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A Comprehensive Guide to Corn Management in Kentucky

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A Comprehensive Guide to

Corn Management in Kentucky

Cover: *No-till corn field in Hardin County, Kentucky. Photo by Chad Lee*

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Corn at dent stage. Image by Chad Lee

Chapter 1

Introduction

Chad Lee

Corn is a summer annual crop that is grown widely across Kentucky, the United States, and around the world. In the United States, field corn is grown on about 85 million acres (34 million hectares) while sweet corn is grown on about 600,000 acres (240,000 hectares) and popcorn is grown on about 200,000 acres (81,000 hectares). Most of the field corn across the United States is yellow dent corn. In Kentucky, both yellow dent corn and white dent corn are grown. Corn acres in Kentucky peaked at 3.85 million in 1917 and have been around 1.2 to 1.5 million acres since the 1970s (Figure 1.1) (USDA-NASS, 2020). Most corn in Kentucky today is grown in minimum tillage or no-tillage conditions. Most corn acres are rotated with soybean or wheat and double-crop soybeans.

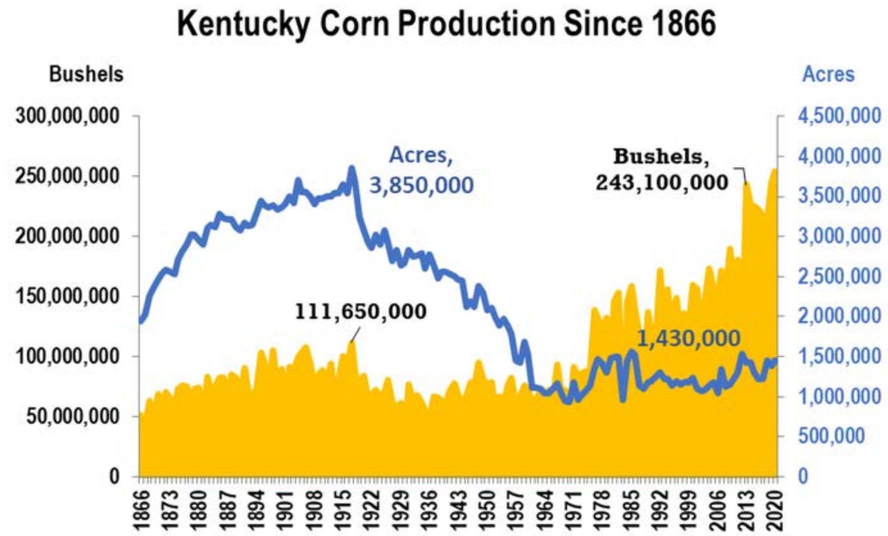

Figure 1.1. Kentucky corn acres (blue line) and total bushels (maize area) produced each year since 1866.

