A Comprehensive Guide to
CORN MANAGEMENT
IN KENTUCKY

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Introduction

Morris Bitzer and James Herbek

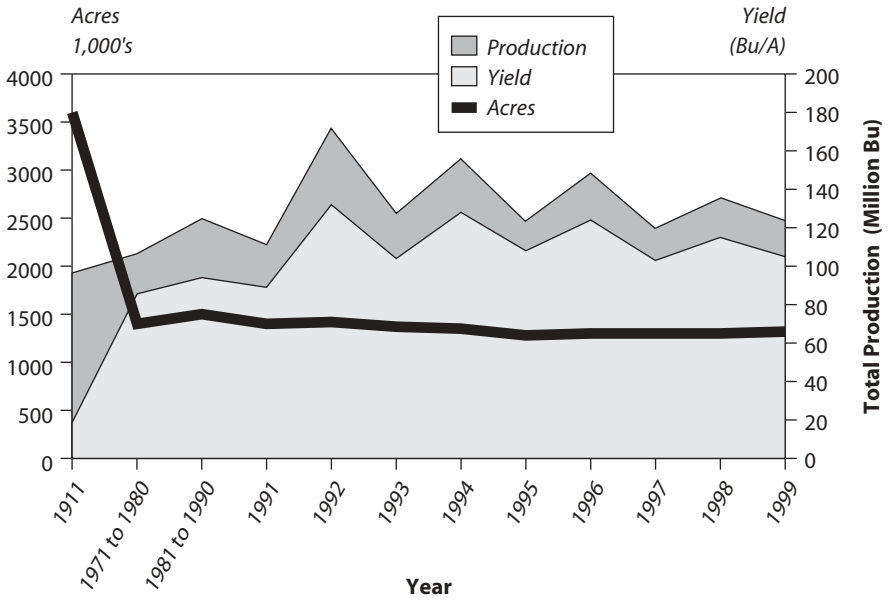
The corn (*Zea mays* L.) grown in Kentucky is used mainly for livestock feed (60 percent) and as a cash crop. As a cash crop sold from the farm, corn ranks third behind tobacco and soybeans but is the number one row crop in terms of acreage. However, in total crop value, as reported by the Kentucky Agricultural Statistics Service, corn ranks third after tobacco and hay. Corn is grown in every county in Kentucky, with a major portion of the acreage in Western Kentucky. Corn acreage in Kentucky dropped from a high of 3.6 million acres in 1911 to a low of 1.13 million acres in 1972. Acreage increased slightly in the 1980s to an average of 1.5 million acres but then declined to an average of 1.34 million acres in the 1990s (Figure 1).

Corn yields have risen dramatically over the last few decades. The average state yield in the 1970s was 85.5 bushels per acre; in the 1980s, 94.1 bushels per acre; and in the 1990s, 112.0 bushels per acre. Since 1990, the highest state average ever was 132 bushels per acre in 1992, and the lowest average during this period was 100 bushels per acre in 1991.

Because the cost of producing an acre of corn is high and the value per bushel has declined in recent years, producers must manage and market their corn crop more carefully for adequate profits. The goal of this publication is to serve as a guide for corn production strategies that focus on efficient use of resources and provide the principles and practices for obtaining maximum, profitable corn yields.

With the introduction of biotechnology in the marketplace, producers now have to make a new decision when selecting corn hybrids. Biotech-derived crops have been altered and improved to include resistance or tolerance to pesticides and improved food and feed qualities. A more thorough discussion of the impact of biotechnology on corn production is presented later in this publication.

Figure 1. Acreage, yield, and production in Kentucky.



Types of Corn

Corn may be classified by kernel characteristics such as dent, flint, flour, sweet, pop, and pod corn. Except for pod corn, these types are based on the endosperm composition of the kernel. The quantity or volume of endosperm determines the size of the kernel (e.g., the difference between dent and flint corns or flint corn and popcorn) is polygenic (controlled by many genes). The pod corn trait is monogenic and more of an ornamental type.

This publication deals mostly with the dent corns that originated from the hybridization of the southern dent or late-flowering maize race called Gourdseed and the early-flowering northern flints. Dent corn is characterized by the presence of corneous, horny endosperm at the sides and back of the kernels. The central core is a soft, floury endosperm extending to the crown of the endosperm where, upon drying, it collapses to produce a distinct indentation.

Dent corn is used primarily as animal food but also serves as a raw material for industry and as a staple food. There are two types of dent corn, yellow and white. Except for some sweet corn and popcorn, dent corn is the main commercial type of corn grown in Kentucky. The majority of dent corn in Kentucky has yellow kernels; however, Kentucky is one of the leading states in the production of white corn, which is grown mainly for the food industry and is about 10 percent of the total corn acreage. In 1995, Kentucky

had 116,000 acres of white corn, and this acreage remains fairly constant from year to year. Very little flint or flour corn is grown in the United States. Pod corn is mainly a curiosity and is not grown commercially.

Special-Purpose Corn

Some corn hybrids have been altered genetically to produce changes in starch, protein, oil, or other properties of the kernels. Some of these special-purpose corns grown in Kentucky are waxy, high-amylose, high-lysine, high-oil, and low-phytate varieties. A very limited acreage of waxy and high-amylose corn is being grown, and only a few swine producers are raising high-lysine corn, but several thousand acres of high-oil corn are contracted each year in Kentucky.

Waxy corn is used as the raw material for the production of waxy cornstarch by wet-corn millers for industry and food uses. Waxy cornstarch contains more than 99 percent amylopectin, whereas regular corn contains 72 to 76 percent amylopectin and 24 to 28 percent amylose. High-amylose corn has an amylose content greater than 50 percent. It is grown exclusively for wet milling for the textile industry, gum candies, biodegradable packaging materials, and as an adhesive in the manufacture of corrugated cardboard. High-lysine corn contains the single recessive gene, opaque-2, that reduces the zein in the endosperm and increases the concentration of lysine, thus improving the nutritional quality of the grain. Its primary use in the United States is feed for nonruminants.

The most recent improvement in special-purpose corn has been the development of hybrids with higher concentrations of oil. The high-oil seeds are produced by a topcross procedure in which the planted seed is a mixture of 9 percent of a very high-oil inbred pollinator seed and 91 percent seed of a male-sterile, high-yielding, single-cross hybrid. The seed produced contains upwards of 8 percent oil compared to a normal hybrid, which contains only 3.5 to 4 percent oil. The added oil makes a high energy feed. Most high-oil corn is contracted and sold at a premium price. The average yield of these high-oil hybrids has usually been about 10 percent lower than normal hybrids. It is usually recommended to plant these at a 10 percent higher seeding rate in an effort to offset some of this yield loss.

Another recent development has been the testing and release of low-phytate corn hybrids. Phosphorus in regular corn is stored as phytate, but phosphorus in kernels of low-phytate corn is digested more efficiently. This results in lowering the need for supplemental phosphorus, better use of the phosphorus by the animal, and less phosphorus excreted into the environment. Initial tests of low-phytate corn hybrids have been encouraging, but economic viability remains to be determined.

Special-purpose corns are usually grown under contract at a price premium. It is important to understand the contract requirements before the special-purpose corn is grown. There may also be certain recommended production management practices, e.g., soil type, fertility, population, planting date and harvest, drying, and handling practices to obtain the highest possible yields while maintaining grain quality. It is important that grain identity of special-purpose corns be preserved from planting through storage to avoid contamination that would eliminate premium prices and decrease marketability. Special-purpose corns also require isolation from other corn to eliminate cross-pollination.

Most, but not all, special-purpose corns have an inherently lower yield compared to normal dent-corn hybrids. However, special-purpose corns can compensate for this reduction in yield potential with adequate premiums. Before producers decide to grow a specialty corn, it is imperative that they determine potential yield reductions, production risks, contract requirements, and the premium amount needed to ensure a profitable return. Because of improved hybrid development, the yield of some specialty corns has improved as compared to normal hybrids.

White and Yellow Food Grade Corn

Kentucky is one of the leading states in the production of white and yellow corn for food. Food grade corn is used to make corn flakes, tortilla flour, and cornmeal. The hybrids for this market are usually selected by the company offering the production contract. The regional testing of the yellow food corn hybrids has been discontinued; however, the white food corn hybrids are still being tested, and results are available from the University of Kentucky corn testing program.

Corn Growth and Development

Morris Bitzer and James Herbek

A cornfield is a complex and constantly changing community made up of many individual corn plants. Within the corn plant, the raw materials (water and minerals from the soil and carbon dioxide and oxygen from the air)—with sunlight providing the energy—combine to produce yield. The growth and yield of a corn plant are functions of the plant's genetic potential to interact with its environmental conditions. Although climatic conditions account for a major portion of the environmental influence on corn growth and development, a corn producer can manipulate the environment with various management practices. By understanding how a corn plant develops, a producer can use the proper production practices to obtain higher yields and profit. Following is a brief discussion of the growth and development of the corn plant.

The corn seed contains adequate stored nutrient reserves to get the seedling established. Seedling emergence usually occurs six to 10 days after planting (four to five days under warm, moist soil conditions). If the seed is placed in a cool, dry soil, it may take two weeks or longer for seedling emergence. The depth of planting also will influence how long it takes for the seedling to emerge. The depth at which the permanent root system (nodal roots) develops is not affected by planting depth and occurs approximately 1 inch below the soil surface. Three or four fully developed leaves are produced during the first three weeks after the plant emerges. A leaf is fully developed when the collar of that leaf is visible. Initiation of all the leaves, ear shoots, and tassel has occurred at the growing point by this stage, and the growing point of the plant is still approximately 1 inch below the soil surface. Damage to the seedling above the ground from frost, hail, or livestock would have little or no effect on the growing point or final yield.

After the tassel and all the leaves and ear shoots are initiated, the stalk begins a period of rapid growth. When six or seven leaves have fully emerged, the growing point has moved above the soil surface and any damage to the leaves and growing point could affect final yield. Plant height increases dramatically during this rapid growth phase, and the plant reaches its maximum height when the tassel is fully emerged from the whorl. Although the ear shoots were formed just before tassel formation (five leaves emerged), the length of the ear and potential number of ovules or kernels per row is determined between the development of 10 or 11 emerged leaves to 17 or 18 emerged leaves or about one week before silking. Moisture or nutrient stresses during this period of ear size determination may seriously reduce the number of potential seeds on an ear. Earlier maturing hybrids will advance through these stages in a shorter time, which usually results in smaller ears than later maturing hybrids. The nodal root system is developing rapidly during this stage, which allows for more rapid uptake of soil nutrients and water to meet the demands of this rapid growth rate. At tasseling, less than half of the final weight of the corn plant has been produced; however, more than 60 percent of the nitrogen, 50 percent of the phosphorus, and 80 percent of the potassium uptake have already occurred.

As vegetative growth nears completion, the ear develops very rapidly. The flowering stage, which includes pollination, is the most critical period in the development of the corn plant. The flowering stage occurs about 65 days after corn emergence in a medium maturity hybrid. Pollen shedding begins two to three days after the tassel has fully emerged from the last leaf sheath and just prior to silk emergence. Under favorable conditions, all silks will emerge within three to five days after tasseling, and the tassel will continue to shed pollen for five to eight days. The silks from near the base of the ear emerge first, and emergence progresses up the ear to the tip. When a pollen grain falls on a corn silk, it germinates and produces a pollen tube that grows the length of the silk in about 24 hours, after which fertilization occurs and a new kernel begins to develop. The silk is released by the kernel immediately upon pollination. Stress (moisture, temperature, nutrient) from one week before to one week after flowering may delay silking until after most of the pollen is shed, resulting in poor pollination, especially on the tips of the ears.

Grain production occurs between pollination and maturity. Drought or nutrient stress during this period can result in unfilled kernels, less weight per kernel, and light, chaffy ears. The grain filling period covers about 55 days for most corn hybrids. Plant physiological maturity is achieved when the kernel has reached its maximum dry weight. A black layer forms at the tip of each kernel at physiological maturity. The average moisture of the kernel at this stage is 30 to 35 percent. Grain drying is a matter of physical moisture loss and varies with climatic conditions but should average at least 0.5 percentage point per day.

Having a knowledge of the growth and development of the corn plant provides the producer with a better understanding of how different problems and stresses affect final yield. By understanding the effects that management practices have during the various stages of corn development, the producer can manage the corn plant more intelligently so that it can nearly reach its yield potential.

Tillage Systems

Lloyd Murdock and Ken Wells

Traditionally, tillage has been practiced for the purpose of mixing surface residues deeper into the soil, loosening the soil prior to seedbed establishment and to aid in weed control. The primary tillage implement for many years was the moldboard plow. The rough surface left by primary tillage was smoothed by secondary tillage implements, usually a disk harrow followed by one or more passes of another fine-toothed harrow for final smoothing of the surface in preparation for seeding. These techniques have been described as "conventional tillage." Another traditional application of secondary tillage has been the use of a myriad of cultivating tools to provide mechanical weed control and to break up surface crusts. However, the advent of widespread use of chemical weed control during the late 1950s greatly reduced the amount of secondary tillage used for weed control. The major disadvantages of these conventional tillage techniques were increased risk of soil erosion on sloping land and breakdown of soil structure.

Largely due to massive nationwide loss of topsoil from conventional tillage, additional primary tillage techniques were developed to leave varying amounts of the residues from the previous crop lying on the soil surface for the purpose of lowering the erosion potential. Several implements, mostly a variation of the chisel plow, were developed to accomplish this. When followed by a shallow harrowing, these conservation tillage techniques provided a seedbed smooth enough for successful planting of corn but still left some residue cover.

Further developments in chemical weed control and planting equipment that could successfully plant through surface residues resulted in development of no-tillage seeding techniques. The only tillage involved in no-tillage seeding is the narrow, in-row disturbance made by the coulter and furrow-opener on the planter. No-tillage results in most prior crop residues remaining on the surface, which causes a dramatic reduction in soil erosion and increased water infiltration. No-till techniques, pioneered by farmers and researchers in Kentucky, are now so widely used in Kentucky that they dominate seeding methods for corn and soybeans (Figure 1). When combined with other conservation tillage practices, greater use of no-till has resulted in only a small percentage of Kentucky's corn and soybean crop being established by conventional techniques (Table 1).

No-tillage has a number of advantages, including less soil erosion as compared with clean-tilled systems, and fuel, machinery, and time savings are all impressive. There is also a tendency toward better crop yields on soils that are moderately well drained to well drained, due to higher water capture and conservation often associated with the mulch of crop residue maintained on the soil surface.

No-tillage is best suited to soils that are moderately well drained to well drained. The residue cover keeps soils cooler and wetter throughout much of the growing season under no-till conditions. This is particularly true with heavy residue. Surface residues that leave somewhat poorly drained soils wetter can be an advantage during dry periods, but no-till planting on such soils during cool, wet springs can cause delayed emergence and reduced stands that reduce yields.

Management practices that can improve the performance of no-till corn in cool, wet conditions are the use of in-row (pop-up) fertilizer (see fertility section) and row cleaners. The row cleaners aid in warming and drying the soil over the row, and the in-row fertilizer improves plant growth under stress early in the season. Seed treatments that protect against root shoot rots (*Pythium ultimum*) are quite helpful and are often routinely added by seed companies.

Conservation tillage is a better choice for poorly drained soils. The tilled surface allows these soils to

Figure 1. Percent of Kentucky's corn, soybean, and wheat acreage established with no-till technology.

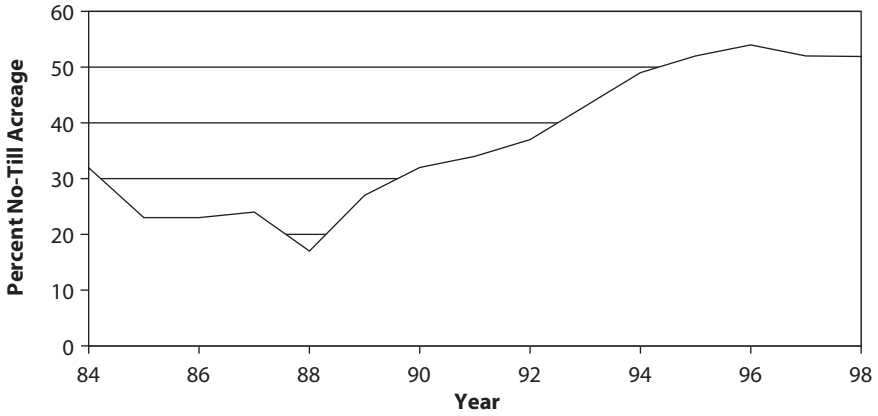


Table 1. Tillage systems used for corn, soybean, and fall-seeded small grain in Kentucky, 1998.[1]

Crop	Total Acres	% Planted		
		No-Till	Conservation Till[2]	Conventional Till[3]
Full Season Corn	1,345,000	51.8	34.5	13.7
Double Crop Corn	62,100	64.4	29.3	6.3
Full Season Soybeans	882,700	51.3	30.8	17.9
Double Crop Soybeans	474,700	86.7	12.4	0.9
Fall-Seeded Small Grains	603,000	24.6	62.0	13.4
All Crops	3,852,500	47.6	33.5	18.9

[1] Conservation Technology Information Center data.
[2] Greater than 15 percent of residues left on surface.
[3] Fewer than 15 percent of residues left on surface.

warm and dry faster in the spring. However, conservation tillage practices used on sloping fields that are prone to erosion should leave at least 30 percent of the soil surface covered by residue at planting to protect the field from excessive erosion. This can be done by reducing the amount of secondary tillage that is done on the field. Secondary tillage is costly, time consuming, and frequently a major culprit in causing soil compaction. It also contributes to erosion, water pollution, and subsequent crop drought stress. Protection against loss of topsoil is of much economic importance. Recent research by the University of Kentucky indicates that each inch of topsoil on a Crider soil, up to the first 8 inches, increases annual corn yield by more than 10 bushels per acre.

Soil Compaction

Soil compaction comes in a number of forms and from several causes, but in Kentucky the most common causes are either traffic or tillage when the soil is too wet. There is a water content at which any soil is most easily compacted. In the words of one expert, "This is when it is a little too wet to work, but I am going to do it anyway."

Sidewall Compaction

Sidewall compaction can result from planting a crop when the soil is a little too wet. This damaging effect can be even greater on soils with a relatively high clay content at the surface. It occurs when the double disc opener leaves the side wall of the planting furrow smooth and compacted (slick as opposed to shattered) as it pushes the soil aside. The trailing press wheel then increases the compaction with its downward force. If the soil stays very moist or wet, the roots may be able to penetrate the compacted mud at the sidewall and expand further into the soil. However, if the weather turns dry after planting, the sidewalls then harden, and roots are not able to push through since there are no pores or cracks. This causes the roots to grow within the planting furrow, along the direction of the row. Although plants may look normal at emergence, they will begin to show nutrient and drought stress after the corn is several inches high. This problem may be more common in no-tillage because no-tillage soils have better structure, and it is easier to traffic them in a wetter condition. The old adage of "waiting on no-till" is a good one. Sidewall compaction can also occur with conventional tillage. If you can mold the soil into a ball in your hand and the soil ball will not easily crumble apart, it is too wet to plant.

Deeper Compaction

Wheel tracks on a wet field can also contribute to a compaction problem. The trend to larger and heavier equipment means that axle weights have increased. A four-wheel drive tractor, a large combine with a full grain hopper, a loaded manure wagon, a fertilizer buggy or truck, or a loaded grain cart can all exert great pressure on the soil below the wheel. These weights, in combination with greater tire pressures, can compact the soil 12 to 18 inches deep. When the degree of compaction is sufficient to diminish pore space to the point that oxygen diffusion, water movement, and root penetration into and through the soil are restricted, crop yields are likely to be lowered.

Disc harrows are tillage tools that can cause severe compaction on wet soils. The weight of a disc transmitted to the soil at the bottom edge of each blade creates enough pressure in a wet soil to compact a zone 4 to 6 inches thick just below the disc blades. This is most common in disc-only tillage systems or where soils are excessively tilled and a disc is used when the soil is a little too wet.

How Common is Compaction in Fields?

A survey of 175 fields in Kentucky in 1992 and 1993 indicated that 46 percent had no compaction, 18 percent were slightly compacted, 18 percent were moderately compacted, and 18 percent were severely compacted. This survey used soil penetrometers to classify the amount of compaction. Limited research indicates that the moderate and severe categories should be considered possible yield-limiting situations. This means that about 30 to 40 percent of Kentucky's cropped fields are compacted enough to possibly limit the growth and yield of some

crops. The more poorly drained fields had the most compaction, with 77 percent of the poorly drained soils being moderately or severely compacted, while only 20 percent of the well-drained soils were in this range. When the primary tillage was discing, fields were twice as likely to have moderate or severe compaction as those where a chisel or moldboard plow was used. The least likely fields to have compaction were no-till fields.

When compaction was found, it was most likely to begin at depths between 6 and 9 inches and to terminate between 12 and 15 inches. However, compaction was found at other depths and depth thicknesses.

Effect of Compaction on Yield

The effect of compaction on yield varies with the crop, weather conditions, and soil type. Corn is more sensitive to soil compaction than soybean or wheat. Based on research in Kentucky and surrounding states, the estimated yield reduction for corn is 30 to 50 percent with extreme compaction such as that found under end rows and at field entrances, 10 to 20 percent for fields with severe compaction, and 5 to 10 percent for those with moderate compaction.

What to Do about Compaction

The best way to solve compaction is to prevent it. Some simple things can make a difference.

- Tire pressure is important. Lower tire pressure increases the size of the tire print and lowers compaction. Many farmers carry 20 to 25 psi in radial tires that are designed for 7 to 12 psi. The proper tire pressure will not only reduce compaction but will decrease slippage by 10 percent.
- Restrict heavy equipment (loaded grain carts, trucks, etc.) to the smallest areas of the field as is possible. Use the same tracks with each pass in the field, if possible.
- No-till means less compaction. There are fewer trips over the field, and the soil has better structure. This may not be evident until the field has been no-tilled for three to five years. By planting in the same rows each year, a controlled traffic pattern will result, restricting the wheel traffic to between certain rows.
- The most important management practice is to prevent traffic on wet soils. Take soil from the tillage zone and squeeze it in your hand. If the soil ball cannot be easily crumbled apart, then the soil is too wet for traffic.

How to Identify Compaction

Sometimes soils are deep-tilled when there is no compaction. This is costly and does not improve yields. The best way to identify compaction in a field is by using a soil penetrometer (soil compaction tester), a tiling rod, or a 3-ft length of 1/2- to 3/4-inch diameter steel rod sharpened on one end with a T-handle on the other end. These tools should be marked (notched) for depth and should only be used when the soil is at field capacity after a rain (too wet to till, but not sloppy muddy). This is best done in December through March when the profile is wet throughout. Under these conditions, compacted layers can be found and the depth and thickness of the compacted zone can be identified. Each Cooperative Extension Service office in Kentucky has a soil penetrometer with instructions on how to use it and a form to record the results. The form also has a method to classify the amount and type of tillage found in the field. When readings reach 300 pounds per square inch, the compaction is considered root limiting. If one-third of the field has readings of 300 or more, a corrective action and change in tillage practices should be considered. When one-half of the field has readings of 300 or more, corrective action and changes in tillage practices definitely are needed.

