied near the row is not likely to increase yields. Regardless of soil test, banded fertilizer will usually increase the vigor and early growth of corn.

Yield increases may sometimes be achieved with starter fertilizer containing N and P, when placed beside or in the row, but they are not always economical. The consistency and amount of the yield increase response depends on soil type, tillage, planting date, and weather. Conditions that place the corn under prolonged stress early in the growing season increase the chances of a positive response and the amount of the response. The response is more consistent and larger for early planting of no-till corn on soils that are not well drained. Although not as consistent, responses to starter fertilizers are also found on early planted no-till corn on well-drained soils. Responses will be much smaller in warmer years and with later plantings. The average yield increase expected from row fertilizer is shown in Table 2.

Expected Yield Response to Row Fertilizer

Most of the response to starter fertilizer in Kentucky soils is response to N. The rest of the response can be achieved by adding P. Potassium has very little effect on the early growth. If the fertilizer is placed in the seed furrow, only 10 to 15 pounds per acre each of N and P_2O_5 are needed. Increasing the rate higher than this will not improve the starter effect and may adversely affect seed germination. If the fertilizer is banded beside the row (2" x 2"), research indicates that 20 pounds per acre each of N and P_2O_5 are needed to achieve an optimal effect.

To prevent germination and emergence problems, the amount of N plus K_2O should be limited to no more than 15 pounds per acre (as shown from recent research) in the furrow and no more than 100 pounds per acre in a 2" x 2" placement beside the row. An N source that contains only urea adds additional risk due to high levels of ammonia generated in the placement area.

Plant Analysis

Plant analysis is the laboratory determination of nutrient elements on a sample of plant tissue. In recent years, this technique has been more frequently used to diagnose nutritional problems related to soil fertility or to monitor effectiveness of fertilizer practices on growing crops.

A plant analysis program is not a substitute for soil testing but is most effective when used in conjunction with a regular soil testing program.

Table 2. Expected yield response to row fertilizer.

Tillage	Soil drainage	Consistency of response	Average yield* increase (bu/ac)
Tilled	All types	Occasional	0-1
No-tilled	Well-drained	Sometimes	1-6
No-tilled	Not well-drained	Most of the time	5-7

* The average yield response includes all yield responses, both positive and negative. There will be times when the yield increase is greater due to cooler and wetter years than normal, and in some unusual situations there can even be a negative response.

The most common elements analyzed for plant analysis are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), boron (B), copper (Cu), zinc (Zn), and aluminum (Al). Others that may be measured either routinely or upon request include sulfur (S), sodium (Na), molybdenum (Mo), cobalt (Co), silicon (Si), cadmium (Cd), nickel (Ni), lead (Pb), chromium (Cr), arsenic (As), and selenium (Se). Although some of these are not essential for plant growth, the results may be used for interpretation and recommendations, or for identifying toxic levels of some elements. Considerable care must be given to collecting, preparing, and sending plant tissue to the laboratory for analysis.

Sampling

Randomly sample plants throughout a uniform field or sampling area. When a nutrient deficiency is suspected or abnormal growth is present, collect one sample from the affected area and a sample from an adjacent normal area. Collect the plant tissue in a new, clean brown paper bag. Dusty or soil-covered leaves and plants should be avoided. If leaves have a slight dust cover, brush gently with a soft brush or perform a "quick rinse" with distilled water. Do not prolong the quick rinse or use a soap solution as nutrient elements will be leached out of the tissue. Do not include damaged, diseased, or dead tissue in your sample.

Good results require sampling a definite plant part. For corn less than 12 inches tall, cut 20 plants at 1 inch above the soil surface. For corn taller than 12 inches but which has not tasseled, pull the entire first mature leaf (completely unrolled) below the whorl from 20 plants. Fully developed plants should be sampled when 50 percent of the ears show silks. Sample the whole ear leaf (the leaf just below the ear) from 20 plants. Do not take samples after the silks have turned brown.

For diagnostic purposes, a good representative soil sample should also be collected. When problem areas exist in the field, take one sample from the affected area and one sample from an adjacent normal area. Take cores or subsamples adjacent to plants that are selected for tissue sampling.

Sufficiency Level of Nutrients

Table 3 summarizes nutrient levels that would be considered sufficient. Levels below those shown might be insufficient for optimal yields.

Nutrient Content and Removal by Corn

Estimated nutrient content of healthy, mature corn and the amounts of nutrients taken up are shown in Table 4. Data were provided by the University of Kentucky.

Table 3. Nutrient sufficiency levels for corn.[1]

	Type of sample		
Nutrient	Whole plants less than 12 inches tall	Leaf below whorl, plants more than 12 inches tall	Ear leaf at tasseling before silks turn brown
N	3.5-5.0%	3.00-3.50%	2.75-3.00%
P	0.3-0.5%	0.25-0.45%	0.25-0.45%
K	2.5-4.0%	2.00-2.50%	1.75-2.25%
Ca	0.3-0.7%	0.25-0.50%	0.25-0.50%
Mg	0.15-0.45%	0.13-0.30%	0.13-0.30%
S	0.15-0.50%	0.15-0.50%	0.15-0.50%
Mn	20-300 ppm	15-300 ppm	15-300 ppm
Fe	50-250 ppm	30-200 ppm	30-200 ppm
B	5-25 ppm	4-25 ppm	4-25 ppm
Cu	5-20 ppm	3-15 ppm	3-15 ppm
Zn	20-60 ppm	15-60 ppm	15-60 ppm
Mo	0.10-10.0 ppm	0.1-3.0 ppm	0.1-3.0 ppm

[1] From *Plant Analysis Handbook for Georgia*. Bulletin 735. Univ. of Georgia Cooperative Extension Service, 1979.

Table 4. Nutrient content of and removal by corn plant parts.

	Content (% by dry weight)				
Plant part	N	P[1]	K[2]	Ca	Mg
Grain	1.30	0.28	0.50	0.12	0.16
Stover	0.70	0.15	1.20	0.37	0.16

		Removal (lb/unit)		
Plant part	Unit	N	P_2O_5	K_2O
Corn Grain	Bu.	0.7	0.4	0.35
Corn Silage	Ton	7.5	3.6	8.0
Corn Stover	Ton	15	7	30

[1] $P \times 2.29 = P_2O_5$
[2] $K \times 1.2 = K_2O$