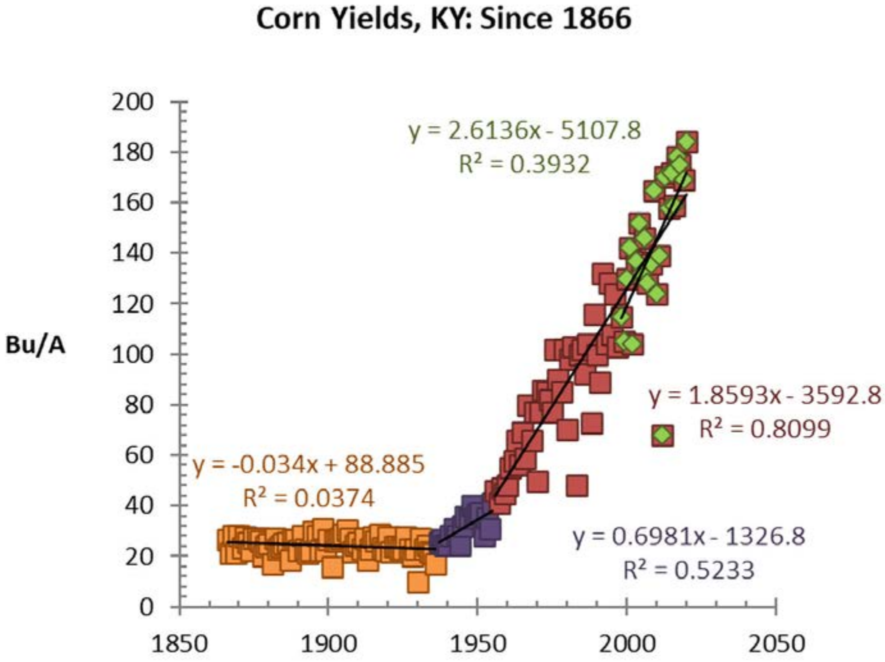

Figure 1.2. Kentucky corn yields for each year since 1866. The corn yields from 1866 to 1936 (orange) represent open pollinated corn when varieties such as Bloody Butcher, Johnny Red, Hickory King, and others were planted. Yields from 1937 to 1955 (purple) represent when the first double cross hybrids were planted in Kentucky. Yields from 1956 to 2020 (red) represent the use of single cross hybrids. Finally, yields from 1998 to 2020 represent the introduction of genetic engineering into corn hybrids. The transitions between varieties, double cross hybrids, and single cross hybrids are approximate. USDA NASS. 2020. United States Department of Agriculture National Agricultural Statistics Quick Stats. https://quickstats.nass.usda.gov/

Corn Uses

Yellow dent corn is used for animal feed, ethanol for fuel, corn sugar in foods, yellow cornbread mixes, bourbon whiskey, and other distilled alcohols. White dent corn is mostly grown for human food, such as cornbread, corn grits, tortillas, polenta, and similar food items. Cornstarch is used in absorbents, biodegradable plastics, and for other industrial uses. Corn oil is used for food.

In Kentucky, nearly 10% of the corn is exported. About 10% is used for fuel ethanol. Another 10% of Kentucky corn likely is used in distilleries. Most field corn in Kentucky is used in animal feeds for cattle, poultry, and swine farms. Nationally, about 39% of field corn is used for animal feed; about 46% is for food, alcohol, and industrial uses; and about 15% is exported (USDA Feed Grains Yearbook Data). Less than 10% of the field corn grown in United States is used directly in food.

Corn Management in Kentucky

Corn yields have increased dramatically since 1956. Since 1996, Kentucky corn yields have increased 2.5 bushels per acre per year (Figure 1.2). The chapters in this publication discuss the best corn management practices for Kentucky based on years of research at the University of Kentucky, research from other land grant institutions relevant to corn in Kentucky, research from agribusinesses, and interactions with growers around the Commonwealth. This publication addresses the management practices that result in high yields that make a return on investment most of the time. This publication also incorporates the wetter growing seasons that Kentucky has experienced since 2012. Those wetter seasons, especially during July and August, also greatly impact corn yields.

Chapter 2

A Brief History of Corn

Chad Lee

Corn by Any Other Name

The English word "corn" refers to the primary grain crop in a region. For Great Britain, corn often refers to wheat. In other parts of Europe and the Fertile Crescent area of the Middle East, the English word "corn" referred to wheat or rye. When Christopher Columbus landed in the Caribbean, he claimed to find India. He took kernels of "Indian corn" back to Europe. "Indian corn" became so popular across Europe and Asia that some people assumed maize originated in Turkey, which is incorrect. Today, in the United States and Canada, "Indian corn" refers to ancient flint corns with multicolored seeds. Any U.S. or Canadian reference to "corn," including the title of this publication, is referring to maize.

Corn Origins

Corn, or maize (*Zea mays* ssp. *mays*), is native to the Western Hemisphere and was grown throughout North and South America by the 1500s. Maize most likely originated in what is now southern Mexico, likely in the Tehuacán Valley, possibly the Balsas Valley, or both valleys. One species of teosinte (pronounced "tee-oh-sin-tay," *Zea mays* ssp. *Parviglumis*) is considered the progenitor of corn. Teosinte and corn have the same chromosome number (10) and can cross pollinate and produce viable seeds. Molecular studies of the DNA of the Parviglumis teosinte and corn provide strong evidence that teosinte is an ancestor of modern corn.

There were several types of corn or maize, including pod corn, where the kernels are enclosed, soft kernel or gourdseed corn and hard kernel flint corn. The intervention of humans who cultivated corn was essential to the survival of the species. Corn is perhaps the most domesticated of all crops grown.