After moderate to severe compaction (lesser amounts of compaction are not harmful) has been identified, there is more than one way to correct it. When tillage or subsoiling is used, be sure the compacted zone is dry enough to shatter. Fall is generally the best time because the subsoil is usually drier and will shatter better. This means that fields with identified problems will be cropped for another summer prior to compaction alleviation. Rotations to some other crops can also help alleviate compaction. Alfalfa, sweet clover, and fescue all have root systems that are helpful but are rather long-term solutions.

Summary

Compaction can be caused by traffic and some tillage operations and can cause yield reductions in some crops. The yield reduction may not be easily seen unless the compaction is extreme. A lot of money is wasted on deep tillage done in response to fear of compaction that does not exist. The key is using a total management system that prevents compaction but also monitors fields for the problem and then corrects it when and where it is found.

Hybrid Selection

Morris Bitzer and James Herbek

One of the most important decisions that a producer must make when planning for the next corn planting season is what hybrid or hybrids to plant. Currently, most commercial corn producers plant single-cross hybrids, and most of these hybrids are produced and marketed by private seed companies. The corn producer's challenge is to select those hybrids that are appropriate for each management situation, keeping in mind the risks associated with potential weather extremes and field limitations. Managing to get the highest possible yield starts with selecting those corn hybrids that are best adapted to your farm and farming practices. Among the agronomic characteristics to consider in choosing hybrids are yield, maturity, standability, insect and disease tolerance, seedling vigor, and stress tolerance.

Yield

The bottom line for most producers, all other things being equal, is to use the highest yielding hybrids available. Under stress conditions, high yielding hybrids with superior stalk quality are most desirable. If a hybrid cannot stand under stress conditions, lodging can severely decrease yields. State yield trial reports provide the most complete and unbiased information on the relationship between yield and lodging. Most state trials are conducted at several locations under varying degrees of stress conditions and include most of the hybrids sold in the state. Each year, the University of Kentucky College of Agriculture conducts the Kentucky Hybrid Corn Performance Tests. This information is made available both on a Web site and as a progress report available from your county Cooperative Extension Service office.

The process of hybrid selection should consider the stability of performance across years and locations. Selection of more than one hybrid will reduce risk from weather and disease. Each year several new hybrids are included in the test. Selecting new hybrids that are within one least standard deviation (LSD) of the best hybrids in the test will provide more chance of stability of performance. In addition to yield, data are presented on moisture at harvest, percent stand, lodging, and test weight. Separate tables are presented on the protein, oil, and starch composition of the corn hybrids.

Other good sources of information about hybrid performance are from well-managed local corn demonstration plots sponsored by county Extension groups, FFA chapters, and seed corn companies. To be meaningful, these plots should have at least three replications of each hybrid or a check hybrid between plots of every two or three hybrids with yield adjustments made for location in the field. Many corn companies today combine data from several locations, which does improve the reliability of the data. Strip test or plots with each hybrid entered only once are of little value for yield comparisons, as field variation is usually greater than most differences among the hybrids.

Maturity

Choosing the appropriate maturity or maturities for each field, situation, or farm operation is important when selecting hybrids. The Kentucky Hybrid Corn Performance Test is a good source of information on relative maturity of hybrids. The hybrids are divided by maturity: early, medium, and late. Once you have selected the desired maturity, you can choose among the hybrids within a maturity group based on their performance characteristics.

Deciding which maturity or maturities to plant depends on a number of factors that may be unique to each field or farm operation. In general, full-season hybrids (hybrids that use most of the growing period in that area) produce the highest yields. However, recent hybrid development has resulted in early and medium maturity hybrids having about the same yield potential as the full-season hybrids. Currently, the majority of the corn grown in Kentucky is of medium maturity. Early and medium maturity hybrids will have an earlier harvest and a lower moisture content than later maturing hybrids. Early maturity hybrids are useful for late plantings (after early June) because of the shorter growing season. Yield potential of early maturity hybrids is comparable to later maturity hybrids when planted at later planting dates with a lower moisture content at harvest. Early and medium maturity hybrids are also a good choice for stress situations, particularly soils with low water-holding capacity since they require less moisture to mature.

Producers should plant several hybrids differing in maturity, particularly if a large acreage of corn is planted. Hybrids that differ in maturity reduce the risk of adverse weather (heat or drought) and stress at pollination. It also spreads the harvest period so corn can be harvested at optimal grain moisture levels. The optimal proportion of different maturities differs for each farm operation and depends on acreage, soil types, and other management factors. A typical recommendation of different maturities might be 10 to 15 percent early hybrids, 60 to 70 percent medium hybrids, and 15 to 20 percent late hybrids.

Growing Degree Days (GDD)

Most producers consider corn maturity as the number of calendar days from planting to maturity. This system allows a farmer to compare the maturities between different hybrids but does not necessarily indicate how many days it will take for that hybrid to reach physiological maturity. The number of days that are required for a hybrid to reach maturity depends on location, date of planting, and the weather during the growing season. A hybrid that is labeled as a 115 day hybrid may take from 110 to 120 days to mature depending on the above factors. This system of measuring corn maturity does not take into account the complicated physiological processes that control growth and development of corn.

Each day that a corn plant grows from emergence to maturity does not contribute equally to the development of the plant. Development is faster during warmer days than it is during cooler days. Although factors other than temperature may enter into determining rate of growth, the corn industry adopted the Growing Degree Days (GDD) system in 1970. This system uses a heat unit approach to the prediction of maturity that is more accurate than the old days-to-maturity ratings and is based on the number of heat units necessary for corn to reach physiological maturity.

Growing degree days are calculated by subtracting the base temperature (50°F) from the average of the maximum and minimum daily temperatures. Little or no corn plant growth occurs when the temperature drops below 50°F, and when the temperature rises above 86°F development is reduced. Consequently, a GDD is calculated according to the following equation:

$$\text{GDD} = \frac{\left(\begin{matrix}\text{Max Temp.}\\(\leq 86^\circ\text{ F})\end{matrix}\right) + \left(\begin{matrix}\text{Min Temp.}\\(\geq 50^\circ\text{ F})\end{matrix}\right)}{2} - 50^\circ\text{ F}$$

The maximum temperature is the highest temperature for the day (adjusted downward to 86°F, if necessary), and the minimum temperature is the lowest for the day (adjusted upward to 50°F, if necessary). For example, if the high temperature for the day is 90°F and the minimum is 60°F, the GDD = (86 + 60)/2 - 50 = 23 for that day. The University of Kentucky Agricultural Weather Center (AWC) starts recording GDDs for corn on April 1. These graphs are available at the following URL: wwwagwx.ca.uky.edu/cgi-bin/cropdd_www.pl. By knowing the GDDs required for a particular hybrid to mature, one can determine from the AWC when a particular hybrid should mature from the date that it emerged. For example, if the corn emerged on April 15 and required 2,700 GDDs to mature, corn would reach physiological maturity about August 26. This assumes fairly normal weather. The same site can also tell you on August 26 how many GDDs has accumulated by that date. This information can be used to determine if a particular hybrid will mature before the average date of the first frost in the fall.

Corn Seed

Hybrid seed corn is available in different kernel sizes and shapes. Location on the ear influences the size and shape of the kernels. Large round seed comes from the base of the ear; small round seed, from the tip; and flat seed, from the center of the ear. The key to accurate planting is to select kernel size and shape to fit their planting equipment. For plateless-type planters that use vacuum or air pressure to hold seed to a plate or drum or finger pickup units, seed size and shape are not as important. These types of planting units can use different seed sizes and shapes.

Research has not found any relationship between kernel size or shape and emergence on yield. Thus, within a given hybrid, seed of any size or shape has the same genetic potential. Growers with plateless planters can take advantage of lower prices often associated with less popular seed sizes and shapes. Corn hybrids should be selected on the basis of their agronomic performance, not on their kernel size or shape, if the planting equipment is suitable.

The following equation can be used to determine the number of live plants that can be expected from corn seed at a given seeding rate:

$$\text{Expected stand} = \text{seeding rate} \times \frac{\text{\% pure seed}}{100} \times \frac{\text{\% germination}}{100}$$

It is fairly common to find that as many as 10 to 15 percent of the seeds planted do not produce a live plant under field conditions.

Impact of Biotechnology

Ric Bessin

Agricultural biotech crops on the market today have been given genetic traits from other organisms to provide protection from pests and tolerance to pesticides or to improve food and feed quality. To transform a plant, the gene that produces the trait of interest is identified and separated from the rest of the genetic material in a donor organism. Most organisms have thousands of genes, and a single gene represents only a tiny fraction of the total genetic makeup of an organism. A donor organism may be a bacterium, fungus, or even another plant species. In the case of Bt corn, the donor organism was a naturally occurring soil bacterium, *Bacillus thuringiensis*, and the gene of interest produces a protein that kills Lepidoptera larvae, in particular, European corn borer. The donor gene along with a genetic promoter (which turns the gene on in the corn plant) and a genetic marker (which allows plants breeders to quickly identify transformed plants) were inserted into corn embryos. These new genes are then incorporated into commercial corn hybrids using traditional backcrossing breeding methods.

Plants produced through biotechnology are closely regulated by the USDA APHIS, the EPA, and the FDA. Producers should not select a hybrid based solely on the fact that it is biotechnology derived. Selection of a biotechnologically derived hybrid for pest-resistant traits should depend on whether the resistant traits are needed. Likewise, selection of biotechnologically derived hybrids with improved food or feed quality should depend on market value and profit potential.

Producers wanting to use ag biotech hybrids should always check with their grain buyers prior to seed purchase to be certain that these hybrids are approved and will be accepted at the market. Some biotech crops have not been approved or accepted in certain markets. The recall of foods containing traces of StarLink corn taught us an important lesson that the utmost care must be taken to prevent commingling of grain intended for different markets. Because corn is pollinated with wind-blown pollen, field isolation of up to 660 feet may be needed to prevent cross-pollination between different hybrids to ensure product identity.

Planting Practices

Morris Bitzer and James Herbek

Planting Date

Planting corn early in Kentucky is not as important as it is in states farther north. Kentucky's growing season is long enough that corn may be planted from early April to mid-May in most years and still obtain high yields. Optimal planting dates usually range from April 1 to May 1 in Western Kentucky and April 15 to May 15 in Central and Eastern Kentucky. In some years, corn is planted in March, but often it must be replanted because of poor stands due to cold soil. The most critical factor in determining when to start planting corn is the soil temperature. Planting when soil temperatures are above 50°F at a 2-inch depth for three or four days appears to be an excellent guide. A soil temperature of 50°F at 7:00 a.m. or 55°F at 1:00 p.m. should assure that temperatures are suitable for germination and growth for at least several hours during the day. Because of residue cover, soils for no-tillage planting usually do not warm up as early as tilled soils. If using no-till, planting may have to be delayed by four to seven days.

Earlier planted corn has usually had fewer insect and disease problems. For maximum yields, corn should be planted before May 1 in extreme Western Kentucky, by May 10 in west-central Kentucky, and by May 15 in Eastern Kentucky. If corn planting is delayed past June 5, an earlier-maturing hybrid should be planted. Several years of research have shown that a 1 percent per day yield loss can be expected in corn planted after May 10-15.

Planting Depth

The speed of germination and uniformity of plant emergence depend not only on soil temperature but also on planting depth. Under good conditions of temperature and moisture, a 1 1/2- to 2-inch depth is ideal. Some research in the Midwest has shown that 2 inches is the best depth for highest yields. For early planting, especially when the soil is cooler, plant at a slightly shallower depth of 1 to 1 1/2 inches. If the soil is dry, which is sometimes the case when planting late, you may need to plant 2 1/2 to 3 inches deep to get the seed to moisture. Soil temperatures in the upper 2 inches are greatly influenced by air temperature and solar radiation and can fluctuate as much as 10°F during a single day.

Planting too deep or too shallow can adversely affect corn performance. Early in the season, soils are colder at deeper depths and may slow germination and subject the seed to disease or insect injury. A seed treatment for insects is recommended with early planting. Planting depths greater than 2 inches may result in seedlings with less vigor, slower growth and development and lower yield. Planting corn seeds too deep can result in the coleoptile growth ceasing below the soil surface leaving the tender shoot to grow unprotected toward the soil surface. An unprotected shoot would be damaged and leaves unfurled before it emerges. Planting depths over 3 inches should not be considered under any soil conditions because of emergence problems. Conversely, planting too shallow can lead to poor nodal root development, shallow rooting depth, and poor drought tolerance. Do not plant less than 1 inch deep under any circumstances because poor nodal root development (permanent root system) may occur, which can result in plants falling over, known as suicidal corn.

Depth is particularly critical in no-tillage planting. For germination to occur rapidly and uniformly, the seed must be at a uniform depth and surrounded by soil. Some types of seed firmers may improve uniform planting depth. Careful control of planting depth improves stands and uniform emergence.

Plant Populations

The optimum plant population depends on the yield level that a particular environment (soil, moisture) permits. Average corn plant populations have gradually increased over the years as have corn yields. These increases can be attributed to improvements in production technology as well as genetic improvement in yield potential, standability, and stress tolerance. Today's corn hybrids have higher yield potentials because of greater yield stability over a wider range of environments, superior stalk strength and standability, and better tolerate competitive stress (less barrenness) at high plant densities than previous hybrids. If a stressful environment occurs under recommended high populations with modern-day hybrids, extremely high yields will not occur, but, it is less likely that a significant yield decrease will occur unless the population has greatly exceeded the recommended optimum range.

Recent studies at the University of Kentucky have shown trends for maximum yields at higher plant populations. In the 3 year study (Table 1), corn yields increased significantly at each increased level of plant population. In the 2-year study with two hybrids (Table 2), there were no significant increases in yields with increased plant populations; however, there was a trend toward slightly higher yields at 28,000 plants per acre.

Corn can compensate for low populations by producing larger ears or additional ears. However, most hybrids today produce only one ear. Hybrids also respond differently to plant populations. When the population is too high, some hybrids may have barren

stalks and lodging potential tends to increase. Consult seed company recommendations for desired plant populations of specific hybrids.

Using the data from Tables 1 and 2 and data collected by R. Barnhisel, University of Kentucky Agronomy Department, during the last five years of variable rate seeding studies, the recommended corn seeding rates for Kentucky are presented in Table 3. Corn planted on low yielding soils should not be seeded above 22,000 seeds per acre, and on high yielding, uniform soils, top yields are obtained with seeding rates of 28,000 to 30,000 seeds per acre. For intermediate yields (120 to 175 bushels per acre), use intermediate populations. Many times yields close to 200 bushels per acre can be achieved at 26,000 to 28,000 seeds per acre. Excessive populations can lead to more lodging, more disease pressure, and lower yields in most years. The final population should be approximately 85 to 90 percent of the seeding rate as shown in Table 4.

Table 1. Effect of plant population and row width on corn yields in Kentucky (eight-location average, 1995-97). Bitzer and Herbek.

Treatment		Yield (bu/ac)
Plant population	22,000	164a*
(Plants/acre)	26,000	171b
	30,000	178c
Row width	20 inch	170b
	30 inch	175a
	36 inch	169b

*Means followed by different letters are significantly different at 0.05 level of significance.

Table 2. Effect of plant population and row width on corn yields in Kentucky (four-location average, 1998-99).

		Yield (bu/ac)		
Treatment		1998	1999	Ave.
Plant population	24,000	167	130	149*
(Plants/acre)	28,000	174	129	152
	32,000	172	126	149
Row width	20 inch	171	126	148
	30 inch	171	131	151

* There were no significant differences among means at 0.05 level of significance.

Row Width

Studies in Kentucky during the 1970s and 1980s showed no advantage in yield for corn planted in rows narrower than 36 inches. However, by the early 1990s, a large percentage of the corn was grown in 30-inch rows because producers had switched to narrower rows for soybean and were using the same equipment for corn. In the early 1990s, much interest was generated for using 20-inch rows for corn. However, research from most of the states surrounding Kentucky did not show any advantage for 20-inch rows over 30-inch rows. Research was started in the mid-1990s comparing 20-inch, 30-inch, and 36-inch row width for corn in Kentucky (Table 1). These data showed an advantage for 30-inch over 36-inch row widths but that there was no advantage for 20-inch rows over 30-inch rows. Actually, 20-inch rows were no better than 36-inch rows. In Table 2, two more years of research on row width gave the same results. Consequently, the recommended row width for corn production in Kentucky is 30-inch rows.

Any consideration for a change in row spacing must take into account the economic return of that change. Most economic analysis comparisons indicate that a yield increase of at least 6 to 8 percent on large acreages (>500 acres) over a seven to 10 year period is needed to cover expenses incurred when switching row widths unless new equipment is needed to replace old equipment.

Replanting Corn

If a corn crop has been damaged or the stand is poor early enough to consider replanting, there are several factors that need to be considered. Some of these factors are seeding rate and expected plant stand, plant stand after damage or loss of stand, uniformity of plant stand being considered, replanting date and seed costs to replant, and potential pest problems with replanted corn. Whether to replant or not comes down to deciding whether the replant-crop yields would be sufficient to cover the costs of replanting and net enough to make it worth the effort. The key factor to consider is found in Table 5. This table will help you decide if replanting will yield more corn than leaving the present stand. The information in this table was obtained and adapted from the *National Corn Handbook*, NCH-30, "Guidelines for Making Corn Replanting Decisions." Refer to this

Table 3. Recommended corn seeding rates for Kentucky.

	Seeding rate* (seeds/acre)
Grain	22,000 - 30,000
Silage	24,000 - 30,000
Irrigated	26,000 - 32,000

* Range depends on potential yield of soil ranging from less than 100 bu/ac for the low range to more than 200 bu/ac for the high range.

Table 4. Corn population planting guide.

		Inches between kernels when planting at various row widths			
Harvest population[1]	Required planting rate	20"	30"	36"	38"
16,200	18,000	17.4	11.7	9.7	9.2
17,100	19,000	16.5	11.1	9.2	8.7
18,000	20,000	15.7	10.5	8.7	8.3
19,800	22,000	14.3	9.5	7.9	7.5
21,600	24,000	13.1	8.7	7.2	6.9
23,500	26,000	12.1	8.1	6.7	6.4
25,200	28,000	11.2	7.5	6.2	5.9
27,000	30,000	10.5	7.0	5.8	5.5
28,800	32,000	9.8	6.5	5.4	5.2

[1] Allows 10 percent stand loss.

publication for a much more detailed explanation of making a replanting decision, or contact your state corn specialist.

Table 5 contains the percentage of expected corn yield for planting date and harvest populations. Optimum population is considered to be 25,000 plants per acre with the optimum planting date to be the first week to 10 days of May. Information in this table along with consideration of the above-mentioned factors should aid in making a replanting decision. To use this table, consider this example: Suppose a field was planted on May 1 with an expected harvest population of 25,000 plants per acre. Later, the stand was reduced to 14,000 plants per acre; the yield loss penalty for the reduced population would be 17 percent (100 percent minus 83 percent). If it was decided to replant the field on May 21 to obtain a desired population of 25,000 plants per acre, a yield of 95 percent of optimum could be expected; for a net gain of 12 percent (95 percent minus 83 percent). Thus, replanting should be profitable in this case. However, if the stand was reduced to 16,000 plants per acre on May 31, a decision to replant would not be profitable, as an expected yield of only 87 percent would be realized as compared to an 88 percent yield if the stand was left standing. This is simply a guide to help you make a decision concerning replanting. Table 5 takes into account the loss of yield at later plantings but does not take into account non-uniform stands. All these factors must be weighed against expected replanting yield gains. If after considering all the factors, there is still doubt as to whether a field should be replanted, it will probably be correct more often if the field is left as is.

Table 5. Grain yields for various planting dates and population rates, expressed as a percent of optimum planting date and population rate (uniformly spaced within row).

	Plants per acre at harvest						
Planting date	**12,000**	**14,000**	**16,000**	**18,000**	**20,000**	**22,500**	**25,000**
	(% of optimum yield)						
April 15	70	76	81	85	88	91	93
April 20	72	78	83	87	90	93	95
April 25	75	81	86	90	93	96	98
May 1	77	83	88	92	95	98	100
May 6	78	83	88	92	95	98	100
May 11	77	83	88	92	95	98	99
May 16	75	81	86	90	93	96	98
May 21	73	78	83	87	91	94	95
May 26	69	75	80	84	87	90	92
May 31	64	70	75	79	82	85	87
June 5	59	64	69	73	77	80	81
June 10	52	58	63	67	70	73	75

Cropping Rotation Benefits

Morris Bitzer and James Herbek

There are many cropping sequences that can be used for growing corn in Kentucky. Economically and agronomically, it is difficult to justify growing corn in a monoculture instead of using a rotation. Data from many states have shown that a yield loss up to 10 percent occurs when corn is grown two or more years in succession. Most of that loss occurs in the second year.

There are several benefits from growing corn in rotation. With less pressure from disease, insects, and weeds, production costs are lower and profits are higher due to higher corn yields. Rotation studies in Kentucky have shown a yield increase of about 10 bushels per acre for corn grown in a rotation with soybean or soybean and wheat. Rotations also improve the use and availability of nutrients, and with the proper selection of a rotation crop, the productivity of the complete cropping system. Corn fits well into most crop rotations. The corn/soybean or corn/wheat/double-cropped soybean (three crops in two years) cropping sequences are commonly used in Kentucky.

Fertility Management

Lloyd Murdock

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 ei-

ther 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 micro-

organisms. 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 nutri-

tional 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 x 2.29 = P_2O_5
[2] K x 1.2 = K_2O

Weed Management

J. D. Green and James R. Martin

The most economically important pests that reduce corn yield each year are unwanted plants that interfere with corn growth, development, or harvest. These plants, called weeds, compete with corn for water, light, and soil nutrients to reduce crop yield. Some weeds are capable of naturally releasing substances into the soil that are allelopathic, or toxic, to the crop. Weeds can serve as hosts for corn diseases, such as the maize dwarf mosaic and maize chlorotic dwarf virus complex (MDM/MCD) on johnsongrass rhizomes, which can be vectored and transported by insects to corn plants, thus reducing crop yield. Weeds also provide shelter and serve as a food source for insects and diseases that overwinter or provide habitat for wildlife species such as prairie voles that reduce corn stands.

A number of decisions must be considered in developing a successful weed control program. To assist in weed management decisions, a corn producer must be able to properly identify the specific weed problems in each field along with other aspects and factors that might influence weed emergence and growth. It is also important to understand the life cycle of weedy plants, their growth habit, and their potential competitiveness or impact on the crop.

Life Cycles of Weeds

Weeds can be grouped into three major categories. Annuals complete their life cycle in one growing season and reproduce only by seed. Summer or warm-season annuals, such as large crabgrass (*Digitaria sanguinalis*) and common cocklebur (*Xanthium strumarium*), germinate in the spring and set seed in late summer or fall. These plants are more likely to directly compete with the corn. Winter or cool-season annuals typically germinate in the fall and complete their reproductive cycle in the spring or early summer. Therefore, cool-season annual plants, such as common chickweed (*Stellaria media*) and Italian ryegrass (*Lolium multiflorum*) are generally more of a concern at the time of planting and during the early stages of corn growth in no-till corn production.

Biennials are capable of completing their life cycle during two growing seasons. The first year normally consists of vegetative growth, whereas the second year involves both vegetative and flower development. Biennials, such as musk thistle (*Carduus nutans*), reproduce only by seed. Sometimes these plants may complete their life cycle within one year.

Perennial plants are capable of existing for more than two years. Reproduction can be by seed and by vegetative structures such as rhizomes, stolons, tubers, taproots, or creeping roots. For example, johnsongrass (*Sorghum halepense*) plants frequently encountered in corn fields emerge from seed; however, johnsongrass plants are capable of emerging from rhizomes. Warm-season perennial weeds have become of increasing concern as no-tillage practices have increased in Kentucky's crop production systems. Ten of the most common and troublesome weeds found in Kentucky corn fields are listed in Table 1.

Weed Scouting

Proper weed identification is an essential component of any successful weed management program. It is even more critical in no-tillage systems because herbicides are the primary method of weed control.

Table 1. Common and troublesome weeds and their life cycle in Kentucky corn fields.

Weed species	Life cycle	Primary reproduction	Native/ Introduced
10 Most Commonly Occurring Weeds			
smooth pigweed	SA	seed	N
giant foxtail	SA	seed	I
large crabgrass	SA	seed	I
johnsongrass	P	seed, rhizome	I
morningglory (ivyleaf & pitted)	SA	seed	I
honeyvine milkweed	P	seed, creeping root	N
fall panicum	SA	seed	N
common cocklebur	SA	seed	N
giant ragweed (horseweed)	SA	seed	I
yellow nutsedge	P	tuber, rhizome, seed	N
10 Most Troublesome Weeds to Control			
honeyvine milkweed	P	seed, creeping root	N
broadleaf signalgrass	SA	seed	N
burcucumber	SA	seed	N
trumpetcreeper	P	creeping root, seed	N
giant ragweed (horseweed)	SA	seed	I
johnsongrass	P	seed, rhizome	I
common pokeweed	P	seed, taproot	N
ivyleaf morningglory	SA	seed	I
fall panicum	SA	seed	N
Italian ryegrass	WA	seed	I

Life cycle: SA = summer or warm-season annual; WA = winter or cool-season annual; P = warm-season perennial.
Origin: I = introduced plant; N = native plant.

Training and a skilled eye are often needed to properly identify weeds during early vegetative growth stages. In fact, an effective postemergence control strategy for weeds often depends on proper identification when weeds are less than 4 inches tall. Thus, field scouting should begin within 2 weeks of corn planting and continue at weekly intervals for 8 to 10 weeks into the growing season. Scouting methods recommended for weeds in corn can be found in *Kentucky Integrated Crop Management Manual for Field Crops—Corn* (IPM-2) available at your county Extension office.

A history of previously known weed problems in a field greatly aids in preparing an overall weed control strategy at the beginning of the growing season. Knowing the previous field history can also provide insight on their identity when weeds emerge. A good method for developing a field history of weed problems is by mapping weeds from previous and current field scouting reports and from observations made at harvest. A detailed weed map for each field will provide information on the location of weed infestations and help monitor changes in these infestations from year to year.

Weed and Corn Interactions

An economic threshold exists when a weed population reaches a level whereby it becomes economically justified to control because of the potential for corn yield reduction, crop quality loss, harvesting difficulties, or other problems caused by the weeds. Low weed populations do not interfere with crop yield, harvestability, or crop quality. Thus, producers may allow low populations of weeds to remain in the field throughout the growing season without affecting the crop. On the other hand, viny weeds such as burcucumber (*Sicyos angulatus*) can reduce yield and interfere with corn harvest at low plant populations. Other weed species such as smooth pigweed (*Amaranthus hybridus*) and common lambsquarters (*Chenopodium album*) are capable of producing thousands of seeds from a single plant. Therefore, it can be a good strategy to control low populations of such annual weeds. The overall impact that replenishing the soil seed bank may have, when some weeds are allowed to grow through maturity, is not fully understood. It is also desirable to control light infestations of perennial weeds and newly introduced annuals before they become a serious problem. The anticipated yield loss from various weed populations is illustrated in Table 2.

Most weed-corn competition studies indicate weeds that emerge and grow with corn during the first 2 to 4 weeks under normal environmental conditions, and then removed, do not reduce corn yield. In addition, if weeds are kept out of the field for up to 4 to 6 weeks after corn emergence, weeds that emerge later are not likely to reduce yield relative to the cost of treatment. However, late emerging weeds may cause harvest problems or reduce crop quality depending on the weed species.

Impact of Tillage

Management practices used in Kentucky and surrounding states emphasize reducing tillage in a rotation of corn, wheat, and double-cropped soybeans during a two-year period. This tillage and rotation system offers both benefits and drawbacks with regard to weed management.

No-tillage practices provide numerous benefits for weed control, and often a shift in the dominant weeds will be noticed. Undisturbed soil, with time, reduces the germination of weed seed that are deep in the soil seed bank. The fact that no-tillage limits the amount of soil disturbance and scarification of weed seeds may explain why such weeds as common cocklebur, burcucumber, and sicklepod (*Cassia obtusifolia*) are observed to a lesser extent in no-tillage compared to more intensive tillage situations. Furthermore, leaving the soil undisturbed for several years may lead to rotting and/or predation of seeds on the soil surface.

The lack of soil disturbance may promote the development of populations of certain weed species. The in-

Table 2. Estimated impact on corn yield with different weed species at various populations in corn with a 100 bu/ac yield potential.[1]

Weed pressure category (yield loss potential)	Foxtail spp.	Johnsongrass	Pigweed spp.	Morningglory spp.	Common Cocklebur	Giant Ragweed (Horseweed)	Estimated yield loss by a single species	Estimated yield loss by all species
	-- Weed density per 100 sq ft --						(bu/ac)	(bu/ac)
Slight (0-5%)	10	8	5	5	4	2	<2	<10
Low (5-10%)	20	15	10	10	8	4	5	20
Moderate (10-20%)	50	30	25	30	10	8	10	30
Severe (20-35%)	100	75	50	60	30	20	20	40
Very Severe (>35%)	200	125	75	100	50	40	35	50

[1] These specific plant density values are based on general observations, and estimates show relative differences among individual weed species. Estimated values can vary greatly depending on the environment and when the weeds emerge relative to the time of crop emergence. Adapted from University of Missouri-Columbia Extension bulletin "Integrated Pest Management—Practical Weed Science for the Field Scout Corn and Soybeans," February 2001.

cidence and severity of weeds such as common pokeweed (*Phytolacca americana*) and curly dock (*Rumex crispus*) are examples of perennials with large fleshy tap-roots that grow well in a no-tillage environment. Also, an occurrence of some annual weed species such as marestail (i.e., horseweed) (*Conyza canadensis*) and prickly lettuce (*Lactuca serriola*) are noticed more frequently under no-tillage conditions. These two weed species can emerge during the late fall or early winter months and maintain active growth throughout the corn growing season. Perhaps one reason marestail and prickly lettuce become established is that their seedlike achenes with tufts of hair are spread easily by wind. Thus, they can easily invade fields where primary tillage is not used to destroy emergence of new plants.

Poor control of perennial weeds is a major complaint about no-tillage corn production. Common pokeweed with its perennial tap-root system grows well and is difficult to control in a no-tillage system. Honeyvine milkweed (*Ampelamus albidus*) and trumpetcreeper (*Campsis radicans*) are warm-season perennial vines with creeping roots, whereas Italian ryegrass is a cool-season annual grass that often escapes control from traditional burndown herbicides but is easily controlled with spring tillage.

Since less tillage leaves previous crop residue on the soil surface, that residue intercepts some of the herbicide spray when it is applied. Less residue is present if the previous crop was soybean compared with corn stubble or when the previous crop was wheat. A rainfall event occurring soon after application generally moves the herbicide off the crop residue and in contact with the soil. This reflects the importance of rainfall, instead of mechanical incorporation, as the avenue by which a major portion of the herbicide is moved within close proximity to germinating weed seeds. Some herbicides intercepted by crop residue may be subjected to loss by processes such as photodecomposition or by volatilization. In general, research data have not indicated that performance of soil-active herbicides is greatly reduced as a result of crop residue left on the soil surface. However, the thick surface mulch often associated with long-term no-tillage production may be one factor that contributes to inconsistent control of broadleaf signalgrass (*Brachiaria platypylla*) with the chloroacetamide herbicides. The mulch may also slow the warming of soil and delay emergence of such weeds as johnsongrass. Delaying the emergence of johnsongrass may limit the opportunities to apply postemergence herbicides for optimum control with minimum risk to corn.

One noted effect of more residue on the surface is the change in soil characteristics at the soil surface. Generally, under continuous no-till corn production an increase in soil organic matter occurs from decaying crop residue, and often the soil surface pH becomes more acidic because of annual additions of nitrogen fertilizers. These two factors can change the effectiveness and the persistence of some herbicides. For example, the triazine herbicides, such as atrazine and simazine (Princep, etc.), tend to persist less and may provide less weed control in a no-tillage system compared to conventional tillage. This can be explained by a faster degradation rate of triazine herbicides under acidic conditions (pH 5.0). Timely applications of lime will overcome this pH effect. On the other hand, overapplication of lime may result in high soil pH levels (pH 7.0) that can cause herbicide carryover concerns to other rotational crops.

Cultural Practices and Mechanical Controls

In addition to a scouting program and field mapping of weed problems, a good program of integrated weed management should employ a variety of crop management tools to deal with weed problems. These include preventing the introduction of new weeds and cultural practices such as seeding rates and planting dates that maximize the competitiveness of the crop. This allows the corn to compete better with weeds by reducing weed seed emergence and growth. Mechanical methods, such as minimum tillage cultivators capable of functioning in high crop residue, will provide weed control between the rows.

Crop rotation can also be an effective tool for managing some problem weeds. It helps limit the increase in the population of some perennial or difficult-to-control weeds in continuous crop production systems. For example, johnsongrass can be difficult to control in corn but easier to control in soybean because a wider variety of herbicide options are available. Rotation to densely planted crops (i.e., forages or small grains) can smother some weeds, such as crabgrass, that compete in row crops. Rotation of crops also allows for more opportunities to rotate herbicides, which in turn helps prevent the development of herbicide resistance in some weed species.

Herbicide Use and Timing

Herbicides are the primary method of weed control in corn production. They are particularly important for combating weed problems in no-till or conservation tillage production systems. Herbicides are generally considered to be either soil active or foliar active. Soil-active herbicides are generally applied to the soil surface since they are most effective shortly after weed seed germination, whereas foliar-active herbicides control weeds after they have emerged from the soil; thus, they are applied postemergence (POST) to the weeds.

Soil-active herbicides are usually applied to the soil surface (i.e., preemergence [PRE]) before the crop and weeds emerge. Herbicide products that contain atrazine, pendimethalin (e.g., Prowl), or other soil-active in-

gredients can also be applied after corn emergence but before weeds emerge. Some soil-active herbicides can also be incorporated into the soil before crop planting and weed emergence (i.e., preplant incorporated [PPI]). Preplant-incorporated herbicide applications are possible with crop management systems that leave some surface residue but not in no-till corn production. This narrows the list of potential herbicides available for use. Herbicides applied to the soil surface are more dependent on rainfall to move the herbicide into the weed seed zone compared to herbicides mechanically incorporated. Weeds, such as broadleaf signalgrass, Eastern black nightshade (*Solanum ptychanthum*), and yellow nutsedge (*Cyperus esculentus*) that are more susceptible to herbicides applied preplant incorporated, are less effectively controlled with herbicides applied to the soil surface.

In no-tillage systems herbicides are usually needed for vegetation control prior to crop emergence (i.e., preplant foliar [PPF]). Paraquat (Gramoxone), glyphosate (Roundup, Touchdown, etc.), dicamba (Banvel, Clarity, etc.), and 2,4-D are often used to "burndown" the existing vegetation (Table 3). In many cases, the green vegetation present among the previous crop residue consists of cool-season annuals and perennials, along with some emerging summer annual weeds. When planting corn into a perennial grass or grass/legume sod, treatment combinations of atrazine plus paraquat or glyphosate provide the best control. Glyphosate applied in the fall is generally more effective for killing sod crops, especially in fields containing orchardgrass, fescue, alfalfa, and/or other forage legumes. To control alfalfa in the spring prior to planting corn, dicamba (Banvel, Clarity, etc.) should be used.

Where previous crop residue exists, an alternative to "burndown" applications at planting is to apply herbicides several days prior to planting (i.e., early preplant [EPP]). In corn, soil-active herbicides can be applied as a sequential treatment with the first application made 15 to 30 days before planting and the second at planting. Single applications can be successful as much as 15 days ahead of planting. When an early preplant herbicide program is used in corn, a nonselective "burndown" herbicide may not be needed.

Table 3. Relative response of cover crops and weeds to burndown herbicides.

	Cover crops									Weeds														
Herbicide[1]	Alfalfa	Clover, Red	Clover, White	Fescue, Tall	Orchardgrass	Rye	Ryegrass, Annual	Vetch, Hairy	Wheat	Brome spp.	Chickweed, Common	Dandelion	Dock, Curly	Fleabane, Annual	Foxtails	Henbit / Deadnettle	Lettuce, Prickly	Marestail	Mustard spp.	Thistle, Musk	Johnsongrass (seedling)	Johnsongrass (rhizome)	Pokeweed	Ragweed, Giant
Atrazine	3	5	4	6	3	6	5	6	6	7	9	4	4	-	6	8	9	9	8	4	0	0	2	9
Dicamba	8	9	8	0	0	0	0	8	0	0	7	8	7	8	0	6	9	7	7	8	0	0	6	9
2,4-D Ester	6	8	5	0	0	0	0	8	0	0	5	8	4	6	0	4	8	8	8	7	0	0	5	8
Paraquat	3	7	5	5	3	7	6	7	7	7	9	4	2	6	9	8	5	4	6	3	7	3	4	7
Paraquat + Atrazine	4	-	-	8	7	7	7	8	9	8	9	7	5	-	9	9	9	9	9	5	7	3	4	9
Glyphosate	6	6	5	7	6	8	7	6	9	9	9	6	4	8	9	8	8	9	8	6	9	8	6	9

Good = 8-9 Fair = 6-7 Poor = 5 or less - Insufficient Data

[1] Herbicide products that contain these active ingredients include atrazine (AAtrex, etc.); dicamba (Banvel, Clarity, etc.); paraquat (Gramoxone); and glyphosate (Roundup, Touchdown, Glyphomax, etc.).

Herbicide formulations are changing to fit the needs of crop production. Package mixtures of herbicides with more than one active ingredient have become prevalent due to the need for a broad spectrum of weed control activity. Water dispersible granules and dry flowable herbicide formulations with low use rates have also increased. Some specialized herbicide formulations can reduce the "binding" of the herbicide with the plant residue left on the soil surface (i.e., micro-encapsulated). Other formulation changes that may evolve in the future include the development of formulations that reduce volatilization loss of surface-applied herbicides.

In recent years there has been greater reliance on postemergence herbicides. Certain weeds, especially warm-season perennials, may not be readily controlled by preemergence treatments. In addition, weed escapes (due to resistance or environmental conditions not conducive to weed control) must be treated with postemergence herbicides. Postemergence herbicides also provide the benefit of allowing the use of a more integrated weed management approach since herbicides are applied only when needed.

Herbicide Persistence and Carryover

Paraquat and glyphosate are tightly bound to soil and offer no soil-residual activity, whereas atrazine (AAtrex or Atrazine) and simazine (Princep) can remain active in soil for a period of time. While persistence of herbicides in soil is beneficial in regard to weed control, it is a concern when associated with carryover to rotational crops or other environmental impacts.

The risk of injury from herbicide carryover is dependent on several factors including the susceptibility of rotational crops and the persistence of the herbicide. The typical cropping sequence used in Kentucky and portions of neighboring states include corn, wheat, and double-cropped soybean. In this cropping sequence crop injury

from carryover seldom occurs from herbicides used in Kentucky. However, some soybean herbicides such as imazaquin (e.g., Backdraft, Scepter, Squadron, Steel), imazethapyr (e.g., Extreme, Pursuit), and chlorimuron (e.g., Canopy, Canopy XL, Classic, Synchrony) have potential to persist long enough to injure corn. Corn herbicides such as atrazine and simazine have label precautions for rotating to wheat or soybean.

Certain herbicide-tolerant crops can limit the risk of injury from herbicide carryover. Clearfield™ corn hybrids have a high degree of tolerance to imidazolinone herbicides; consequently, they have more flexibility than regular hybrids when rotating to corn where imazaquin was applied the previous season under dry soil conditions. Similarly, STS soybeans are tolerant to many sulfonylurea herbicides and are recommended where prosulfuron-containing products (e.g., Exceed, Spirit) were applied to corn during conditions that limited herbicide degradation processes.

Environmental conditions also affect herbicide persistence and rotational crop injury. Factors that help promote herbicide dissipation and limit carryover problems in Kentucky include: 1) an ample supply of moisture throughout the growing season, 2) mild winter temperatures, 3) relatively low levels of organic matter (usually 2 to 3 percent), and 4) soils with medium pH levels (usually pH 6.0 to 6.8).

Many of the soil-active herbicides used in corn have the potential to contaminate surface and groundwater. The labels of these products have groundwater advisory statements that recommend not applying where the water table is close to the surface and where the soils are very permeable. Atrazine-containing products have special label restrictions for use near ground or surface waters. Emphasis is placed on using low atrazine rates, buffer zones, and conservation tillage practices as strategies for minimizing the risk of contaminating water sources.

Herbicide Interactions

Mixing herbicides with other chemicals, either as tank mixtures or sequential applications, is practiced widely. It is important to recognize the potential benefits as well as drawbacks for using such strategies. The "jar test" method that is described on many product labels helps determine physical signs of compatibility of tank mixtures but will not indicate the potential for synergism (i.e., enhancement) or antagonism (i.e., less activity) as it relates to crop injury or weed control.

Nitrogen fertilizers such as 28 to 32 percent liquid nitrogen, 10-34-0, or ammonium sulfate are sometimes used as additives with postemergence herbicides. Although the benefit of these materials as additives is debatable for certain herbicides, there are situations where their use can enhance control or limit antagonism. It is well known that the use of nitrogen fertilizers as an additive enhances postemergence control of velvetleaf. Ammonium sulfate and liquid nitrogen may reduce activity of Accent Gold, whereas 10-34-0 is the preferred source of nitrogen as an additive with this product. The sequence in which nitrogen fertilizers are added in the spray mixtures may also impact the activity of certain herbicides. For example, it is recommended that ammonium sulfate be added first in the spray mixture to limit antagonism of certain tank mixtures with Roundup Ultra and other glyphosate products in hard water or with certain herbicides.

While herbicide interactions with insecticides are seldom a problem, there are situations where their use as tank mixtures or sequential sprays can result in problems. Corn injury can occur when tank mixing certain Acetolactate Synthase (ALS)-inhibiting herbicides with organophosphate insecticides. The use of insecticides and herbicides as separate applications in the same field, such as in-furrow treatments of certain organophosphate insecticides followed by postemergence sprays of ALS-inhibiting herbicides, may result in corn injury.

The risk of antagonism varies depending on specific products, methods of application, and environmental conditions. Some products are not stable in water over time and should be sprayed soon after mixing. This is especially true of many of the sulfonylurea herbicides, which may degrade within four to 24 hours after mixing. Consulting the labels of all materials involved in a spray mixture will help avoid physical incompatibility issues with mixing, as well as potential problems with crop injury, or weed control.

Herbicide-Resistant Weeds

A major concern in weed management is the resistance of weeds to commonly used herbicides. Not all pigweed plants are created alike. Nor are all common lambsquarters or johnsongrass plants the same. There is genetic diversity among plants of the same species. Sometimes this diversity is expressed by small differences in the physical appearance of the plants. These differences can also be expressed as a differential response to herbicides. The basis for herbicide resistance is the fact that genetic diversity allows biotypes within a species to survive a herbicide treatment that is generally known to be lethal to that plant species.

Examples of herbicide-resistant weeds documented in Kentucky corn fields include smooth pigweed to triazine type herbicides (i.e., Atrazine and Princep) and to ALS-type herbicides (i.e., Accent, Beacon, Exceed, etc). The potential for weed resistance to develop increases with a continuous use of a herbicide or herbicide products that have the same mode of action on the same field for several seasons. Therefore, herbicide use should be monitored and production

practices implemented to prevent and reduce the potential for weed resistance to occur.

A key to avoiding development of herbicide-resistant weed populations is prevention. Listed below are management strategies to consider in preventing and dealing with herbicide-resistant weeds.

- Scout fields regularly and identify weeds present. Respond quickly to shifts in weed populations to restrict spread of weeds.
- Select a herbicide based on weeds present and use a herbicide only when necessary.
- Rotate herbicides. Avoid using the same herbicide or another herbicide with the same mode of action (i.e., herbicides that inhibit the same process in target weeds) for two consecutive years in a field. It is possible for a herbicide used in one crop to have the same mode of action as a different herbicide used in another crop. For example, Accent, Basis, Beacon, Canopy, Classic, Exceed, FirstRate, Harmony Extra, Harmony GT, Lightning, Permit, Pursuit, Python, Scepter, Spirit, and Synchrony "STS" contain active ingredients with the same mode of activity in plants (i.e., these herbicides are ALS inhibitors).
- Apply herbicides with different modes of action as a tank mixture or sequential application during the same season.
- Rotate crops. Crop rotation helps disrupt weed cycles, and some weed problems are more easily managed in some crops than others.
- Combine mechanical weed control practices such as cultivation with herbicide treatments where soil erosion potential is less of a concern.
- Clean tillage and harvest equipment to avoid moving weed problems from one field to the next.

Herbicide-Tolerant Corn Hybrids

Crops traditionally susceptible to some herbicides have been developed and are now available that are tolerant to specific herbicides. Herbicide tolerance in crops results from two different procedures: 1) selection by traditional plant breeding methods and 2) biotechnology techniques. Examples of corn hybrids include Clearfield corn tolerant to imidazolinone-type herbicides (i.e., Lightning or Pursuit); Roundup Ready™ corn hybrids tolerant to glyphosate (Roundup, Touchdown, etc.); Liberty Link™ hybrids tolerant to glufosinate (Liberty); and Poast Protected corn hybrids (see Table 4).

Herbicide-tolerant crops provide additional options to control some weed problems. However, there are concerns associated with their use. These include a) misapplication to a normal or traditional crop hybrid, b) drift to nearby susceptible vegetation, c) greater selection for resistant weed species or shifts in weed populations, d) herbicide-tolerant crops becoming weedy and difficult to control, e) marketing issues, and f) negative public reaction to biotechnology-derived crops. Herbicide-tolerant crops do require greater management to prevent problems such as misapplication, spray drift, or further development of weed resistance.