Dent corn, which is the most productive of all corn types, occurred because of European settlers in North America. At the time of those early settlements, the most common corn grown in what is now the southern United States had soft kernels. Those settlers called this type of corn "gourdseed" corn. In what is now the northern United States and Canada, the most common type of corn grown had a hard kernel. This was called flint corn and often had white or yellow kernels. The Colonial settlers grew both the gourdseed and flint corn in the same settlements. At some point, the soft gourdseed corn crossed with the hard flint corn to produce dent corn. Dent corn became popular quickly because of its superior

Heirloom corns including Reid's Yellow Dent and Hickory King White. Blue kernels are from Hopi Blue Dent pollen. Image by Chad Lee

Image 2.1. Corn ears, from left to right, are modern yellow dent hybrid, modern white dent hybrid, open-pollinated line Bloody Butcher (two ears), and Reid's yellow dent (two ears). The red kernels on Reid's yellow dent are from Bloody Butcher pollen. All these corns are dent corns. The modern hybrids produce three to four times as many ears per acre as the open-pollinated corns. Photo by Bianca Machado.

yields. Dent corn is the primary genetic source for modern corn hybrids.

Corn Biology and the Dawn of Hybrids

Corn (*Zea mays* ssp. *mays*) is a summer annual crop in the grass family (Poaceae). It is a grain, meaning that the seed is high in starch. Corn kernels contain about 70.8% starch, 9% oil, and 4.2% protein. Within recommended populations, a single plant from a corn hybrid grows 7 to 9 feet tall and produces one ear with about 450 to 600 kernels or seeds. Corn has separate male and female flowers on the same plant. The tassel is the male flower and produces pollen. The ear is the female flower and produces the ovules. Pollen grains land on the silks and travel down the silk to fertilize the ovule. With proper conditions, each fertilized ovule develops into a seed.

Having separate female and male flowers on the same plant allowed scientists to easily take pollen from one corn plant and cross it with the silks of another corn plant. The resulting offspring were hybrids. Scientists learned that hybrids developed from parents with different backgrounds resulted in offspring that produced yields far greater than either parent. This concept is called "hybrid vigor" and the concept applies to many plants and animals.

Hybrid seed corn was one of the largest paradigm shifts in agriculture (Images 2.1 and 2.2). Before hybrid corn, farmers collected seed, saved seed, and planted that seed the next season. Farmers who use hybrid corn bought new seed every year. Buying new seed each year was a massive shift in how farming was done. To be clear, before hybrid seeds, farmers would buy some new seed. But most farmers saved some seed as well. What farmers realized is that hybrid seed corn produced a yield large enough to allow them to use the corn they needed and sell the remainder. Over a few decades, farmers switched from open-pollinated corn (and saving seed) to hybrid corn (and buying new seed every year).

Successful adoption and management of hybrid corn seed includes many more facets of crop management than just genetics. Nitrogen fertilizer, chemical weed control, mechanization, and other factors all contributed to the successful use of hybrid corn. Hybrid corn alone did not cause the paradigm shift. Hybrid corn along with these other management tools changed corn production and agriculture. The changes in productivity between the open-pollinated corn

Image 2.2. Modern white hybrid when kernels are in the dough stage. Photo by Chad Lee.

and the hybrid corn systems is amazing. For example, a farmer in 1920 would have planted open-pollinated corn (or, what some now call "heirloom corn") at about 10,000 seeds per acre and a crop would yield about 30 bushels per acre. A farmer in 2010 would have planted about 30,000 seeds of hybrid corn per acre and yielded about 160 bushels per acre. To put this in other terms, the farmer in 1920 planted about 7 pounds of seed per acre and yielded about 1,680 pounds of grain per acre. The Kentucky farmer in 2010 planted about 21 pounds of seed per acre and yielded about 9,500 pounds per acre. Many hybrid cornfields since the 2010s in Kentucky yielded over 11,000 pounds per acre. Some hybrid cornfields and some research fields in Kentucky yield more than 18,000 pounds of corn per acre.