Other Information

This publication explains general concepts of weed management in corn. More specific information on herbicides and their use in corn can be found in University of Kentucky Extension bulletin *Weed Control Recommendations for Kentucky Farm Crops* (AGR-6), revised annually. A computerized decision aid (WeedMAK II—Weed Management Applications for Kentucky), which is designed to rank treatment options for weed problems in corn and soybean, is another source of information for Kentucky corn producers and crop consultants. Information about these reference materials can be obtained through your local county Extension office or the University of Kentucky Agricultural Distribution Center.

This table should be used only as a guide. Information presented in this table is the relative burndown response of emerged plants to herbicides applied at normal rates for no-till corn. This information generally does not reflect soil residual effects of the herbicides. The relative response values are based on a numerical scale from 0 to 9 and compare effectiveness of herbicides to control a particular cover crop or weed species. A herbicide may perform better or worse than indicated in the table due to weed size or environmental conditions or when tank mixed with other herbicides. If farmers are achieving satisfactory results under individual conditions, they should not necessarily change products as a result of information in this table.

Table 4. Herbicide-tolerant corn hybrids and method of development.

Year released	Herbicide-tolerant corn	Herbicides	Method of development
1992	Imidazolinone Tolerant (IT) and Resistant (IR) (also known as Clearfield or IMI-hybrids)	Pursuit, Lightning	Plant breeding techniques
1995	Poast Protect hybrids	Poast, Poast Plus	Plant breeding techniques
1997	Liberty Link hybrids	Liberty, Liberty ATZ	Gene insertion
1998	Roundup Ready hybrids	Roundup Ultra, ReadyMaster ATZ, Touchdown, and several other glyphosate products.	Gene insertion

Disease Management

Paul Vincelli

Diseases of crops can occur whenever a *disease-causing agent* is in contact with a *susceptible host plant* in an *environment that is favorable for disease development*. These three fundamental ingredients are necessary for a disease to develop and are often referred to as the *disease triangle* (Figure 1).

Understanding this fundamental relationship helps us understand disease management since all disease management practices presented in this publication affect one or more sides of the disease triangle. For example, planting a hybrid with some resistance to gray leaf spot targets the *host* side of the disease triangle. Crop rotation helps to starve a *pathogen* (disease-causing agent) by depriving it of its food source; this affects the pathogen side of the disease triangle. Delaying planting until soil temperatures exceed 50°F reduces the amount of seedling damping off by targeting the *environment* side of the disease triangle.

Preplant Decisions That Affect Disease Development

Most of the agronomic decisions corn producers make have some impact on disease development. In fact, once a corn field is planted, a producer's disease management program is essentially in place, for better or worse. Thus, consider your preplant decisions as disease-management decisions also.

Crop Rotation

Many corn pathogens survive between crops in the corn residue, and some do not attack other field crops commonly grown in rotation with corn. Consequently, rotating to wheat, soybean, or other crops helps to starve certain corn pathogens that survive in the field by depriving them of a food source as the crop residue decomposes. Crop rotation is thus one of the most important disease control practices for corn production worldwide.

Pathogens that are not as effectively controlled by crop rotation include those that do not survive in the production field itself. For example, rust fungi that attack corn overwinter south of Kentucky and are blown into our corn fields each season on wind currents. Pathogens that attack a wide range of field crops are also less effectively controlled through rotation. For example, the charcoal rot pathogen can attack corn, soybean, and grain sorghum and is not controlled through a corn/soybean rotation. Likewise, pathogens that persist indefinitely in agricultural soils are not effectively controlled through crop rotation. An example is the fungus *Pythium ultimum*, the most common cause of damping off of corn.

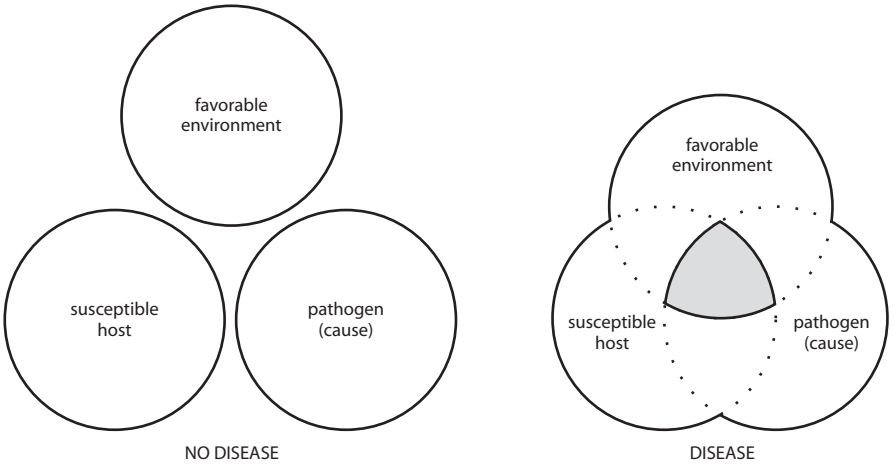
Resistant Hybrids

One of the most practical and economical means of disease control is to select agronomically suitable hybrids with adequate resistance to diseases of concern on your farm. Unfortunately, resistance is not available for some diseases. However, when available, disease resistance should be the foundation for economical disease control.

No single corn hybrid is resistant to all diseases present in Kentucky. Furthermore, the importance and prevalence of corn diseases vary from one farm to the next and from one year to the next. These facts can complicate the hybrid selection process. Nevertheless, an informed decision can be made by selecting hybrids with resistance to the diseases most likely to be a problem. Resistance to other diseases should be considered on a secondary basis.

When selecting a hybrid, the producer should recognize that there are different levels of disease resistance. If available, agronomically acceptable hybrids with high levels of resistance usually provide the best protection against a serious disease outbreak. Hybrids may also exhibit moderate or even low levels of resistance to particular diseases. This means that, while the disease still can develop on these hybrids, lower incidence of disease can be expected in most circumstances than on a fully susceptible hybrid. For some diseases, low to moderate resistance is all that is available

Figure 1. Disease triangle. Disease only develops when three conditions are met: a pathogen infects a susceptible host under disease-favorable conditions.



among current commercial hybrids, even though higher levels of resistance would be desirable. In these cases, use of a hybrid with even a low level of resistance is usually superior to planting a susceptible hybrid. Sometimes a moderate level of resistance is acceptable for fields where reduced disease pressure is expected. However, under high disease pressure, low to moderate levels of disease resistance will not provide adequate disease control. Such hybrids may require you to pay greater attention to other disease management strategies in order to achieve good results.

Hybrids can also be selected for tolerance—the ability to yield well even though symptoms develop. Information on disease-tolerant hybrids is limited, but tolerant hybrids can be useful when available.

It is important to plant more than one corn hybrid on your farm. Planting one hybrid is like "putting all your eggs in one basket." Should a disease problem develop on that hybrid, your whole crop is at risk. Planting several hybrids helps to spread the risk of losses from disease.

Tillage

Conservation tillage systems provide for less soil erosion, less fuel consumption, savings of time and labor, moisture conservation, and easier double-cropping. Conservation tillage systems can, however, increase pressure from certain diseases, especially under continuous corn production. Prime examples are gray leaf spot and Diplodia ear rot. Spore levels of the fungi that cause these diseases are higher in fields where previously infected corn residue is left on the soil surface. When residue is tilled into the soil, spores are trapped underground and cannot easily spread to aboveground plant parts. Furthermore, buried crop residues decompose faster, which reduces pathogen survival. Activity of seedling diseases can also be increased in no-till systems because soils remain cooler and wetter during spring under conservation tillage.

While conservation tillage systems may favor certain diseases, they can also reduce pressure from certain others. For example, charcoal rot, which is favored by high soil temperatures and low soil moisture early in the growing season, would be expected to be worse in a conventional system than a no-till system.

The possibility of enhancing pressure from certain diseases under conservation tillage is not necessarily an argument to return to conventional tillage. However, producers should recognize situations when their production system may enhance disease activity so they can employ other disease management practices in order to maintain adequate levels of disease control.

Other Cultural Practices

Other preplant decisions can also influence disease activity. For example, early planting tends to enhance activity of Pythium seedling diseases, which are favored by cool, wet soils. Conversely, late planting can enhance pressure from gray leaf spot, a late-season disease that is more damaging on younger crops than more mature ones.

Plant populations are usually selected on the basis of hybrid characteristics and yield potential of the field. Some diseases can be more severe at high plant populations; several of the stalk rot diseases are examples. A fertility program that is inadequate or excessive, or in which major nutrients are not in proper balance, may also enhance disease activity.

Fungicides

Essentially all corn seed is treated before purchase with fungicides to help control seed rots and seedling diseases. This provides inexpensive protection against stand loss, should conditions favor these diseases after planting. Untreated seed should be treated with fungicides before planting.

Foliar sprays of fungicides may be economical in seed corn fields to protect against a variety of leaf diseases. They may also occasionally be justified for production of certain specialty corns. However, fungicide sprays typically do not show justifiable economic returns for commercial production of dent corn.

Scouting for Diseases

While it is not possible to know with complete certainty which diseases will develop in a given season, the disease history of the farm and area will indicate the diseases most likely to occur. A disease history for a farm is established by scouting fields and identifying disease outbreaks when they occur. Your county Extension agent, farm supply dealer, and crop consultant can also be good sources of information. However, farm-specific information obtained through field scouting is the most reliable basis for developing a farm disease history. Unless you are absolutely certain as to the cause of a particular problem, have the condition diagnosed by a reputable field specialist, or submit the sample to the University of Kentucky Plant Diagnostic Lab.

Mycotoxins

Several mycotoxins—toxins produced by fungi—can occasionally be found in shelled corn. Aflatoxins occur very infrequently in Kentucky, but when they occur, they are often associated with hot, dry weather during grain fill or with improper storage conditions. Fumonisins can also sometimes be found in Kentucky corn, as can vomitoxin (also called deoxynivalenol, or DON), and zearalenone. More information on mycotoxins in corn can be found in the Extension publications *Aflatoxins in Corn* (ID-59) and *Mycotoxins in Corn Produced by Fusarium Fungi* (ID-121).

Diseases of Corn

Anthracnose

Cause: Colletotrichum graminicola

Symptoms: Tan to brown leaf spots surrounded by a yellow halo, usually more abundant toward leaf tip. Lesions may coalesce, blighting entire leaves. Early in season, anthracnose symptoms are most common on lower leaves. Late in season, symptoms of anthracnose include blighting of upper leaves and possibly breakage of plant tops (see Top Dieback). Anthracnose also causes a late-season lower stalk rot. Black spines may be visible in dead leaf spots with a hand lens.

Damage: Early-season leaf symptoms usually are not damaging but indicate the need to scout later for stalk rot. Yields can be reduced from leaf blighting, although this is uncommon. The stalk rot phase can cause stalk lodging.

Key Features of Disease Cycle: The fungus survives in undecomposed corn residue. Spores are spread by wind-blown rain and rainsplash.

Management: Use resistant hybrids, especially where corn is grown without rotation under reduced tillage. Rotate away from corn for one to two years.

Ear and Kernel Rots

Cause: Stenocarpella, Gibberella, Fusarium, Aspergillus, Penicillium

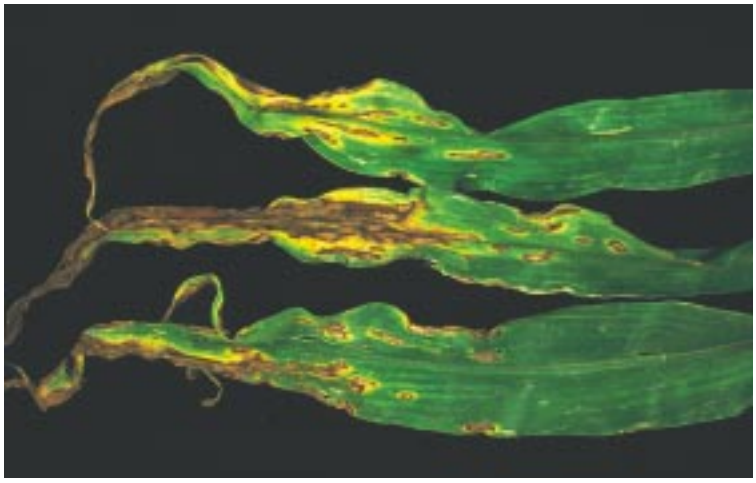
Symptoms: Moldy growth on ears and kernels. Helpful distinguishing features:

- Diplodia ear rot, caused by *Stenocarpella*—white mold growth between kernels, usually progressing from base of ear.
- *Gibberella*—pink to reddish mold growth, often progressing from ear tip.
- *Penicillium*—green or blue-green powdery mold on and between kernels, often at the ear tip.
- *Aspergillus*—greenish-yellow mold on and between kernels.
- *Fusarium*—whitish pink to lavender mold growing on individual kernels or small clusters of kernels.

Damage: Ear and kernel rots reduce feed value and marketability. Yield and test weight may also be reduced. When severe, *Diplodia* ear rot can affect 50 percent or more of the ears in a field. Contamination of grain by mycotoxins from certain ear molds can also reduce nutritional value and marketability of the corn. *Aspergillus* can contaminate grain with aflatoxins, although this toxin is very uncommon in Kentucky. *Fusarium verticillioides (=Fusarium moniliforme)* and related fungi can produce fumonisins in the grain, and *Gibberella* can contaminate the grain with vomitoxin (=DON or deoxynivalenol), zearalenone, or both.

Key Features of Disease Cycle: Wounds made by birds and insects provide infection sites for these fungi, although infection may occur in unwounded tissues. Other factors that can aggravate ear and kernel rots include lodging of stalks that brings ears in contact with soil, incomplete coverage of ears by husks, and maturation of ears in upright position.

Management: For *Diplodia* ear rot, rotate away from corn when 2 to 3 percent of ears have the disease; break up corn residue if practical to enhance decomposition; and avoid highly susceptible hybrids. For all ear and kernel rots, choose hybrids in which ears are well covered by husks and in which ears point downward at maturity. Control insects that feed on ears in the field. Harvest at about 25 percent moisture for shelled corn to minimize kernel damage and field losses. Adjust harvesting equipment for minimum kernel damage and maximum cleaning. Avoid harvesting faster than drying facilities can operate effectively. Dry shelled grain to below 15.5 percent moisture within 24 to 48 hours after harvest. Clean bins before storage and maintain dry storage conditions. Control insect infestations in storage. Periodically aerate and check for heating, crusting, or musty odors. Maintain stored corn uniformly as indicated in Table 1.



Anthracnose leaf symptoms. *(R. Stuckey)*

Table 1. Recommended temperatures for stored corn.

Average monthly temperature	Minimum grain temperature	Maximum grain temperature
Below 40° F	35° F	45° F
40° - 60° F	Within 5° F of average monthly temperature	Within 5° F of average monthly temperature
Above 60° F	55° F	65° F

Diplodia ear rot. *(P. Vincelli)*

Gibberella ear rot. *(D. G. White)*

Sources of Additional Information: Principles of Grain Storage (AEN-20), *Aeration, Inspection, and Sampling of Grain in Storage Bins* (AEN-45), *Aflatoxins in Corn* (ID-59), *Mycotoxins in Corn Produced by* Fusarium *Fungi* (ID-121).

Gray Leaf Spot

Cause: Cercospora zeae-maydis

Symptoms: Gray to tan, narrow, rectangular lesions $^1/_4$ to 2 inches long. Lesions on some hybrids exhibit a yellow border. Lesions are restricted by veins. Substantial numbers of leaf lesions usually do not appear until tasseling or later. Older leaves are affected first; severely affected leaves can be killed when lesions coalesce. Weakening and lodging of stalks may occur if a severe outbreak blights leaves during grain fill.

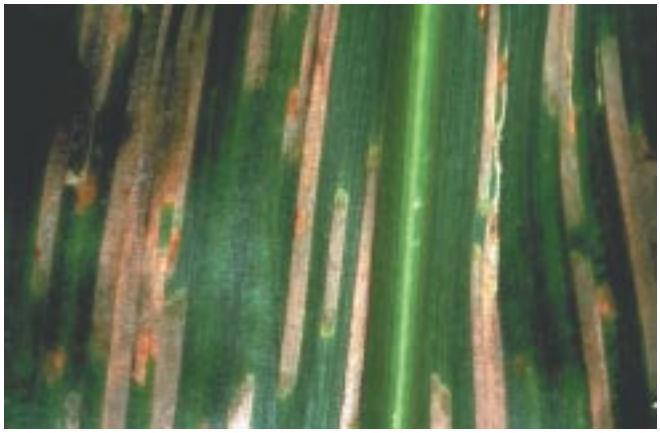
Damage: Yield is reduced through shorter ears and smaller kernels. Yield losses in the range of 10 to 20 percent are typical in susceptible hybrids grown in Kentucky, although losses of 50 percent or more may occur under very high disease pressure. Test weight may also be reduced. When leaf blighting is severe, stalks may weaken and lodge as the plant draws nutrients from the stalk to fill ears.

Key Features of Disease Cycle: The fungus survives for one to two years in undecomposed residue of infected leaf blades and sheaths. Spores are spread by air movement. Leaves become infected during prolonged periods (11 to 14 hours or more) of high relative humidity (>95 percent) and warm temperatures (72° to 86°F). The disease is most severe in fields with corn following corn under conservation tillage. Severe yield loss can occur when leaves become blighted during early grain fill.

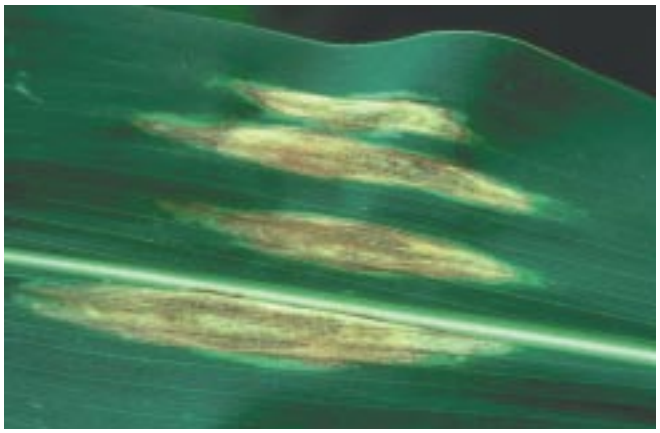
Management: Use resistant hybrids, especially when grown without rotation under conservation tillage. Recognize that there are no immune hybrids, although hybrids exist with a wide range of levels of partial resistance. Typically there is a greater choice of resistant hybrids among mid- and full-season hybrids than among early-maturing hybrids. Consider using a hybrid with high levels of resistance in fields where 1) last year's crop was corn, or 2) corn was grown two years ago and residue cover is at least 30 percent, or 3) there is untilled corn residue within 150 to

Fusarium ear rot. *(R. Stuckey)*

Aspergillus ear rot. *(R. Stuckey)*



Gray leaf spot on a susceptible hybrid. *(D. G. White)*



Northern leaf blight on a susceptible hybrid. *(D. G. White)*

500 feet of the field to be planted (the later the planting, the further it should be from untilled corn residue if it is a susceptible variety). Fungicidal control of gray leaf spot may occasionally be economically justified in certain fields of specialty corns. However, fungicide sprays usually do not show justifiable economic returns for commercial dent corn production.

Sources of Additional Information: Gray Leaf Spot of Corn (PPA-35).

Northern Leaf Blight

Cause: Setosphaeria turcica (= Exserohilum turcicum, = Helminthosporium turcicum)

Symptoms: Elliptical, grayish-green or tan lesions 1 to 6 inches long with smooth margins. During damp weather, greenish-black fungal sporulation is produced in lesions. Older leaves are affected first. Severely affected leaves can be killed when lesions coalesce. On hybrids carrying an Ht_2 resistance gene, long, yellow to tan lesions with wavy margins and no sporulation are observed on leaves infected with *S. turcica*. These resistance-reaction lesions can be easily confused with Stewart's wilt.

Damage: Yield and test weight can be substantially reduced in cool, wet summers, although most hybrids grown in Kentucky have adequate resistance.

Key Features of Disease Cycle: The fungus survives in undecomposed corn residue. Spores are spread by air currents. Spores germinate and infect leaves during wet weather with moderate (64° to 81°F) temperatures. Severe yield loss can occur when leaves become blighted during early grain fill. More severe in fields with corn following corn under reduced tillage. Also infects sorghum.

Management: Use resistant hybrids, especially when grown without rotation under conservation tillage. Hybrids with either single-gene (Ht) or multiple-gene resistance are available. Rotate away from corn and sorghum for one to two years.

Rusts

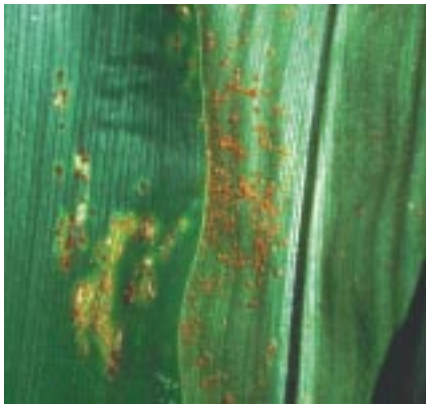
Cause: Puccinia sorghi, Puccinia polysora

Symptoms: Pustules that are circular to oval, golden-brown to cinnamon brown, up to 1/8 inch long. Pustules become brown to black at harvest. Leaves turn yellow and dry up when severely infected. Pustules of common rust (*P. sorghi*) are common on both leaf surfaces. Pustules of southern rust (*P. polysora*) are densely scattered on upper leaf surface with few on lower surface.

Damage: Common rust rarely causes economic loss in field corn in Kentucky. An aggressive outbreak of southern rust in late-planted crops may reduce stalk strength in a grain crop and quickly desiccate silage corn.

Key Features of Disease Cycle: Spores of both fungi are carried on springtime winds from southern areas of the United States. Common rust is active during cool (60° to 75°F), humid weather; southern rust is most active during warm (80°F), humid conditions. Both fungi infect leaves when spores are present and leaf surfaces are wet. Both are potentially more severe in late plantings. Greatest yield loss occurs in susceptible hybrids when outbreaks begin during early grain fill.

Management: Most hybrids in Kentucky have adequate resistance levels to common rust for our conditions. Resistance to southern rust is limited in hybrids commonly grown in Kentucky. Southern rust outbreaks, when they occur, develop in late summer. Therefore, minimize late plantings, which would be at a younger age and therefore more subject to yield loss should an outbreak occur.



Common rust (left) and southern rust (right). *(D. G. White)*

Seed Rot and Damping Off

Cause: Principally *Pythium ultimum*, but also *Stenocarpella*, *Fusarium*, *Penicillium*, *Rhizoctonia*

Symptoms: Rotting of seed before or after germination. Yellowing, wilting, and death of leaves of emerged plants. Soft rot of stem tissues. Rotting of roots, which may appear brown, watersoaked and grayish, faintly pink, or greenish-blue. May result in uneven stand height later in season.

Damage: Stand establishment and early-season vigor can be reduced, leading to lower yields.

Key Features of Disease Cycle: These pathogens are common fungi in Kentucky soils. They usually do not limit stands but can do so when seedlings are stressed. Common stresses include planting in cool, wet soils and chemical injury. Early planting dates preferred by many farmers tend to enhance these diseases.

Management: Use high-quality, vigorous seed treated with fungicide. Plant in warm (above 50°F), moist soils; measure soil temperature at a 2-inch depth after sunrise. Place herbicide, fertilizer, insecticide, and seed properly to avoid stress or injury to seedling.

Symptoms of Pythium root rot. The outer root cylinder appears watersoaked and easily is pulled away from vascular tissue. *(D. G. White)*

Smut, Common

Cause: Ustilago maydis

Symptoms: Greenish-white or silvery galls, or swellings, up to 6 inches in diameter. Galls can occur on any aboveground plant part. As galls age (except those on leaves), the interior darkens and turns into masses of powdery, dark olive to black spores. Galls on leaves usually remain small (0.5 inch or less) and become hard and dry without rupturing. Plants with galls on the lower stalks may be barren or produce small ears.

Damage: Hybrids of field corn grown in Kentucky typically have adequate resistance, and consequently, yield losses typically are minimal (2 percent or less) to nonsignificant.

Key Features of Disease Cycle: The fungus survives for several years as spores in corn residue and in soil. Spores can infect any actively growing aboveground plant part. Wounding (stinkbugs or other forms of injury) enhances infection substantially. Once infection occurs, galls develop, enlarge, turn powdery, and rupture to release spores.

Management: Use hybrids with adequate resistance.

Common smut. *(R. Stuckey)*

Southern Leaf Blight

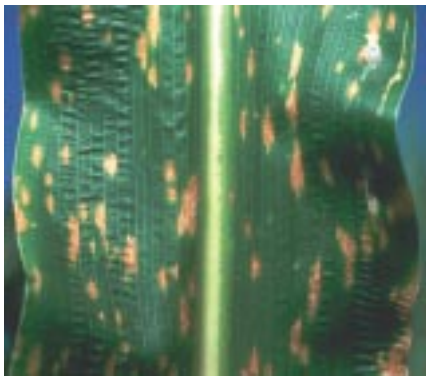
Cause: Cochliobolus heterostrophus (=Bipolaris maydis, =Helminthosporium maydis)

Symptoms: Elliptical, tan to light brown, small lesions ($^1/_8$ to $^1/_4$ inch by $^1/_4$ to $^3/_4$ inch), often with somewhat parallel sides, and sometimes with a brown border. Older leaves are affected first; severely affected leaves can be killed when lesions coalesce.

Damage: Yield and test weight can be reduced, although most hybrids have adequate resistance for our conditions.

Key Features of Disease Cycle: The fungus survives in corn residue. Spores are spread by air currents. Spores germinate and infect leaves during warm (68° to 90°F), wet weather. More severe in fields with corn following corn under reduced tillage. Greatest yield loss can occur when leaves become blighted during early grain fill.

Management: Plant resistant hybrids, especially when grown without rotation under reduced tillage. Rotate away from corn for one to two years.



Southern leaf blight. *(D. G. White)*

Stalk Rot

Cause: Stenocarpella maydis (= Diplodia maydis), Gibberella zeae (= Fusarium graminearum), Fusarium verticillioides (= Fusarium moniliforme), Macrophomina phaseolina, Colletotrichum graminicola

Symptoms: Lower stalk is spongy and internal tissue (pith) shredded and often discolored. Stalks weaken and lodge. Plants sometimes turn grayish-green and dry prematurely during grain fill. Helpful distinguishing features:

- Diplodia stalk rot, caused by *Stenocarpella*—Stalk and pith light brown. Small, dark-brown to black pimple-like fruiting structures develop just below epidermis near base of stalk.
- *Gibberella*—Pith pink to reddish. Small black pimple-like fruiting structures develop superficially on stalk near nodes and can be easily scraped off with fingernail.
- *Fusarium*—Pith whitish-pink to salmon-colored. Roots often rotted. Difficult to distinguish from *Gibberella*.
- Charcoal Rot (*Macrophomina*)—Pith contains many very tiny black fungal structures, giving charred appearance. Roots rotted and black.
- Anthracnose (*Colletotrichum*)—Dark brown to black discoloration on exterior of lower stalk. Dark spines may be visible with hand lens, especially near soil line. Pith light to dark brown.

Damage: Plants lodge and become difficult or impossible to harvest. In severe cases, grain yield may be reduced.

Key Features of Disease Cycle: These fungi survive on corn residues. All but charcoal rot are favored by warm, wet weather during grain fill. Charcoal rot is favored by hot, dry weather during grain fill. Other aggravating factors:

- High plant populations.
- Loss of leaves from disease, insects, or hail.
- Excessive nitrogen, especially when combined with low potash.

Early-season hybrids are often more susceptible than full-season hybrids. Several stalk-rot fungi also cause ear and kernel rots. *Colletotrichum* also causes anthracnose of leaves, as well as top dieback. *Macrophomina* also infects sorghum and soybean.

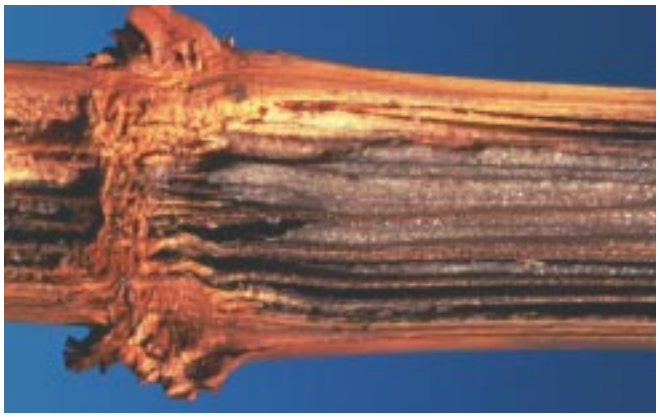
Management: Use hybrids resistant to stalk rots and important leaf diseases like gray leaf spot. Avoid excessive plant populations. Maintain balanced soil fertility and adequate but not excessive nitrogen. Control insects that feed on leaves, stalks, and roots. Scout for stalk rots by either pinching the lower two or three stalk internodes or by pushing stalks 8 to 12 inches from vertical to check for lodging. Harvest early if 10 to 15 percent show disease. Avoid growing continuous corn. Consider avoiding soybean and sorghum following severe outbreaks of charcoal rot.

Sources of Additional Information: Corn Stalk Rots (PPA-26).

Diplodia stalk rot. *(R. Stuckey)*

Gibberella stalk rot. Note pink to reddish discoloration in pith. *(D. G. White)*

Gibberella stalk rot. Note fruiting structures on thumbnail. *(D. G. White)*



Charcoal rot. *(D. G. White)*

Anthracnose stalk rot. *(D. G. White)*

Stewart's Wilt

Cause: Pantoea stewartii (=Erwinia stewartii)

Symptoms: Long (2 to 10 inches), linear (1/8 to 1 inch wide) leaf lesions with very wavy margins. At first, lesions are pale green to yellow, but they become light brown when they dry. Severely affected leaves are killed. Lesions of Stewart's wilt are easily confused with lesions on hybrids carrying an Ht_2 resistance gene to northern leaf blight. To aid field diagnosis, hold leaves to light and look in lesions for scratch-like feeding marks of flea beetle; if uncertain, submit samples to the University of Kentucky Plant Diagnostic Labs. Infection of seedlings causes rapid wilt and death.

Stewart's wilt. *(D. G. White)*

Damage: Yield and test weight can be reduced in susceptible hybrids, although most hybrids of dent corn have adequate resistance. In a highly susceptible variety, stands may be reduced if infected as seedlings.

Key Features of Disease Cycle: Overwinters in body of corn flea beetle, which also spreads the bacterium. Disease pressure is usually high in Kentucky but can be low following a very cold winter, which kills overwintering flea beetles.

Management: Plant resistant hybrids. Control of the disease in field corn through application of insecticides targeting the flea beetle is uneconomical.

Sources of Additional Information: Stewart's Wilt of Corn (PPA-33).

Top Dieback (Upper Stalk Rot)

Cause: Colletotrichum graminicola

Symptoms: Plants turn yellow or red from top downward during grain fill. Leaves at ear level remain green. Lodging and breakage of stalks occur when severe. Internal stalk tissue has brown discoloration. Be sure to rule out stalk injury from European corn borer.

Damage: Yield and test weight can be reduced, although serious outbreaks of this phase of anthracnose have not been commonly reported in Kentucky in recent years. Stalk lodging may occur.

Key Features of Disease Cycle: The fungus survives in corn residue. Spores are spread by windblown rain and rainsplash. Also causes early-season anthracnose on leaves, as well as anthracnose stalk rot.

Management: Use resistant hybrids, especially when grown without rotation under reduced tillage. Rotate away from corn for one to two years.

Top dieback. *(R. Stuckey)*

Virus Complex

Cause: Maize Dwarf Mosaic Virus (MDMV), Maize Chlorotic Dwarf Virus (MCDV)

Symptoms: Symptoms can be variable. MDMV typically causes stunting and irregular, light and dark green mosaic patterns in the leaves, especially the youngest leaves. MCDV typically causes stunting, yellowing, and sometimes reddening of the youngest leaves and sometimes causes leaf tattering. Usually most severe around areas of fields highly infested with johnsongrass rhizomes.

Damage: Yield and test weight can be reduced substantially in localized outbreaks in and around areas with rhizome johnsongrass.

Key Features of Disease Cycle: Both viruses overwinter in johnsongrass rhizomes. MDMV is spread by certain aphids; MCDV, by certain leafhoppers. Late-planted fields have greater risk of serious disease outbreaks. Compared to corn planted on time, late-planted corn is at an earlier stage of crop development when insect vectors become active. Earlier infection usually results in more severe symptoms. MDMV also causes a disease of sorghum.

Management: Use virus-tolerant hybrids in fields with heavy infestations of johnsongrass rhizomes. Eliminate johnsongrass rhizomes to reduce disease pressure. Avoid late planting since the younger a crop is when an outbreak occurs, the more yield loss is possible.

Sources of Additional Information: Virus Diseases of Corn in Kentucky (PPA-40).

Virus complex. *(P. Vincelli)*

Acknowledgment

Thanks to Donald Hershman for reviewing a previous draft of this chapter and to Donald G. White and Richard Stuckey for providing photos.

Insect Pests

Ric Bessin

To manage insect pests of corn, producers have a large number of effective options including preventive cultural controls (such as rotation), insecticides, and resistant hybrids from natural and biotech sources. The challenge for producers is to select only the insect management tools that are needed to prevent economic losses. Producers use crop growth information, pest intensity levels and development stage, pest history, weather conditions, grain price, expected yield, and cost of the control to determine the need for action.

Insect Resistance through Biotechnology

Agricultural biotechnology is producing highly effective tools to manage troublesome corn insect pests. These hybrids use various genes from the soil bacterium *Bacillus thuringiensis* (Bt) to produce proteins that disrupt the digestive system of certain insect pests. These Bt proteins are very selective, i.e., each one will affect only specific groups of insects. These proteins are nontoxic to mammals and other animals. Biotech hybrids are available that control European and southwestern corn borer and suppress fall armyworm and black cutworm. In the near future, other types may be available that provide control of corn rootworm and enhanced control of black cutworm.

In the case of Bt corn, to kill a susceptible insect, a part of the plant that contains the Bt protein (not all parts of the plant necessarily contain the protein in equal concentrations) must be ingested. Within minutes, the protein binds to the gut wall and the insect stops feeding. Within hours, the gut wall breaks down and normal gut bacteria invade the body cavity. The insect dies of septicaemia as bacteria multiply in its body. Even among Lepidoptera larvae, species differ in sensitivity to the Bt protein.

Producers using pest-resistant biotech crops must use recommended resistance management strategies because pests may have a high potential to develop tolerance to crops containing Bt. It is the producer's responsibility to use approved resistance management practices when using biotech crops.

Pest Monitoring Procedures

To monitor for insect pests in corn, random sites are selected in the interior of fields. Scouting methods will differ among the key pests. The number of sites depends on the size of the field. In fields of fewer than 25 acres, three sites are needed. In larger fields, add one site for each additional 10 acres. Use recommended scouting methods for specific pests so that scouting information can be compared with the established treatment guidelines.

Key Factors

Planting date and spring weather conditions to a large part determine the potential for insect damage to corn. Southwestern corn borer, European corn borer, fall armyworm, and corn earworm are generally more damaging to late-planted corn. Typically, corn planted after May 10 in Western Kentucky and after May 20 in Central Kentucky is at greater risk to sustain economic losses from these pests. Very early planted corn may experience greater first generation European corn borer activity but will usually escape damage by the second generation. Cool weather conditions and low soil temperatures after seedling emergence may expose young plants to cutworm and flea beetle damage over an extended period. Greater attention should be paid to monitoring plants for seedling pests during these growing conditions.

Major Pests

Black Cutworm

Cutworms are potentially very destructive but are unpredictable, and the chances of significant damage in any given year are relatively low. Corn can be seriously damaged by cutworms from planting through mid-June while the plants are less than 18 inches tall. Serious losses are often associated with wet springs that have caused a delay in planting or during periods of cool weather. Cutworms feed mostly at night and hide during the day under clods of soil or in burrows below the soil surface. They cut off the seedlings at or just below the soil surface. The potential for cutworm infestations is influenced by late planting, low and wet areas of the field that drain poorly, and fall and early season weed growth. Preventive treatments made at planting may or may not provide sufficient control. A rescue treatment may be necessary for moderate to heavy in-

Black cutworm.

festations even when a preventive treatment was used. Early land preparation and weed control help to reduce cutworm problems because infestations usually develop on early season weed growth. Control weeds at least 2 weeks before planting.

Scouting Procedures

Description: Cutworms vary from dark greasy-gray to black. They have a lighter colored stripe down the middle of the back, smooth skin, and a brown head capsule. Cutworms may reach 1 3/4 inches in length. Cutworms commonly coil up into a "C" shape when disturbed.

Damage: Small larvae chew small holes in leaves; large larvae chew into the base of seedlings, cut small plants, and may pull plant parts into the burrow. Symptoms are wilted or cut plants.

When to monitor: Corn should be monitored for cutworms at least twice a week for the first 3 to 4 weeks after seedling emergence.

How to scout: Begin making counts when wilted or cut plants are first observed. Examine 20 consecutive plants and record the number of cutworm-damaged plants. Look for live cutworms near damaged plants as they hide during the day. Dip up an area 3 inches in radius around the base of a damaged plant. Note the number and size of cutworms.

Economic threshold: 3 percent or more cut plants and 2 or more live larvae, 1 inch or smaller, per 100 plants. If conditions are borderline, check field again in 24 to 48 hours.

Corn Flea Beetle

Flea beetles are among the first insects to feed on emerging corn. These beetles overwinter as adults near corn fields and are active in weeds early in the spring. Populations are generally highest following mild winters. These very small, dark insects jump readily when disturbed; hence the name flea beetles. Flea beetles are important in corn for two reasons. First, they are leaf feeders and large infestations can kill small seedlings. Feeding by these beetles results in scarring of the leaf surface that appears from a distance as frost injury. Serious damage can occur on plants less than 6 inches tall. Most hybrids will recover from moderate levels of flea beetle damage under good growing conditions. Control is rarely justified, unless damage is extensive and growing conditions are poor. Early feeding often occurs during cool weather when corn growth is retarded. Second, flea beetles are also vectors of Stewart's wilt, also known as bacterial leaf blight. Selection of corn varieties resistant to this disease should be considered.

Scouting Procedures

Description: Corn flea beetles are very small, dark insects that jump readily when disturbed.

Damage: These beetles are leaf feeders. They make small feeding scars on the surface giving leaves a gray, frosted appearance. Damage is generally serious on plants less than 6 inches tall. Flea beetles transmit Stewart's wilt, also known as bacterial leaf blight.

When to monitor: Check corn from emergence until 12 inches tall. Flea beetle stress may be great on late-planted corn. However, early-planted fields may also show noticeable damage.

Economic threshold: Treat only when 50 percent or more of the plants show signs of feeding on new leaves with some leaves turning white or brown.

Corn Rootworms

Corn rootworms can be serious pests of continuous corn in Kentucky. The typical damage symptom is lodging or "goose-necking" of corn that may begin to appear near the end of the larval feeding period. The entire root system may be destroyed by a

Corn flea beetle.

Western corn rootworm larva.

heavy population pressure. Pruned roots place physiological stress on the plant by reducing water and nutrient uptake that reduces yields, especially when coupled with low moisture or poor fertility. Emerging corn rootworm beetles feed on green silks, pollen, and green epidermal layer of corn leaves. While rootworm adults may be found in soybean, alfalfa, or sorghum late in the growing season, unlike in states farther north, damage by rootworm larvae to corn following these crops is rare in Kentucky. Crop rotation continues to be the most effective method of controlling rootworm larval damage. Because most rootworm eggs are laid in corn fields during the growing season, if corn is not planted in the field the following year, the hatching larvae are left without food and will starve. Treatment of first-year corn for rootworm is not normally needed in Kentucky.

Scouting Procedures

Description: Corn rootworm larvae have cylindrical white to cream bodies with a brown to black head and a pair of small legs on each of the first three segments behind the head. There is a small brown or black area on the top of the last segment. Full grown larvae are about ½ inch long. Three species of corn rootworm beetles are found in Kentucky. The northern corn rootworm adult is pale green to yellow and about 1/4 inch long. The southern corn rootworm adult (also called the spotted cucumber beetle) is about 3/8 inch long. It is yellow-green with 11 conspicuous black spots on the wing covers. The western corn rootworm beetle is yellow with three black stripes on the wing covers.

Damage: Larvae feed on corn roots reducing the uptake of water and nutrients. High winds may blow down severely damaged plants. Adult beetles feed on silks, pollen, and leaves. Large numbers during pollen shed may clip silks and interfere with pollenation. Adult rootworm feeding on leaves generally does not affect yield.

When to monitor: Monitor for rootworm symptoms from late May through June. Watch for irregular growth patterns and plant stress. Monitor for adult rootworms from onset of silking until silks are brown. Also late-planted corn should be inspected in the whorl stage for adult beetles.

How to scout: Dig up a 6-inch cube of soil containing the root zone of stressed plants to scout for larvae and their damage. Carefully break away the soil from around the root zone and look for rootworm larvae and evidence of chewing on the plant roots. To monitor for adults, look for beetles as you walk through the field. If beetles are active, follow these guidelines: 1) Make counts on 20 plants from each location beginning with random selection of the initial plant. Make counts on every third or fourth plant until 20 plants per location are examined. 2) Rootworm beetles fly readily when disturbed so approach each plant carefully. Count the beetles on the ear tip, tassel, leaf surfaces, and behind the leaf axil.

Economic threshold: There are no effective rescue treatments once symptoms of rootworm damage begin to appear. Damage by rootworm larvae indicates the need to rotate to another crop next year or to use a soil insecticide at planting if planting corn in that field next year. Treatment may be necessary to control adult rootworms if silks are clipped back to 1/2 inch or less before 50 percent of plants are pollinated and five or more beetles are present per plant. Counts of northern and western corn rootworm beetles are used to make soil insecticide recommendations for the following year. If counts of western or northern or both together approach or reach an average of 20 beetles per 20 plants (1 per plant), the farmer will be advised to use a rootworm insecticide if corn is grown in this field next year.

Armyworm

Armyworm is a sporadic early season pest that can cause occasional losses in corn and should be monitored in the spring. Infestations usually first develop in fields of small grains or in other grass cover crops. In conventional tillage systems, partially grown larvae can migrate into corn fields from grass waterways or wheat fields. Damage is usually first noticeable around the field margins adjacent to these areas. Armyworms usually feed at night and damage corn by chewing leaves. They prefer to feed on the succulent leaves in the whorl first. Feeding is usually confined to leaf margins, but occasionally the insects may strip the entire plant, leaving only the midrib of the leaves. During the day, armyworms are found in the soil or underneath groundcover.

Scouting Procedures

Description: The full-grown 1 1/2-inch armyworm has a greenish brown body with a thin stripe down the center and two orange stripes along each side. The head is brown with dark honeycombed markings.

Damage: Armyworms usually feed at night and damage corn by chewing leaves. They prefer to feed on the succulent leaves in the whorl first. Feeding is usually confined to leaf margins, but occasionally they may strip the entire plant, leaving only the midrib of the leaves.

When to monitor: Mid-May through June. Armyworm damage is often associated with cool, wet spring weather conditions.

How to scout: In conventional tillage, infestations usually begin around the field margins adjacent to small grains or grassy strips. These areas should be scouted first. If armyworms are present, determine how far the infestation extends into the field. To sample for armyworms, examine 20 consecutive plants in each of at least five random locations in the field. Note the number of plants with the characteristic damage and the size of

Armyworm moth.

Armyworm.

the larvae. When scouting for armyworms, look on the armyworms for parasitic eggs. These small, oval, yellowish eggs are usually located just behind the head of the larva. These are eggs of a fly parasite that will kill the larva.

Economic threshold: Control actions in corn are recommended when armyworms average between ½ and ¾ inches and the entire field averages 35 percent infested plants or 50 percent or more defoliation is seen on damaged plants. Do not include parasitized larvae in the counts used to determine the economic threshold.

European Corn Borer

The corn borer larva tunnels into corn stalks and ear shanks and feeds on kernels in the ear. The severity of corn borer infestations varies from year to year and even from field to field on the same farm. First-generation moths are attracted to early-planted corn, while late-planted corn is most susceptible to damage from the second generation. Corn borers cause damage in two major ways. First, tunneling in the stalk reduces water and nutrient flow and contributes to physiological yield loss. This is the primary cause of yield reduction. Second, borers produce cavities in the plant that weaken it. Stalk breakage and ear drop, prior to harvest, can lower yields through harvest losses. These losses increase if harvest is delayed. Strong winds or driving rains during early season moth flight may reduce corn borer activity for the entire season. However, calm, warm nights during the egglaying promotes high corn borer populations, even if the adult population is relatively small. Early harvest can reduce losses due to broken or lodged plants or dropped ears. Second-generation damage is the primary cause of harvest loss. Early planting combined with early harvest can be an effective management strategy.

Scouting Procedures

Description: Eggs are creamy white when first laid and develop a dark spot close to hatch. Eggs are laid in groups of 15 to 35 and overlap each other much like fish scales. Larvae are pinkish colored, marked with small round brown spots and a faint grey stripe running the length of the back. They reach 1 inch when fully grown.

Damage: Small first-generation larvae make "window pane" holes in leaves that are noticed as they emerge from the whorl. Some enter leaf midribs and cause them to break. Larger larvae tunnel into the stalk. Second-generation damage include feeding on the stalks, tassels, ear shanks, and developing kernels.