Corn in the Current Era in Kentucky

Proper management of corn is necessary to maximize economic returns, improve soils and provide long-term viability to farms (Image 2.3). Most acres of corn in Kentucky are either no-tillage or minimum tillage. In no-tillage systems, the soil is not tilled prior to planting. In a minimum tillage system, a shallow tillage pass is made, such that some residue remains on the soil surface. The traditional conventional tillage system, which may include a moldboard plow and/or a disk, are used on some flat, poorly drained fields. But conventional tillage corn in Kentucky is rare. The no-tillage system reduces erosion and improves soil structure and water infiltration. When it can be used, no-tillage is the most sustainable option for corn.

Image 2.3. Open-pollinated corn being grown on 40-inch centers on a historical farm in Virginia, where three seeds were planted per hill. This was the common practice in the 1700s, 1800s, and early 1900s for open-pollinated corn in the United States. Modern corn field (on the right) in Taylor County, Kentucky Photos by Chad Lee.

Most definitions of sustainability include three pillars of economic, environmental, and social impacts. Most farms in Kentucky that produce corn are family farms. Practices that protect and improve soils help ensure that farms will be economically viable for this generation and future generations. Corn is an essential part of the sustainability of grain farms in this region.

Corn produces more total biomass per acre than any other grain crop in Kentucky. For every pound of seed or grain produced, corn produces about one pound of fodder, which includes the stalk, leaves, tassels, and husks. In no-tillage systems, a portion of that biomass is turned into soil organic matter. In a properly managed system that includes no-tillage or minimum tillage, corn is a viable component to improving soil health. Most corn in Kentucky is rotated with either full season soybeans or wheat and double-crop soybeans. The corn-soybean rotation allows for two harvested crops in two calendar years. The corn-wheat-double crop soybean rotation allows for three harvested crops in two calendar years.

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Chapter 3

Corn Growth Stages

Chad Lee and Montserrat Cortasa Salmeron

Corn or maize is a member of the grass family. When properly managed, a single corn plant reaches 7 to 9 feet tall and produces a single ear with 450 to 600 kernels. Corn grown in Kentucky normally produces over 11,000 pounds of seed and 11,000 pounds of fodder per acre. That is nearly 200 bushels per acre. Understanding how a corn plant develops and understanding key development stages will help Kentucky producers, agronomists, and consultants better manage corn.

For corn to produce a plant and kernels, it must conduct both photosynthesis and respiration. Photosynthesis uses sunlight to convert water and carbon dioxide into glucose sugar. Respiration uses sugar to build structures such as stalks, leaves, cob, kernels, etc.

Corn is a member of the C4 class of plants (also called warm-season plants), which means that corn is among the most efficient group of plants for photosynthesis. Corn is more efficient at converting sunlight to sugar than soybean, wheat, barley, or rye. Respiration helps maintain the plant. In simplistic terms, photosynthesis produces sugar and respiration uses that sugar to build and maintain the plant. Photosynthesis occurs during the day, and most respiration occurs at night. Over the entire growing season, a typical field of corn in this region will produce about 80 pounds of glucose for every bushel of grain produced (D. Egli, personal communication). So, an acre of 200-bushel corn requires photosynthesis to produce about 16,000 pounds of glucose sugar over the season.

Growing Degree Days

Corn hybrids typically grown in Kentucky require approximately 110 to 120 days to go from emergence to physiological maturity (blacklayer) depending on temperature and light. The seed fill period occurs for about 30 to 40 days depending on heat unit accumulation.

Corn maturity is dictated primarily by heat unit accumulation. Because temperatures differ each season, that same corn hybrid may require a different number of days to reach maturity in two different seasons. Corn growing degree days (GDDs or Heat Units) were developed to better track corn development over a season. The corn seed companies report a hybrid maturity in days, but this calculation is based on the expected number of GDDs to complete growth and development. The estimate of GDD accumulation can vary widely based on planting date and seasonal temperatures.

Corn silks ready to receive pollen. Image by Chad Lee

Corn growing degree days calculate each day as:

GDD = (Tmax + Tmin)/2 – Tbase

Where Tmax is the maximum daily temperature but limited to 86˚F, Tmin is the daily minimum temperature and limited to 50˚F. The Tbase is the base temperature which is 50˚F.

For example, a day has a high of 75 and a low of 55.