European corn borer.

European corn borer moth.

When to monitor: First generation: Late May to early June. Early-planted corn has the greatest potential for damage. Second generation: Late June to August. Late-planted corn is most susceptible to this generation.

How to scout: Randomly select 20 consecutive plants at each site. For the first generation note the number of plants with fresh damage to leaves emerging from the whorl. Pull the whorls from two damaged plants and examine for the presence of borers. For the second generation, pay special attention to late-planted fields. Examine 20 plants per locations and check plants for egg masses and signs of feeding and larvae feeding on the leaves, tassels, leaf axils, or behind leaf sheaths.

Economic threshold: Treat for first generation if 50 percent or more of the plants are infested and live larvae are present in the whorls. For the second generation, treatment is recommended if an average of one egg mass per plant is recorded or if 50 percent of the plants have live larvae feeding on the leaves, tassels, leaf axils, or behind leaf sheaths. A more comprehensive economic threshold can be found in *European Corn Borers in Corn* (ENT-49).

Southwestern cornborer.

Southwestern corn borer moth.

Comments: All of the currently available Bt-corn hybrids provide effective control of first-generation larvae, but some do not maintain this level of control against the late-summer generations.

Southwestern Corn Borer

While similar in biology to the European corn borer, southwestern corn borer is more difficult to control. It is found in the western part of the state and has two generations per year. The first generation attacks whorl-stage corn and is associated with losses to yield by stunting or killing plants. The second generation occurs during mid- to late summer and increases harvest losses through stalk breakage due to extensive tunneling. In the fall, overwintering larvae increase plant lodging by girdling the base of the stalk just above the soil. Early planting, when practical, is generally the most efficient and economical method of preventing plant damage and yield losses to this pest. However, wet weather frequently delays corn planting and increases the possibility of borer infestations. Corn planted after May 1 has a greater potential for southwestern corn borer infestations. Lower establishment rate by second-generation borers on older plants is the primary reason for early planting.

Scouting Procedures

Description: Eggs are laid singly or in groups of two to five, with the flattened eggs overlapping like fish scales. Initially eggs are greenish-white but develop three distinct red transverse lines within 24 to 36 hours. Larvae are creamy-white with numerous conspicuous black spots and a brown head capsule. The full-grown larva is 1 1/4 inch in length.

Damage: For the first 2 weeks, first-generation larvae feed within the whorl of the plant; later they tunnel into the stalk. Numerous holes in the emerging leaves and leaf breakage due to midrib tunneling are characteristic. The second generation causes the greatest damage. These larvae begin feeding in the mid and lower zones of tassel-stage corn in mid-to-late July. After about two weeks, the larvae begin tunneling in the stalk. Characteristically, they make a straight line through the middle of the stalk. In the fall, borers that will remain larvae throughout the winter migrate to the base of the plant and girdle the plant at the base before tunneling downward. Larvae girdle the stalk by chewing a complete or partial internal groove, leaving only a thin outer layer for support.

When to monitor: First generation: Late May to the end of June. Early-planted corn has the greatest potential for damage. Second generation: Early July to the end of August. Late-planted corn is most susceptible to this generation.

How to scout: Use the same methods described for the European corn borer.

Economic threshold: Controls for first-generation southwestern corn borer should be considered if 35 percent of the plants show signs of damage and live larvae are present in the whorls. Control of second generation with insecticides is difficult because the attack is concentrated low on the stalk.

Comments: All of the currently available Bt-corn hybrids provide effective control of first-generation larvae, but some do not maintain this level of control against the late-summer generations. Currently, only the YieldGard hybrids provide the full-season control needed to prevent the stalk girdling caused by the late-season larvae.

Fall Armyworm

Fall armyworm can be one of the more difficult insect pests to control in field corn. Late-planted fields and

Western corn rootworm adult.

Fall armyworm.

late-maturing hybrids are more likely to become infested. Fall armyworm causes serious leaf feeding damage as well as direct injury to the ear. While fall armyworms can damage corn plants in nearly all stages of development, they will concentrate on late plantings that have not yet silked. Large fall armyworm larvae consume large amounts of leaf tissue, resulting in a ragged appearance to the leaves similar to grasshopper damage. Larger larvae are usually found deep in the whorl, often below a "plug" of yellowish brown frass. Beneath this plug, larvae are protected somewhat from insecticide applications. Plants may recover from whorl damage without any reduction in yield. Producers should pay close attention to late-planted fields; problems are usually associated with fields planted after June 1. Some Bt-corn hybrids may suppress this insect.

Scouting Procedures

Description: The spherical gray eggs are laid in clusters of 50 to 150, usually on the leaves. Egg masses are covered with a coating of moth scales or fine bristles. Larvae hatch in three to five days and move to the whorl. Larvae range from light tan to black with three light yellow stripes down the back. There is a wider dark stripe and a wavy yellow-red blotched stripe on each side. Larvae have four pairs of fleshy abdominal prolegs in addition to the pair at the end of the body. Fall armyworm resembles both armyworm and corn earworm, but fall armyworm has a white inverted "Y" mark on the front of the dark head. Fall armyworm has four dark spots arranged in a square on top of the eighth abdominal segment.

Damage: Small larvae cause elongated "window pane" damage to leaves similar to European corn borer. The most common damage is to late pre-tassel corn. Large fall armyworm larvae consume large amounts of leaf tissue resulting in a ragged appearance similar to grasshopper damage. Large larvae are usually found deep in the whorl, often below a "plug" of yellowish brown frass. Beneath this plug, larvae are protected somewhat from insecticide applications. Plants often recover from whorl damage without any reduction in yield. On later stages of corn, fall armyworm larvae often attack the developing ear directly.

When to monitor: Begin monitoring in mid-June. Pay close attention to late-planted fields or fields with a history of these problems.

How to monitor: Survey 20 consecutive plants from at least five locations in the field. Examine the plants for egg masses, signs of damage, and live larvae in the whorl. Pull the whorl on two damaged plants to determine if the larvae are protected beneath a frass plug.

Economic threshold: If present in damaging numbers in the field, it must be controlled while the larvae are still small. Control needs to be considered when egg masses are present on 5 percent of the plants or when 25 percent of the plants show damage symptoms and live larvae are still present. Controlling large larvae, typically after they are hidden under the frass plug, will be much more difficult. Treatments must be applied before larvae burrow deep into the whorl or enter ears of more mature plants.

Economics for Corn Production

Greg Ibendahl

Corn producers grow corn to make a profit. Thus, an understanding of some basic economic concepts and tools should help them become better managers.

Enterprise Budgets

One of the best tools for planning purposes is an enterprise budget. Enterprise budgets predict profitability by incorporating quantities and prices of all inputs and outputs. Enterprise budgets are started by estimating the expected corn production in bushels per acre and the expected price received. These two pieces of information give the expected gross revenues per acre. Next, all the expected quantities and prices of inputs are listed to provide the expected expenses per acre. Table 1 shows a typical corn budget for Kentucky. This interactive budget is available from the Department of Agricultural Economics at the University of Kentucky. The Web address is: http://www.uky.edu/Agriculture/AgriculturalEconomics/data/baledcropbudgetinstr495.html.

The corn budget in Table 1 is divided into three main sections: gross returns, variable costs, and fixed costs. These are all stated on a per acre basis. Gross returns are calculated by multiplying the expected yield per acre by the expected price. For situations where corn is used by a livestock enterprise, a value is still assigned to those bushels.

Expenses are divided into variable and fixed costs by whether the expense varies as the size of the enterprise changes. Most of the expenses, such as seed, fertilizer, chemicals, etc., vary as the enterprise size varies. However, depreciation, insurance, and taxes are not dependent on the size of the corn enterprise. For example, insurance is the same whether the farm grows 70 acres of corn and 30 acres of soybeans or if 30 acres of corn are grown with 70 acres of soybeans. In establishing a cost for the variable inputs, a usage rate per acre is multiplied by the appropriate price per unit.

The last item for the variable costs is an interest charge. This cost reflects the money needed to plant a crop. When the crop is sold, the money is returned. If the money is borrowed, this is the actual interest expense. When the farmer's own equity is used, this cost is an opportunity cost since the money could have been earning interest. Usually six months is used as the time frame for the interest on variable costs (i.e., planting to harvest is roughly six months).

The difference between gross returns and total expenses is the return to operator labor, land, capital, and management. The return to operator labor and management is compensation for the farmer's time and expertise invested in growing a corn crop. The return to land and capital is an opportunity cost for using the land and other capital. Because the farmer has equity invested in the land, those funds cannot be earning interest in a bank or used for other purposes.

Any preexisting budget should be used with care. More than likely, the quantities and prices will need to be adjusted to fit an individual producer in a given year. In Table 1, the price of corn will almost certainly need to be adjusted. The interactive budget from the Department of Agricultural Economics makes this process easy since it automatically adjusts the computations.

Determining prices and quantities is probably the most difficult aspect of building a corn budget. Input prices can be readily obtained from many agribusinesses. However, the best source for quantity information, is a farmer's own records. Good production records can provide information about yields and about how much fertilizer and chemicals normally are used.

The Department of Agricultural Economics also provides a tool that can help a farmer develop his or her own corn budget. This budget generator is the "Corn Cost and Return Estimator" and is available at: http://www.uky.edu/Agriculture/AgriculturalEconomics/data/baledcorninstr495.html. The tool uses information about how the corn is grown, soil tests, price information from suppliers, etc., to develop a more detailed corn budget.

Estimates of corn prices are probably more uncertain than the other estimates. Prices can vary a lot during the summer due to weather-related events. Proper marketing can help here too. The price on the budget should be the average price received and not the price at harvest. The price should also reflect any government payments that change in response to enterprise size. For example, LDP payments, since these are tied to production, should be added to the budget price.

An additional step to enterprise budget preparation and use is to conduct sensitivity analysis. The original numbers used in the budget were probably the producer's predictions of normal yields and prices. However, as most producers are aware, very few years are average. By conducting a sensitivity analysis, producers can see the effects on their incomes by trying other combinations of yields and prices. At a minimum, a producer should examine a worst case, an average case, and a best case scenario. These results should help farm managers do forward planning. In addition to yields and corn prices, producers might also conduct sensitivity analysis of fertilizer and fuel prices.

Table 1. Typical corn budget.

	Amount	Unit	Price	Total
Gross returns per acre				
Corn	125	bu	$2.75	$343.75
Variable costs per acre				
Seed	0.32	bag	$78.00	$24.96
Fertilizer	1	acre	$51.90	$51.90
Lime	1	ton	$12.12	$12.12
Herbicides	1	acre	$20.00	$20.00
Insecticides	1	acre	$15.00	$15.00
Fungicides	1	acre	$0.00	$0.00
Fuel and oil	2.2	hrs	$6.31	$13.88
Repairs	1	acre	$22.77	$22.77
Custom application	1	applications	$4.12	$4.12
Equipment rental	1	acre	$0.00	$0.00
Drying	125	bu	$0.11	$13.75
Crop insurance	1	acre	$0.00	$0.00
Cash land rent	1	acre	$0.00	$0.00
Hired labor	0	hrs	$0.00	$0.00
Interest on variable costs (½ year)	$178.50	dollars	4.50%	$8.03
Total variable cost				$186.53
Return above variable cost				$157.22
Budgeted fixed costs/acre				
Depreciation				$40.00
Taxes and insurance				$10.00
Total budgeted fixed cost				$50.00
Return to operator labor, land, capital, and management				$107.22
Less operator labor	4.5	hrs	$7.00	$31.50
Return to land, capital, and management				$75.72

University of Kentucky, College of Agriculture, Cooperative Extension Service.

Break even price **$1.49** per bu to cover variable costs at **125** bu per acre
Break even yield **67.8** bu to cover variable costs at **$2.75** per bu

Partial Budgets

Enterprise budgets are great for showing how an enterprise contributes to profitability. However, sometimes a producer might be interested in examining how some adjustment to an enterprise or combination of enterprises affects profitability. Examples include growing high-oil corn instead of conventional corn or replacing soybean acres with corn acres. Partial budgeting is a good tool for these situations because only those costs, incomes, and resource needs that change with a proposed adjustment are examined. The resources, costs, and income that are not affected with the proposed change are ignored.

Partial budget analysis is a three-step process. Step one determines what increases the profits of the farm business when a change is implemented. This increase in profitability can come from either greater income or less costs. Step two determines what decreases the profits of the farm business. A reduction in income and an increase in costs can decrease the profitability of the farm business. Step three determines the net change in profits. This step compares the increase in profits from step one to the decrease in profits from step two. If the increase in profits are greater than the decrease in profits, then the change should be made.

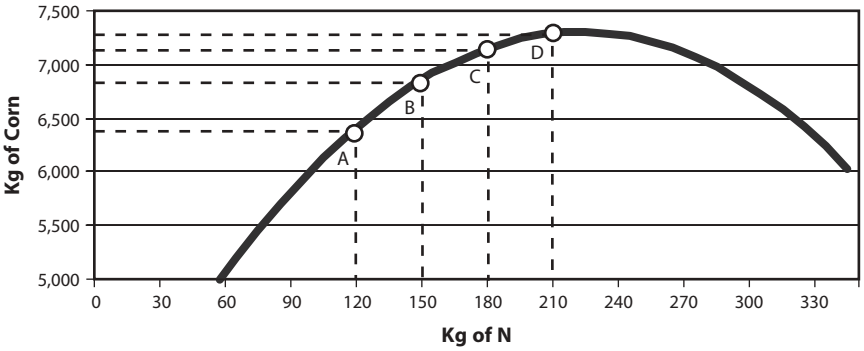
An example should help clarify the process. Consider a farmer looking at replacing 40 acres of conventional corn with 40 acres of high-oil corn. Step one requires the farmer to determine the increase in farm business profits. For step one, the farmer should have greater income from the 40 acres of high-oil. This is calculated as 40 acres times yield per acre times price received. Growing high-oil may not have any reduced costs, so the only contribution to step one is the increase in income. Step two has the farmer determining the decreases in farm business profits. Here, there are two contributions, less income and more costs. Reduced income is from giving up the 40 acres of conventional corn (acres x yield x price). Increased costs occur from likely higher costs for seed, transportation, and storage associated with high-oil corn production. If the benefits from step one outweigh the decreases in step two, the farmer should make the switch to high-oil corn.

Cost Concepts

Input costs are a concern for many producers since it seems that the prices of inputs rise faster than the price of corn. Corn producers should be aware of at least two cost concepts, fixed versus variable costs, and long-run versus short-run costs. The two concepts are related and help explain the rationale behind many farm decisions.

As Table 1 shows, budgets are divided into variable and fixed costs. Variable costs change with the volume of corn produced. You can think of variable costs as those that the manager has control over at a given point in time. Seed, fertilizer, herbicides, fuel and oil, etc., are directly related to how much corn is produced and are directly controlled by the manager. As more of the input is used, more output is produced. However, there is some limit to most inputs where additional input use does not increase corn yield. For example, fertilizer helps increase yield up to a point. Once this point is reached, additional fertilizer may actually decrease corn yields. At most, a farm manager would only use a level of the input until yields are maximized. As

Figure 1. Corn yield response to nitrogen.



shown later, however, the profit-maximizing level of an input is probably below the yield-maximizing level of that input.

Fixed costs, on the other hand, do not change with the volume of corn produced. These are the costs incurred even if the input is not used. Another characteristic of fixed costs is that they are not under control of the manager. As shown in Table 1, depreciation, taxes, and insurance are all fixed costs since they must be paid even if no corn is produced.

The concepts of variable versus fixed costs need to be discussed within some sort of time frame. Short-run and long-run are time concepts, but they are not defined by a specific length of time. Short-run is defined as a period of time during which one or more of the inputs is fixed in amount and cannot be changed. Long-run is defined as that period of time during which the quantity of all inputs can be changed.

These concepts are important because costs that are defined as fixed in the short-run become variable in the long-run. Likewise, variable costs may become fixed if the short-run is defined to be a small enough time frame. The corn budget in Table 1 uses a short-run time frame of a year. Thus, most of the input costs are variable and can be changed by the farm manager. If a long enough time frame was considered, then depreciation, insurance, and taxes would also become variable since a long enough time span allows the manager to consider selling assets as part of the decision process.

The short-run versus long-run concept is particularly important for those decisions where the short-run is a very small time interval. In these situations, most of the costs are fixed and only a few are variable. An example is a decision of whether to harvest corn in a very severe drought year. The short-run decision rule for farm managers is to cover variable costs. If the corn has already grown, the only variable costs are harvesting, drying, transportation, and storage. Decisions about fertilizer, herbicides, etc., are already fixed. Thus, as long as the value of the corn exceeds these few remaining costs, the harvest should continue. Even though the crop may be so small that not all costs are accounted for, at least the variable costs at the time are covered.

Economic Concepts

One of the basic questions facing corn producers is how much corn to produce on an acre. Because farmers are growing corn to make money, they want to maximize profits per acre. This is probably not the same as maximizing yield. The marginalism principle is very important for helping producers decide on the optimal amount of an input. The basic idea concerns the last unit of an input utilized or of an output produced. As an example, the cost of the fertilizer to produce the last bushel of corn should be less than the price per bushel. Another way of looking at this is that the value of corn produced from the last pound of fertilizer used should be greater than the cost of that pound of fertilizer.

Figure 1 shows how corn yield responds to N fertilizer. The four points in the figure have the following yield responses:

Point	Kg of nitrogen	Kg of corn
A	120	6495
B	150	6917
C	180	7185
D	210	7301

The yield-maximizing point is D; however, this is not the profit-maximizing point. Here's how the marginalism principle works if corn is worth $2.50 per bushel and N costs $0.20 per pound. For each additional 30 pounds of additional N applied, the farmer pays $6. By increasing yield from point A to B, the farmer earns $17.50 in additional revenue (7 bushels of corn times $2.50 per bushel). From point B to C, the farmer earns $10 in additional revenue. From point C to D, the farmer earns $2.50 in additional revenue. Thus, point C is the profit-optimizing point. Moving from 110 to 140 and from 140 to 170 pounds on N is profitable because each 30 pounds of N increases costs less than the value of corn produced. However, the move from 170 to 200 pounds of N is unprofitable because this 30 pounds of N increases costs $6 but only increases corn profits by $2.50.

Figure 1 is for illustration only. Actual corn response to N will depend on many factors such as soil type, date of N application, N carryover, etc. The point here is that the benefits from the additional input should outweigh the costs from the additional input. These techniques apply to all inputs and not just N fertilizer.

A few general assumptions can be made about marginalism. The first is

that yield-maximizing goals are not the same as profit-maximizing goals. The second is that an increase in the cost of an input relative to the price of corn causes a producer to use less of that input. For example, if N fertilizer increases in price while corn does not, then the farmer should use less N. In addition, if the corn price increases while the N price stays the same, then the farmer should use more N.

Opportunity Cost

Finally, corn producers should be aware of opportunity cost. This concept was briefly discussed in relation to return to land and capital from the enterprise budgets. Producers are probably most concerned about accounting profits and cash flow. However, opportunity costs should be considered as well. Producers who provide equity for their farming operations should be rewarded for using that equity. That is why the enterprise budgets have these returns to equity and management lines.

Opportunity cost can be defined as the maximum net return that is sacrificed because the resource is not employed in its next most profitable alternative. Producers who own their own land sacrifice the return they could earn by investing their land equity in the bank. Producers can almost think of opportunity costs as the cost for borrowing money from themselves.

This concept really is apparent for producers who own rather than rent. Renters have a rental cost as part of the enterprise budget, while producers who own will have a zero for the rent charge. At first glance, farmers who own their land might appear to have a tremendous advantage over renters, and in some ways they do. Farmland owners will almost certainly have greater cash flow and earn larger profits from a cash accounting perspective. However, farmland owners should be sure to include the opportunity cost of the land when looking at economic profits.

These are just some of the economic issues that corn producers should consider. Proper planning and a good understanding of the true costs of corn production should help farmers increase their long-term profitability.

Corn Harvesting, Handling, Drying, and Storage

Samuel McNeill and Michael Montross

Introduction

Drying and storing corn on-farm can help producers and farm managers control elevator discounts and improve economic returns to their operation. The use of such facilities requires operators to maintain grain quality from the field to the point of sale to capture market premiums. Treatment of grain soon after harvest often determines the storability of a crop and can strongly influence its quality when delivered to the end-user—which may be several weeks, months, or even years after harvest. Thus, it behooves grain farmers to implement sound grain harvest, drying, and storage practices to maintain the reputation of the United States as a reliable supplier of good quality corn to the global market. Successful post-harvest grain processing with on-farm facilities requires a thorough understanding of the factors that influence grain quality.

On-farm drying and storage facilities let producers avoid excessive unloading times that often plague country elevators during the peak harvest season. Numerous delays throughout a harvest season can increase harvest losses for some individuals, especially if insects, disease, or weather threatens their crop during this period and unusually high stalk lodging problems develop.

Disadvantages of on-farm drying and storage are the high initial equipment costs and additional management requirements. Drying, handling, and storage equipment can easily cost several hundred thousand dollars, and the best way to protect this investment is through prudent management throughout harvest and the post-harvest period—from the field to the elevator or miller. Such an investment in drying and storage facilities mandates that producers and crop managers do a good job of maintaining grain quality after harvest and keeping it in good condition throughout the storage period. Otherwise, the potential profit from these enterprises may be lost.

Preparing for Harvest

All equipment that will contact corn as it moves from the field to the storage bin should be thoroughly cleaned prior to harvest to minimize mold and insect infestations and protect the purity of individual corn varieties or seed lots. This is especially true for genetically enhanced crops, which should be harvested after non-genetically altered crops to avoid possible/probable mixing. All combines, hauling vehicles, conveyors, drying equipment, and storage bins should be thoroughly cleaned before the rush of harvest begins.

Ideal corn varieties have high yield potential, high test weight, a sound disease-resistance package, and strong stalks to avoid lodging problems and rapid dry-down in the field, and they are disease and insect free at harvest. Less than ideal conditions require more management skill to avoid potential problems after harvest. Combines should be serviced and adjusted according to the owner's manual prior to harvest to assure minimal mechanical damage to corn kernels. Clean grain dryers, perform a routine maintenance check on the sensors and controls, and test fire the unit(s) prior to the beginning of harvest to avoid equipment downtime.

Spray the vegetation around storage bins with herbicide and thoroughly clean out bins prior to harvest to prevent creating a harborage for rodents and insects. Sweep down walls, ladders, ledges, and floors inside grain bins to remove old grain and fine material where insects and mold spores can lie in wait to contaminate the incoming crop. Provide dust protection masks so workers will avoid potential breathing problems when cleaning bins and equipment. After mowing and cleaning, spray a residual pesticide inside the bin to the point of runoff for additional protection from insects. Be sure to read pesticide labels carefully for any specific delays prior to filling the bin or other restrictions after application. It is always a good idea to fumigate the space under the false floor of grain bins to eradicate that area of insect populations. Don't confuse residual pesticides with fumigants, which have no carry-over effect, and keep in mind that fumigants are toxic to humans and other warm-blooded animals and therefore are Restricted Use pesticides.

Harvest Considerations

Harvest should begin when operators can optimize profits, which is influenced by the price of corn, potential yield, length of harvest period, weather, and costs for equipment, labor, and energy. Some of these variables change during the course of the harvest season so this is usually a very dynamic situation each year. Operators should have a realistic figure for each of these variables before harvest begins and should be flexible enough to compromise between any conflicting situations. For example, corn usually reaches the maximum dry

matter accumulation at a grain moisture level of 35 to 38 percent, but machine losses are usually lower when shelling corn below 25 percent moisture. Consequently, most farmers with dryers opt to begin harvest a little above 25 percent moisture with the hope of being able to finish before it dries completely in the field.

The length of the harvest period is highly dependent on the size of the operation, combine speed and capacity, efficiency of the harvesting-hauling-handling-drying-storage system, and weather. Total harvest losses generally increase with the time required to gather the crop and can occur from pre-harvest losses and machine losses. Pre-harvest losses can be caused by high winds, hail, or similar weather event, from disease or insect pressure, or from a combination of these situations. Machine losses are inevitable, so the challenge is to:

1. Know where they occur.
2. Understand how to measure them.
3. Know what to do to correct them.
4. Motivate combine operators to measure these losses and take action when they reach economic thresholds.

The income gained by reducing machine losses is achieved with very little added equipment and labor expense, so the time required to carefully adjust and operate the combine can be extremely profitable.

Where Do Combine Losses Occur?

Combine losses can occur during any of the three main areas of the machine (function in parentheses)—header loss (gathering), rotor or cylinder loss (threshing), or fan and shoe losses (cleaning). Table 1 shows typical losses from each machine area for an average and expert operator. Ear losses are intact ears that are left on the stalk or dropped from the header after being snapped. Threshing losses are kernels that remain on the cob due to incomplete cylinder/rotary action. Loose kernels on the ground can be caused by shelling at the snapping rolls or by an overloaded cleaning mechanism. Differences between operators are largely due to combine adjustments and operation and can obviously impact profitability (4.3 bushels per acre in this case). Excess losses can often be avoided by taking a few minutes to measure them and by making the machine adjustments necessary to correct them.

How to Measure Combine Losses

Ear Losses

The first step in knowing whether combine losses are excessive is to determine the total loss behind the machine. Experienced operators can make this first check in five to 10 minutes and should do so when conditions change from field to field or within a field (different variety, planting date, or grain moisture level). Mark off a 1/100-acre area and look through the residue for whole and broken ears that are loose on the ground and those still attached to stalks. See Table 2 for the row length needed to make up 1/100-acre with different row widths and header sizes. Gather all whole and broken ears in this area and weigh them to the nearest 0.1 pound (1.6 ounces or 35 grams). Each 3/4-pound ear (or equivalent) represents a loss of one bushel per acre.

If ear losses are more than 1 bushel per acre and many intact ears are found on stalks, pre-harvest loss should be measured. Check an adjacent 1/100-acre area of unharvested corn and gather and weigh all ears on the ground. Figure pre-harvest loss on the basis of a ¾-pound ear. Subtract pre-harvest loss from header loss. If header loss exceeds 1 bushel per acre consider reducing ground speed, adjusting the header height, or snapping rolls to reduce this loss.

Kernel Losses

The first step in measuring loose kernel loss is to make a frame from wood, wire, or string that covers a 10-square-foot area (see Table 3 for frame dimensions for different row widths). Center the frame over each row behind the combine and count kernels still attached to broken cobs (threshing loss) and loose kernels lying on the ground (cleaning loss). A coffee can is handy to collect a commingled sample from all rows that can be inspected to assess kernel damage during threshing. Two kernels per square foot are equal to a bushel per acre loss, so divide each count from each row by 20 to determine threshing and cleaning losses. If the threshing and loose kernel loss is below 0.3 and 0.5 bushels per acre, respectively, you are an expert combine operator! If your losses exceed these limits, combine adjustments are advised. If separation loss exceeds 0.3 bushels per acre, adjust cylinder or rotor speed for better shelling.

Table 1. Typical combine losses for operators with different skills.

	Combine losses (% of yield)	
Type of loss	**Average**	**Expert**
Ear loss	4.0	1.0
Threshing loss	0.7	0.3
Loose kernel loss	1.4	0.5
Total loss	6.1	1.8

Table 2. Row length (feet) for 1/100-acre area at different row widths and header sizes.

Row width (inches)	Header size			
	4 rows	**6 rows**	**8 rows**	**12 rows**
	Row length (feet)			
20	65.3	43.6	32.7	21.8
30	43.6	29.0	21.8	14.5
36	36.3	24.2	18.2	12.1

Table 3. Dimensions of a 10-square-foot area for different row widths.

Row width (inches)	20	30	36
Row length (inches)	72	48	40

If loose kernel loss is above 0.5 bushels per acre 1 final measurement is needed to determine the problem area. Stop the combine between the ends of the row and back it up about 20 feet. Now place the frame over each row in the area previously under the header and count loose kernels to determine header loss. The difference between loose kernels counted behind the combine and those counted under the header can be attributed to the cleaning mechanism (walker and shoe).

Adjustments to Improve Combine Performance

If excessive harvest losses are found, it is important to make the right machine adjustments quickly to minimize economic loss. Some problems require the adjustment of a single component, while others involve several different areas of the combine. It is usually best to make small individual changes one at a time and measure the outcome of that adjustment before more modifications are made.

A ground speed of 2.5 to 3 miles per hour usually produces good results. Position the header accurately over the rows to feed the material smoothly into the gathering chains and snapping rolls. Run snouts low enough so that the ears contact the upper third of the snapping rolls. Set snapping rolls according to stalk width and match their speed to ground speed to reduce ear loss.

Flights on gathering chains should be opposite each other and should extend about ¼ inch beyond the snapping bar. Chain speed should be set to guide stalks into the rolls without uprooting them. Snapping bars should be spaced closer together in the front (~$1^1/_4$ inch) than at the rear (~$1^3/_8$ inch) to avoid wedging. Keep trash knives sharp and set them as close to the rolls as possible to prevent wrapping the stalks and plugging the machine.

Operation of the cylinder/rotor affects corn kernel damage more than any other machine setting, so attention to this detail will yield large benefits during drying and storage. Grain moisture also influences the amount of kernel damage and may vary with different varieties, but fines generally increase at moisture levels above 25 percent. Since large variations exist among current combine models, producers should closely follow the operator's manual for speed and clearance settings suggested for their cylinder or rotor machine. Avoid overthreshing, which increases kernel damage, produces excess fines, and consumes more power and fuel.

Economic Incentive to Reduce Harvest Losses

Many farmers are not aware of the magnitude of their harvest losses. Although they can vary widely from year to year, studies have shown them to be as high as 15 percent or more of potential yield. Perhaps the best motivation for measuring harvest losses is to consider the cost of grain left in the field. These are shown in Table 4 for various corn prices, potential yield, and harvest loss levels. Even with low corn prices, producers obviously need to keep losses below 5 percent regardless of yield. Also, corn left in a field will be a "weed" the following year and will have to be controlled, resulting in a higher cost.

Drying Considerations

Corn drying equipment consists of bin dryers, column dryers, or a combination of these two types. Each system uses different amounts of heat and airflow to achieve the desired capacity, control drying costs, and maintain grain quality. Regardless of the type used, high-moisture corn should be dried to 16 percent moisture within 24 hours and cooled to the outside air temperature within 48 hours after harvest to avoid losses due to heating, which can provide an ideal environment for mold activity and can lead to mycotoxin production. If heating is prolonged, dry matter loss and an associated loss in quality and test weight will most certainly occur. The amount of time that clean high-moisture corn can be held safely without a loss in quality varies with grain tem-

Table 4. Comparison of harvest losses at different yield levels and corn prices with drying energy costs.

Value of harvest losses ($/ac)						Drying energy cost[2] ($/ac)	
			Corn prices ($ / bu)			Moisture removed	
Loss level (% of yield)	Potential yield (bu/ac)	Harvest loss[1] (bu/ac)	$ 2.00	$ 2.50	$ 3.00	5 pts.	10 pts.
2%	100	1.97	$ 3.94	$ 4.93	$ 5.91	$ 7.72	$ 15.44
	150	2.96	$ 5.91	$ 7.39	$ 8.87	$ 11.58	$ 23.16
	200	3.94	$ 7.88	$ 9.85	$ 11.82	$ 15.44	$ 30.88
5%	100	4.93	$ 9.85	$ 12.31	$ 14.78	$ 7.48	$ 14.96
	150	7.39	$ 14.78	$ 18.47	$ 22.16	$ 11.22	$ 22.44
	200	9.85	$ 19.70	$ 24.63	$ 29.55	$ 14.96	$ 29.92
8%	100	7.88	$ 15.76	$ 19.70	$ 23.64	$ 7.24	$ 14.48
	150	11.82	$ 23.64	$ 29.55	$ 35.46	$ 10.86	$ 21.72
	200	15.76	$ 31.52	$ 39.40	$ 47.28	$ 14.48	$ 28.96

[1] Harvest loss above an assumed minimum of 1.5% of potential yield.
[2] Drying energy cost based on a fuel price of $ 0.75 per gallon of LP or equivalent.

perature, as shown in Table 5. These times can be reduced by as much as one-half or more for broken corn with a high level of fines, trash, and foreign material.

The amount of water in shelled corn at various moisture levels is shown in Table 6. No. 2 yellow corn is usually marketed at 15.0 or 15.5 percent wet basis (w.b.), whereas food-grade corn is usually sold at 14.0 percent w.b. All corn should be dried to 13.0 percent moisture if it will be held into the summer, so the storage costs for drying and moisture shrink must be recovered by market increases. Otherwise, corn should be dried to the market level, cooled as soon as possible in the fall, and sold before warm weather the following spring rather than risk the chance of spoilage because of mold and insect activity.

Corn dryers range in capacity from a few hundred to several thousand bushels per day. Producers should size their dryer(s) to match daily combine capacity and harvest moisture target levels. Suggested operating conditions for different corn drying systems in Kentucky are listed in Table 7. More information for each drying system is available in other Extension publications.

Because fan capacity diminishes as a bin is filled, full bin drying with unheated or low temperature air takes several weeks to accomplish because of low airflow rates. Consequently, these slow processes are not recommended for corn above 18 percent moisture. Also, the top layer of corn is the last to dry in bins without stirring augers, so this layer should be checked frequently during drying to avoid environmental conditions that favor mold growth. If more drying capacity is needed, first reduce the depth of corn to increase airflow, then add more heat if possible. Other suggestions for increasing bin drying capacity are presented in the Extension publications listed in Table 7. Consider installing grain temperature and moisture content sensors in new or existing bin dryers to control fan and heater operation or unloading equipment cycles. Reducing labor and overdried or underdried corn can often quickly pay for automated controls.

Table 5. Allowable holding time for clean shelled corn at different temperature and moisture levels before a loss in grade occurs.[1]

Grain temperature	Corn moisture content (% wet basis)						
	18%	20%	22%	24%	26%	28%	30%
	Allowable holding time (days)						
40˚F	195	85	54	38	28	24	20
50˚F	102	46	28	19	16	13	11
60˚F	63	26	16	10	8	6	5
70˚F	37	13	8	5	4	3	2
80˚F	27	10	6	4	3	2	1

[1] A grade loss occurs when corn loses 0.5 pound of dry matter per bushel. Source: ASAE.

Table 6. Amount of water in shelled corn (test weight of 56 lb/bu) at different base moisture levels.

Moisture content, % wet basis	13	15	17	19	21	23	25	27	29
Water (15.0% base), lb/bu	7.1	8.4	9.8	11.2	12.7	14.2	15.9	17.6	19.4
Water (14.0% base), lb/bu	7.2	8.5	9.9	11.3	12.8	14.4	16.1	17.8	19.7

High temperature in-bin and column dryers provide the most capacity and flexibility for drying corn at high moisture levels. Drying times are usually between a half-hour and two hours. A potential trouble area with these systems is the wet holding bin where grain accumulates as it is delivered from the field and awaits transfer to the dryer. When high-moisture corn stays in a wet bin too long, mold growth can begin within 24 hours and accelerate rapidly if left in the bin.

Aeration in wet holding bins provides some temperature control for wet corn, but it is not a substitute for timely drying. Hopper bottom bins are preferred for holding wet corn because they are self cleaning when unloaded completely. Consequently, it is a good idea to empty hopper tanks completely each day during harvest to avoid the possible accumulation of small amounts of wet grain. If flat bottom bins are used to hold wet corn, use a power sweep auger to unload the bin completely each day or form a "false" hopper bottom with dry corn to facilitate daily unloading of wet grain.

Dryeration or in-bin cooling of hot, dry corn is a popular way to increase drying capacity, reduce drying costs, and reduce stress-cracked kernels, yet it can create some problems if corn is not cooled within 48 hours after drying. A minimum airflow rate of 0.5 cubic feet per minute (cfm) should be provided for each bushel of hot corn to achieve the desired cooling time. Also provide 1 square foot of roof exhaust for every 1,000 cfm of fan capacity. When cooling hot corn in a bin, the fan should run continuously to remove condensed moisture that accumulates on the roof and inside wall.

Storage Considerations

The best way to protect dry stored corn from spoilage by mold and insect activity is to apply integrated pest management practices, which are based on an understanding of the ecology of grain pests. The application of a broad range of preventive practices has a cumulative effect on pest control. Examples include cleaning grain bins and the area surrounding them prior to harvest, controlling grain moisture throughout drying, cleaning dried corn prior to storage

to remove broken kernels and trash, controlling temperature throughout storage, managing the depth of grain in the bin to permit uniform airflow, and monitoring grain during storage for temperature, moisture, and mold and insect populations. By applying all these practices, a post-harvest Integrated Pest Management (IPM) strategy can be substituted for some or all of the chemicals that have traditionally been used to control pests in stored grain.

Corn with a high level of trash and fine material that has been underdried or not dried uniformly can develop problems during storage quickly even though the average moisture readings throughout the bin may be 15 percent. Thus, it is wise to check the top layer of corn in all storage bins about a week after drying and cooling to be sure that no moisture buildup has occurred. If elevated temperatures or moisture conditions are left unchecked, mold and insect growth can flourish even in cool weather because their activity produces heat, which accelerates grain deterioration further.

Controlling the moisture content and temperature of corn throughout the storage period is the most cost-effective way to prevent spoilage problems and potential dockage from musty odors, insects, low test weight, and poor condition. Table 8 shows the recommended storage conditions for clean corn throughout the year in Kentucky. These are based on the equilibrium moisture content properties of corn and the fact that mold and insect activity is held in check when grain temperatures are below 55°F and the relative humidity in the air space between corn kernels is below 65 percent (Table 9 and Figure 1). Clean corn that is dried to 15 percent moisture, cooled in September to 65°F, and cooled an additional 10° to 15°F each month during the fall should store well for up to six months.

Stored corn can spoil if it is dried to the recommended moisture level but not cooled thoroughly. Uneven grain temperatures can lead to moisture migration (which usually occurs in the top center of the bin), which can promote mold growth and insect activity. Aeration equalizes grain temperatures throughout the bin and prevents moisture migration. The time required to aerate corn depends primarily on the size of the fan relative to the amount of grain. Approximate times for different combinations of fan horsepower and bin capacity are given

Table 7. Comparison of corn drying systems for Kentucky conditions.

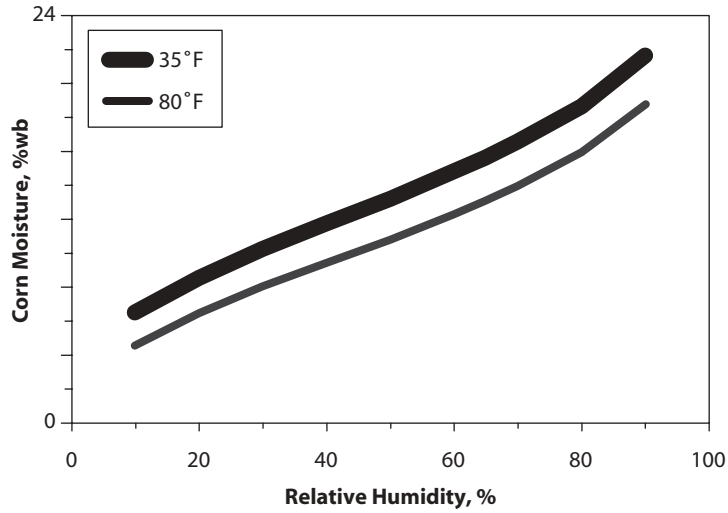
Dryer type	Relative drying capacity (bu/day)	Airflow rate cfm/bu	Air temp. °F	Harvest moisture content limit % wet basis	Relative initial cost	Grain quality	Disadvantages	UK publication
Bin dryers								
No heat	Low (150)	1 2	Outside air	16% 18%	Low to medium	Excellent	Very limited capability at high moisture levels	AEN-23
Low temperature	Low (150)	1 2	Outside + 5 – 10	18% 20%	Low to medium	Excellent	Limited capability at high moisture levels	AEN-22
Layer fill	Low (150)	2 5	Outside + 20	22% 24%	Low to medium	Good	Limited capability at high moisture levels	AEN-56
Medium temperature	Medium (2,000)	8 - 12	120 – 140	28%	Low to medium	Good	Requires level grain depth, batch transfer, labor, and downtime	AEN-57
High temperature	High (6,000)	15 - 70	160 – 180	30%	Medium	Good	Metering equipment requires maintenance	AEN-63
Column dryers								
Recirculating	High (6,000)	75 - 125	180 – 220	30%	Medium	Good	High labor required to load/unload dryer	AEN-64
Automatic batch	High (8,000)	75 - 125	180 – 240	30%	High	Fair	Requires wet holding bin and support handling equipment	AEN-65
Continuous flow	High (10,000)	75 - 125	180 – 240	30%	High	Fair	Requires wet holding bin, support handling equipment, and controls	AEN-65
In-bin cooling away from dryers								
High temperature dryer with dryeration	High (10,000)	10 – 125 & ½ - 1	120 – 240 & outside air	30% & 16%	Medium	Excellent	Requires extra grain handling and managing moisture condensation	AEN-23 AEN-65
High temperature dryer with in-bin cooling	High (10,000)	10 – 125 & ½ - 1	120 – 240 & outside air	30% & 16%	Medium	Good	More management for moisture condensation and cooling	AEN-22 AEN-65

Table 8. Recommended grain temperature and moisture levels during storage in Kentucky.[1]

Month	Average air temperature	Target grain temperature	Target grain moisture content
September	70° F	60° – 70° F	14.0 %
October	60° F	50° – 60° F	15.0 %
November	47° F	42° – 52° F	15.0 %
Dec – Feb	37° F	32° – 42° F	15.0 %
March	47° F	42° – 52° F	14.0 %
April	55° F	50° – 60° F	13.0 %

[1] Source: AEN-45, *Aeration, Inspection, and Sampling of Grain in Storage.*

Figure 1. Equilibrium moisture content (% w.b.) for shelled yellow corn for winter and summer conditions.



in Table 10. Times shown are required to move an aeration cycle completely through a bin. Two to three cycles are normally required each fall to cool corn from 70°F to 35°F in Kentucky.

Another good management practice is to remove the top cone of corn that occupies the upper portion of the bin. Many managers are reluctant to do this because they view this as a loss of storage capacity. However, most corn storage problems in overfilled bins begin in the upper center of the grain mass because that area receives little airflow since air follows the path of least resistance and bypasses the deepest grain. While removing the top cone of corn, trash and fines that tend to accumulate in the center of the bin are reduced, which lets air move through the center of the bin much more easily. Corn from this area should be held in a separate bin and fed to livestock or sold quickly since it has a relatively high concentration of broken corn, trash, and fine material. The trade-off of removing the top cone of corn is improved airflow and adequate room for workers to probe the bin and check for possible problems.

Stored corn should be inspected every 1 to 2 weeks in the fall and spring and once every 2 to 4 weeks after conditions in the bin have stabilized during the winter months. All workers should be made aware of the suffocation and entrapment hazards that exist with flowing grain as well as the personal safety risks associated with grain dust. A safe sampling protocol is provided in more detail in Extension publication *Aeration, Inspection, and Sampling of Grain in Storage Bins* (AEN-45).

A suggested list of equipment needed to inspect stored grain safely is shown in Table 11. Corn samples may be sealed in plastic bags and taken to a farm shop or office for observation. Kernel moisture, temperature, and condition should be recorded during each inspection and compared with previous samples. Samples should be sieved to look for insects when corn temperatures rise above 55°F. If conditions change to-

Table 9. Equilibrium moisture content (% wet basis) for shelled yellow corn.[1]

Temperature		Relative humidity (%)									
°C	°F	10	20	30	40	50	60	65	70	80	90
2	35	6.5	8.6	10.3	11.8	13.3	14.8	15.7	16.6	18.7	21.7
4	40	6.2	8.3	9.9	11.5	12.9	14.5	15.3	16.2	18.3	21.3
10	50	5.7	7.8	9.4	10.9	12.3	13.8	14.7	15.5	17.6	20.5
16	60	5.3	7.3	8.9	10.3	11.8	13.3	14.1	15.0	17.0	19.9
21	70	4.9	6.9	8.4	9.9	11.3	12.8	13.6	14.4	16.4	19.4
27	80	4.6	6.5	8.0	9.4	10.8	12.3	13.1	14.0	16.0	18.8
32	90	4.2	6.1	7.7	9.1	10.5	11.9	12.7	13.5	15.5	18.4
38	100	3.9	5.8	7.3	8.7	10.1	11.5	12.3	13.1	15.1	17.9

[1] Source: ASAE Data D245.4 (average of two prediction equations).

Table 10. Approximate operating times for different size fans (by horsepower).

Fan capacity hp/1000 bu	Hours of fan operation	Operating mode when cooling hot corn[1]	Operating mode when aerating[1]
1.0	15 – 20	C	I
¾	20 – 25	C	I
½	30 – 40	C	I
¼	60 – 80	NR	C
1/5	75 – 100	NR	C
1/10	150 – 200	NR	C

[1] C = continuous fan operation for the time shown when the average air temperature is in the desired range. I = intermittent fan operation when the air temperature is in the desired range. NR = not recommended.

ward temperature or moisture levels that favor mold or insect activity (i.e., elevated grain temperature or moisture), run aeration fans to cool the corn thoroughly (see fan operating times in Table 10 as a guideline). If conditions continue to worsen, transfer the grain to another bin and collect a sample every two to five minutes during unloading. Redry moist corn to a safe level as quickly as possible or sell the lot to an elevator if drying is not an option.

Diligent monitoring of stored grain can help producers avoid problems that too often go entirely unnoticed. The authors have seen cases where grain spoilage was so severe that attempts to unload corn from a storage bin were unsuccessful because deterioration had advanced to the point where a large mass of grain was stuck together and wouldn't flow. Such cases can be avoided entirely with prudent management of stored corn. Hopefully, the reminders and recommended actions mentioned here will help producers and overseers of stored grain maintain and market high quality corn.