For this day, GDD = [(75+55)/2]-50 = 15 GDDs.

Another day has a high of 97 and a low of 66. In this case, Tmax is capped at 86.

So, the GDD = [(86+66)/]-50 = 26 GDDs.

This process is repeated for each day. (Using the Celsius system, the Tmax is capped at 30 C, Tmin is capped at 10 C, and Tbase is 10 C.)

Crop scientists have determined that corn requires an approximate number of GDDs to reach various stages of growth. By tracking the GDDs during the growing season, a farmer can estimate when the corn is expected to reach certain stages. For example, if a farmer wants to estimate when the corn will reach V6 growth stage, the farmer can calculate how many GDDs have been accumulated since planting and make an estimate of accumulated GDDs will be sufficient to reach V6. (Note: See the next section for more details on growth staging).

Growth Stage Method

The leaf collar method is most commonly used to define corn growth stages. For a detailed reference on corn growth stages, consult "Corn Growth and Development" from Iowa State University. A shorter reference to corn growth stages is *Corn Growth Stages and Growing Degree Days A Quick Reference Guide* (AGR-202) from University of Kentucky Cooperative Extension Service. This chapter will provide a summary of corn growth stages.

In this method, corn growth stages are divided into vegetative stages, signified with a "V" and reproductive stages, signified with an "R." The V stages begin at emergence (VE) and then are based on each fully emerged leaf with a visible leaf collar (V1, V2, etc.) until a tassel is emerged (VT) (Figures 3.1 and 3.2). The R stages begin with silk emergence (R1) and end at physiological maturity (R6).

Using GDDs to predict growth and development is a guide.

VE Emergence (about 100 GDDs)

Emergence occurs when the coleoptile shoot consisting of leaves wrapped inside pushes through the soil surface. The radicle is the first organ to emerge from a germinating seed and quickly develops a seminal root system.

V3 Three visible leaf collars (about 275 GDDs)

Three leaves are fully emerged with visible collars. At this stage, roots have emerged from the first couple nodes (nodal roots) above the seed but below the soil surface. These nodal roots are active. The growing point is below the soil surface.

V6 6 visible leaf collars (about 475 GDDs)

The growing point is now above the soil surface (Figure 3.3). Tassel and dominant ear development have started. While this stage is a vegetative stage, some reproductive organs are beginning to develop. More nodal roots are developing and the plant is relying on these nodal roots for anchoring and nutrient uptake. This is the last stage before exponential growth occurs, where the corn plants grow rapidly in height. Approximately 30 pounds of nitrogen per acre has been taken up the by the plants. The first leaf often tears off the corn plant soon after V6.

V12 12th Fully Emerged Leaf (about 870 GDDs)

Twelve leaves have fully expanded. The first two or three leaves have torn off the plant from an expanding stalk. Thus, the plant may only have eight visible fully emerged leaves at this stage. The plant can be dug up, the stalk split in half and the sixth node can be identified. The sixth node will be very close to the soil surface and there is a distinct internode between the fifth and sixth nodes. From that sixth node, the sixth leaf can be identified. Additional leaves can be counted to identify stages V7 until tasseling.

Ear size, kernel size and potential kernel number are being determined. Again, even though this is a V stage, manage-

Image 3.1. Corn at the VE growth stage, but very close to V1. The leaf collar is not visible yet on the first leaf. Photo by Chad Lee.

Image 3.2. Corn at the V2 growth stage with two collars visible on each plant. Photo by Chad Lee.

Image 3.3. Corn at the V6 growth stage. The growing point is above the soil surface and the primordial tassel and dominate ear are forming. Corn often starts to experience rapid shoot growth at this stage. Plant height is not a good estimator of V6 growth stage. Photo by Chad Lee

ment decisions or stresses can impact reproductive development and yield. Limits of water and or nutrients at this stage will reduce yields. Water demand is about 0.26 inches per day.

V15 15th Fully Emerged Leaf

At this stage, all the ovules are formed on the dominant ear so the potential kernel number is set. The two uppermost ears are similar in size, but the uppermost ear will be dominant. (A single corn plant will commonly start six to seven ears, but under proper management, only the dominant ear will produce seed.)