Table 11. Cost estimates for tools needed to collect and inspect corn samples from on-farm bins.

Tool	Recommended/ Optional	Approximate cost
Dust mask(s)	R	$ 1 - 500
Insect probe traps	R	$ 20
Portable moisture meter	R	$ 300
Dial thermometer	R	$ 10 - 55
Grain probe/trier	R	$ 80
Corn sieves	R	$ 70
Temperature/RH psychrometer	R	$ 60
Temperature readout device	O	$ 300 - 500
Temperature cables (per bin)	O	$ 200 - 800
Aeration controller	O	$ 400 - 4,000
Total range		$ 541 - 6,385

Marketing

Steve Riggins

Acreage devoted to corn production in Kentucky has been quite stable ever since farmers have had time to adjust to the new lower loan rates for corn that came out of the 1985 Farm Bill. The government programs of the 1970s and the 1980 law led to increases in corn acres both nationally and in Kentucky (Figure 1). These programs had built-in adjustments for higher loan rates if costs of corn production increased. Very sharp increases in energy cost and increases in interest rates produced higher loan rates and guaranteed minimum prices for farmers participating in the feed-grain government program. In contrast, the soybean loan rate was frozen.

As stockpiles of corn grew and corn exports remained relatively flat in the United States, prices to farmers fell sharply, except during a few drought years when supply was reduced. The 1985 farm law changed the way loan rates were determined, and the 1990 and 1996 laws continued that approach. The average corn loan rate in the United States has been stable at $1.89 per bushel since 1994.

Yield-enhancing technology, however, has continued to propel production ever higher, with national average corn yields improving about 1.7 bushels per acre per year. Annual yield improvement in Kentucky has just about matched the national rate of increase at 1.6 bushels per acre per year. It is also apparent that Kentucky corn yields closely track national corn yields in most years. However, the years 1997, 1998, and 1999 were evidence that sometimes Kentucky corn yields don't mirror what happens in the corn belt (Figure 2).

As acreage devoted to corn production has remained relatively flat and while yield has steadily improved, the number of farms that grow corn in Kentucky has dropped significantly over the past several years (Table 1). It is also apparent from Table 1 that farms with small corn acreages are dropping out while the number of the largest corn farms are increasing their share of total state corn production.

As the concentration of corn (and soybean and wheat production) increases, so does the concentration within the agribusiness sector serving grain farms. According to the *Directory of the Kentucky Feed & Grain Association of 1994*, there were 194 licensed grain dealers and warehouses, while the most recent listing indicates there are only 181 such entities. Additionally, the *Kentucky Fertilizer & Agricultural Chemical Association Directory of 1994* listed 143 different firms as members, while the 2001 directory contains a listing for 120 different firms.

Data from the most recent issue of Kentucky Agricultural Statistics (1999-2000) also support the idea of a mature corn industry in Kentucky that is increasingly becoming more concentrated at both the farm and associated agribusiness level. The number of commercially operated off-farm grain storage facilities has dropped from 224 in 1985 to 217 in 1999, while total storage capacity has essentially remained stable. In addition, on-farm rated grain storage capacity has remained relatively unchanged at approximately 180 million bushels (Table 2). It will be interesting to observe what happens to grain storage capacity with time under the more "market oriented" 1996 Farm Bill. The excellent weather and resulting large crops have created a very strong

Figure 1. Kentucky harvested corn acreage.

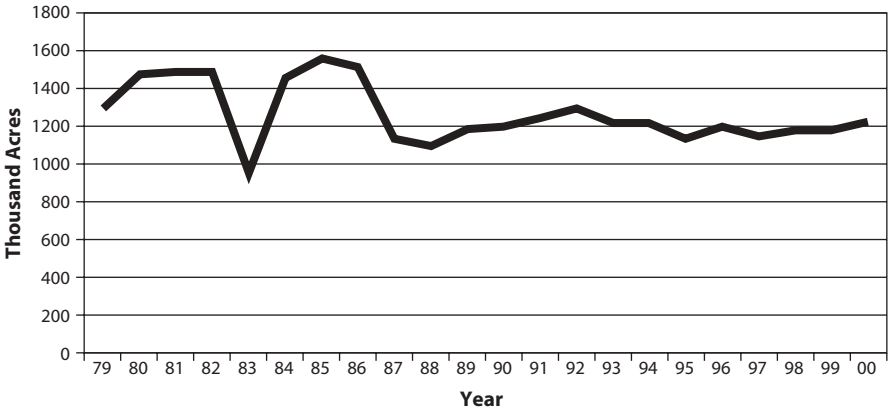


Figure 2. U.S. and Kentucky corn yields.

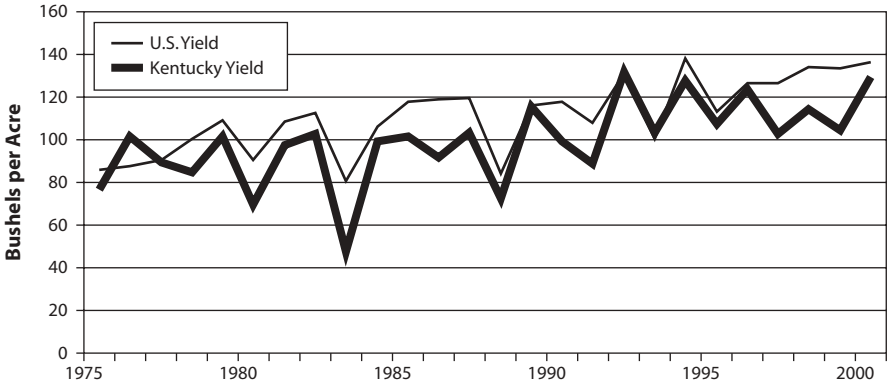


Table 1. Number of corn farms in Kentucky by size 1987-1997.

	1987	1992	1997
Corn for grain (all farms)	25,067	16,945	11,021
1-14 acres	13,147	7,293	4,060
15-24 acres	3,657	2,315	1,440
25-49 acres	3,642	2,692	1,615
50-99 acres	2,209	1,897	1,408
100-249 acres	1,555	1,599	1,390
250-499 acres	598	716	607
1,000 acres or more	48	109	157
Total number of all farms	92,453	90,281	82,273

Source: Census of Agriculture. Various issues.

Table 2. Kentucky off-farm and on-farm grain storage capacity: December 1, 1985-1999.

	Off-farm storage		On-farm storage
	Number of facilities	Rated storage capacity (1,000 bu)	Rated storage capacity (1,000 bu)
1985	224	56,350	NA
1990	262	61,350	190,000
1994	238	57,500	180,000
1995	236	55,510	170,000
1996	233	57,820	190,000
1997	229	59,250	180,000
1998	218	58,870	180,000
1999	217	59,200	180,000

Source: Kentucky Ag Statistics 1999-2000.

"carry" in the market for grain storage. Casual observation indicates that farmers have responded in the past 18 to 24 months by adding significantly to on-farm storage capacity. This should begin to show up in the Kentucky Agricultural Statistics reports starting with the 2000-2001 issue.

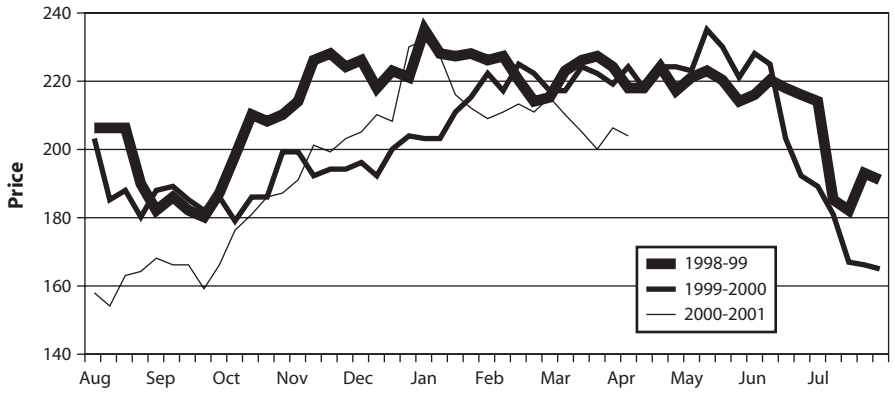
The mature corn and soybean/wheat industry and the increasing concentration of grain production implies that competition for available land base for grain production will be very intense and result in very thin average operating margins over time for grain farmers. In years of above-average yields, farmers should earn ample profits, while in poor yielding years, it will be nearly impossible for non-owned land to cash flow.

The skill or luck involved in the timing of the pricing decision is one area that could make a difference in farm survivability. Recent weekly corn price data from the Green River area of Kentucky serve to illustrate both the within-season and season-to-season price variability faced by Kentucky grain farmers. At first glance, the price pattern for the past three crop season looks remarkedly similar. However, the September/early October 2000 price was some 15 to 20 cents per bushel less than the price from the same time period for the 1998 and 1999 crops. At the 2000 Kentucky corn average yield of 130 bushels per acre, that difference represents $20 to $25 per acre, a substantial sum for a typical Kentucky large grain farm. The within-season price range for the 2000-crop corn marketing year in this area ranged from just under $1.60 per bushel at harvest to more than $2.30 per bushel in late December, and back down to $2.00 in late March 2001 (Figure 3). With perfect hindsight, it is clear that cash receipts per acre could have varied as much as $90 (70 cents/bu x 130 bu yield). This is on a farm with average state yields for that crop year. Clearly farmers stand to benefit from improving both their production skills as well as their marketing skills.

In an attempt to better understand current pricing and marketing practices of large Kentucky grain farms, survey data were collected from a non-random sample of Western Kentucky grain producers. The full details of this research are contained in "Pricing Practices of Selected Western Kentucky Grain Farms," Agricultural Economics Extension No. 2000-12, published by the University of Kentucky Cooperative Extension Service in May 2000. The following sections of this paper draw heavily on that report.

Usable data were obtained from 130 farms in 11 counties in Western Kentucky. The average farm in the survey cropped 624 acres of corn, 617 acres of soybean, and 211 acres of wheat. In addition, these farms averaged slightly more than 55,000 bushels of grain storage capacity, frequently an important component of a grain marketing plan. Based on average state yields for corn, soybean, and wheat, the average sample farm of 1,452 acres controlled sufficient grain storage capacity to cover about half of their expected total grain and soybean production.

Figure 3. Cash corn prices—Green River area.



Pricing Methods

The specific aim of this research project was to discover the method(s) and time frame most often employed by grain producers to price and market their crop production. Farmers were asked to indicate the percentage of each crop (corn, soybean, wheat) they had priced via 11 different techniques over the 1995 through 1997 crop marketing seasons (Table 3). They were instructed to account for 100 percent of each crop each season. The 11 marketing methods and a short description, if necessary, follows:

1. Cash out-of-field—no explanation necessary.
2. Cash out-of-bins—farmer owns bins or elevator storage program; grain still owned by farmer.
3. Elevator cash- forward contract—traditional cash contract for future delivery.
4. Elevator basis contract—quantity/delivery date specified in advance of delivery; basis negotiated on initial contract date; title transfers to elevator at delivery; farmer may or may not receive any cash at delivery; final pricing could be before or after delivery, typically at or after delivery; final pricing must occur by definite date, or farmer must negotiate new ending date and pay additional fees.
5. Elevator delayed price (DP) contract—farmer delivers grain; may or may not receive any cash at delivery; title transfers to the elevator; farmer must set final cash price by set date or pay fees to "roll" the contract to a later date.
6. Elevator hedge-to-arrive (HTA) contract—specific futures contract month and price and a specific quantity negotiated prior to delivery; basis typically negotiated at or prior to delivery.
7. Elevator minimum price contract—minimum price; quantity and delivery date set on initial contract date; elevator typically shorts the appropriate futures contract month and buys an appropriate call option strike price and delivery month; they charge the farmer all costs plus an additional service fee; final total net farm price is established on delivery date.
8. Futures market plus cash sale—cash sales could be from field or bin; futures transaction could be a short hedge coupled with a later cash sale, or it could be the purchase of a long futures position as a replacement for a cash sale.
9. Futures market plus cash forward contract sale—offset short hedge and replace with cash contract or add a long futures position to an existing cash forward contract.
10. Futures options plus cash sales—cash sales could be from the field or bin; could buy a put first and sell cash grain later; could sell cash grain first and replace with the purchase of a call option.
11. Futures options plus elevator contracts—could be the purchase of a call option combined with an elevator cash forward contract; could also be offsetting a put option and converting to a cash forward contract.

Table 3. Farmers' marketing methods: Corn.

		Farmers using this technique	% of farmers reported using this technique	Average % of crop marketed by this method
1. Cash out-of-field	COF	80	61.5	16.8
2. Cash out-of-bins	COB	84	64.6	28.2
3. Elevator cash-forward contracts	El.FC	77	59.2	26.3
4. Elevator basis contracts	El.BC	24	18.5	4.1
5. Elevator delayed price (DP) contracts	El.DPC	43	33.1	10.3
6. Elevator hedge-to-arrive contracts	El.HTA	19	14.6	3.4
7. Elevator min price contract	El.MPC	2	1.5	0.1
8. Futures markets plus cash sales	FH+Cash	7	5.4	1.6
9. Futures markets plus elevator contracts	FH+El.C	8	6.2	0.0
10. Futures options plus cash sales	FO+Cash	6	4.6	0.7
11. Futures options plus elevator contracts	FO+ElC	7	5.4	1.4

Clearly, the 11 pricing methods do not cover all possible convolutions of marketing methods that could be devised or offered by the marketplace. However, the authors believe the above list of methods account for essentially all pricing methods currently in use in Kentucky. Additionally, it should be noted that methods eight through 11 could involve some slight variations beyond those listed in the above explanation. The goal of the survey instrument was to measure the degree of use of futures and futures options market in a general sense, not as an exact measurement of each possible variation of use of these methods.

Nearly two-thirds of the respondents in the survey reported using cash out-of-bins as a marketing method for corn (Table 3). This was closely followed by cash-out-of-field and elevator cash forward contracts as the methods used by most farmers in the sample data. A sizeable percentage of farmers, 18.5 percent, also used DP contracts, while 14.6 percent of farmers in the sample also used HTA contracts. The number of farmers in the sample who reported using futures or options as marketing methods during the 1995-1997 crop marketing years was very modest, ranging from 4.6 percent to only 6.2 percent.

When asked to identify the percent of their corn crop marketed by each method, farmers showed the strongest preferences for cash-out-of-bins and cash-forward contracts as the two dominant marketing methods. These two methods accounted for nearly 55 percent of all sales during the three-

year period examined by the survey instrument. Cash-out-of-field (16.8 percent) accounted for the third largest percentage of corn marketings among farmers in the survey. DP contracts, at slightly more than 10 percent, was the only other method with double digit use by farmers marketing corn. The top four marketing methods (two cash strategies and two elevator contracts) represented more than 81 percent of all corn sales by survey respondents. In contrast, the four methods involving the use of futures and options markets accounted for less than 6 percent of total marketings. Even though farmers were instructed to account for all sales, some did not do so; therefore, total sales from all methods only adds to 95 percent.

Contract Delivery Periods

Farmers make extensive use of elevator contracts as a method of marketing corn, soybean, and wheat. The 130 farmers represented in this sample priced 26 percent, 24 percent, and 26 percent, respectively, of their corn, soybean, and wheat with cash-forward contracts. Additionally, other types of elevator contracts accounted for 18 percent of corn sales, 32 percent of soybean sales, and 12 percent of wheat sales. The primary delivery period for contracted corn was January-February, followed by the "Fall" period while March-May was the third most contracted delivery time period (Table 4). Farmers were supposed to account for 100 percent of all contracted grain; however, some failed to do so, leaving nearly 16 percent of all contract sales unaccounted for from a delivery time perspective.

Table 4. Periods of contract delivery: Corn.

	Average % of crop contracted for delivery during specified period
June-July	2.0
Aug-Sept	6.5
"Fall"	25.2
Jan-Feb	38.1
Mar-May	12.5

Timing of Grain Sales

Timing of grain sales is a question of interest in understanding farmers' marketing habits. The survey form broke the marketing year into seven time periods (Table 5) and asked farmers to indicate the percentage of each crop priced during each period. Clearly, the period identified as more than a month after harvest is the most used time period for pricing corn. The second major pricing period is the period labeled as more than a month before planting. Together these two time periods account for 53 percent of annual corn pricing decisions. It is also clear there could be some overlap between these two ill-defined time periods. These results are consistent with the earlier data for corn that indicate a heavy reliance on cash-out-of-bins, cash-forward contracts, and DP contracts as significant pricing methods and the corn data on contract delivery periods that indicate the January-February and March-May time periods as the two major periods of contract delivery. The data are also consistent with the harvest season being the third most important pricing period and cash-out-of-field being the third most used pricing method.

Information obtained from the survey results concerning farmers' use of futures options was somewhat consistent. Farmers were asked how many total times over the past three marketing years they had used options to set price floors prior to any active pricing on the cash side and how many times they had used options to participate in a futures market rally after they had priced the cash grain. They were also asked to list the total number of puts and calls (by crop) they had purchased over the same time period (Table 6). As an example, corn farmers had used options to set price floors 142 times, and they claimed to have purchased 134 puts, "reasonably close." They also claimed to have used options 97 times to participate in a futures market rally after they had priced cash corn and they purchased 109 calls.

Only nine of the 130 farmers claimed to have speculated in the options market over the time period surveyed. Essentially all of this activity was focused on corn, with 35 puts sold and 25 calls sold. There were three soybean puts sold and four soybean calls sold. For wheat, only two call contracts were sold as speculative positions, while no puts were sold.

Factors Influencing Pricing Decisions

Survey respondents were asked to rank, from 1 to 10 (with 10 being the most important), their sources of information and contingent factors that influenced the pricing decisions for their crops. Satellite market information systems were the top choice among the 10 provided on the survey form (Table 7). Marketing newsletters and private consultants also ranked high in the farmer survey. Neighbors, bankers, and cash flow needs/requirements were less well regarded as aids in making crop pricing decisions.

Table 5. Timing of pricing decisions: Corn.

	Total responses per each	% of farmers reported using this technique	Average % marketed at this time	Code
More than a month before planting	68	52.3	13.9	BePlnt
During planting season	35	26.9	5.4	@Plnt
Planting until mid-season	47	36.2	7.8	Plnt-Mid
Mid-season until crop maturity	55	42.3	10.3	Mid-Mat
During harvest season	56	43.1	12.7	@Harv
During month after harvest	35	26.9	7.6	AftHar
More than a month after harvest	94	72.3	39.1	>1moAftHar

Table 6. Direct use of futures and options markets by farmers.

		Corn	Soybean	Wheat
Short hedge:	Contracts	407	220	143
	Farmers who speculated	17	16	8
Option use:	Before pricing	142	67	37
	After pricing	97	94	67
Options bought:	Puts bought	134	51	42
	Calls bought	109	72	89
	Farmers who sold options (all grains)	9		
Options sold:	Puts sold	35	3	0
	Calls sold	25	4	2

Table 7. Farmers' sources of marketing decision information: All grains.

	Rank[1]	
Grain dealer	7	G.D.
Private market consultant	8	P.MktC.
Commodities broker	4	CmBro.
University resource	6	U.K.
Banker/Lender	2	Bank
Marketing newsletter	9	Mktlet.
Satellite market info. system	10	S.Mktinfo
Mass media	5	MassM
Neighbor	1	N. Farm
Cash flow	3	Cash Fl

[1] Rank over the survey population (10 = most important source or factor).

Conclusions

The farmers who participated in this non-random sample farm much larger acreages than are common for non-grain farms in Kentucky. These farmers also own or control sufficient on-farm storage to handle about half of their expected annual grain production. This group of farmers relies heavily on the latest communication technology and paid professionals for marketing advice and assistance. While the group as a whole does not make heavy use of futures or options markets to price grain directly, they also sell less than 17 percent of their corn and less than 15 percent of their soybean directly out of the field at harvest. These farmers make significant use of on-farm storage to contract for mid-to-late winter delivery, they contract in late winter and early spring for harvest and fall delivery, and they also store sizeable quantities unpriced to sell after harvest.

This survey did not address the question of whether farmers are doing a good job of marketing. That is a very complicated question to answer. Clearly, these farmers are actively seeking marketing advice, and they are trying to spread sales throughout the marketing year. They are also employing a wide array of marketing methods. These are all signs of strong marketing skills. It is possible that increased use of futures and options markets by farmers could be beneficial, but that is a testable hypothesis, not a fact.

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AEN-45 ..... *Aeration, inspection, and sampling of grain in storage bins.*
ID-59 ..... *Aflatoxins in corn.*
ENTFACT 108 ... *Armyworms in corn.*
AEN-57 ..... *Batch-in-bin grain drying.*
BREI-2 ..... *Biotechnology and the environment.*
ENTFACT 118 ... *Bt corn.*
ENTFACT 128 ... *Bt-corn refuges.*
ENTFACT 130 ... *Bt corn: What it is and how it works.*
ENTFACT 100 ... *Common stalk borer.*
ENTFACT 125 ... *Corn leaf aphid.*
PPA-26 ..... *Corn stalk rots.*
ENTFACT 59 ..... *Cutworm management in corn.*
PPFS-AG-C-1 ..... *Diseases of concern in continuous corn.*
PPA-43 ..... *Ear rot of corn caused by Stenocarpella.*
ENTFACT 49 ..... *European corn borer management in corn.*
ENTFACT 110 ... *Fall armyworm.*
PPA-35 ..... *Gray leaf spot of corn.*
AEN-63 ..... *In-bin continuous drying, method, and management.*
ENTFACT 16 ..... *Insecticide recommendations for corn.*
IPM-2 ..... *Kentucky integrated crop management manual for field crops.*
ENTFACT 129 ... *Lesser cornstalk borer.*
AGR-1 ..... *Lime and fertilizer recommendations.*
AEN-22 ..... *Low temperature drying: Methods and management.*
AEN-23 ..... *Low temperature drying: Use and limitations.*
ID-121 ..... *Mycotoxins in corn produced by fusarium fungi.*
IP-9 ..... *Pesticide residues in grains, vegetables, fruits, and nuts.*
AEN-61 ..... *Portable batch and continuous flow drying method and management.*
AEN-20 ..... *Principles of grain storage.*
ENTFACT 140 ... *Resistance management with Bt corn.*
ENTFACT 309 ... *Seedcorn maggots.*
PPA-33 ..... *Stewart's wilt of corn.*
ENTFACT 305 ... *Stink bug damage to corn.*
AEN-62 ..... *Stirring devices for grain drying.*
AEN-39 ..... *Suffocation hazards in grain bins.*
PPA-40 ..... *Virus diseases of corn in Kentucky.*
AGR-6 ..... *Weed control recommendations for Kentucky farm crops.*
ENTFACT 120 ... *Wireworms in corn.*

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