VT/R1 – Tassel/Silking (about 1,100 to 1,400 GDDs, depending on hybrid maturity)

In older hybrids, the tassel emerged fully from the whorl before the silks emerged. The VT stage identified the fully emerged tassel. The R1 stage identified silking (Figure 3.4). In modern hybrids, the silks will emerge before tassel emergence is complete. In some fields, the tassel will start to drop pollen before the tassel is fully emerged. One study in Kentucky measured the time between full tassel emergence and silk emergence to be between -1.5 days to 0.5 days. So, in most cases, corn silks were emerged before the tassel was fully emerged. For these reasons, VT/R1 are grouped together in this publication.

Pollination occurs at this stage when pollen drops from the tassel, lands on the silk and travels down the pollen tube (silk) to fertilize the ovule. The corn plant is extremely sensitive to water stress about a week before to a week after pollination. Pollen drop will take about six to seven days for a single plant, with the vast majority of pollen drop occurring over three days. Most pollen drop occurs early in the morning to help ensure successful pollination. Extremely hot and dry weather will kill pollen. Drought stress prior to and during VT/R1 can result in pollen drop occurring before silk emergence. In extreme cases, the tassel will drop pollen before it emerges from the whorl. Severe pollination

Image 3.4. The R1 growth stage occurs when silks are visible on the ear. Pollen drop from the tassel on most modern hybrids occurs within a day of silk emergence. The tassel in this image has been dropping pollen for two or three days. Photos by Chad Lee.

Image 3.5 and 3.6. The R5 growth stage occurs when the end of the kernels are dented. At this stage, the harder starch forms at the end of the kernel first and moves down the kernel. A distinct line is observed. This line is called the "milk line," even though the upper kernel is a harder starch and the lower kernel is at a dough consistency. It is strange since R5 is two stages past R3, the milk stage. We did not determine the name, but that it what it is called. Photos by Chad Lee.

problems are rare. Kernel abortion at later growth stages is more likely to occur.

Although rare, complete leaf loss from hail damage at the VT/R1 stage will result in nearly complete yield loss.

In Kentucky, many hybrids will produce about 16 leaves and be about 7 to 9 ft in height at the base of the tassel. At tasseling, the corn plant has taken up about 60% of nitrogen, 35% of the potassium and 75% of potassium. At tasseling, potassium uptake is rapid. By silk emergence potassium update is nearly complete. Nitrogen and phosphorus uptake are rapid. Corn water demand is about 0.33 inches per day, which is the maximum daily demand for water.

R2 – Blister

Ear length is complete. Corn water use is about 0.32 inches per day. Stress can cause an abortion of fertilized ovules. In Kentucky, we often observe kernel abortion at the tip of the ear. In dry years, kernel abortion can occur farther down the ear.

R3 – Milk

Kernels are light yellow for yellow dent corn and white for white dent corn. Squeezing a kernel between a thumb and a finger will push out a milk-like fluid. The milky fluid is the result of starch accumulation. Starch accumulation will continue until physiological maturity. Corn plant water use starts to decrease. Stress can cause kernel abortion, initially from the ear tip and then moving down the ear.

R4 – Dough

Yellow dent corn kernels are darker yellow. White dent corn kernels are white. Kernels gain starch and lose moisture, so kernel consistency becomes firmer or like dough. The kernel is about 70% moisture at the beginning of R4. Starch accumulation is rapid. Stresses at this point have a greater effect on kernel weight and less on kernel number. Corn plant water demand is decreasing.

Image 3.7. Corn at the R6 stage has reach black layer or physiological maturity. No more dry matter can be accumulated at this point. The kernels start to dry down by simple physics, the combination of temperature, relative humidity, sunlight, and windspeed in addition to the thickness of the husks and tightness of the kernels all determine how fast the kernels dry. Photos by Chad Lee.

R5 – Dent

Kernels at the top of the ear have dented (Figure 3.5). The starch layer (called a milk line) has formed and progresses down the kernel towards where it attaches to the cob. Kernels are at about 45% of total dry weight at the start of R5 and near 90% total dry weight when the milk line is halfway down the kernel (half milk line). Crop water use is at about 0.24 inches per day at the beginning of dent and drops to about 0.2 inches per day when all kernels are dented. Stress at R5 will reduce kernel weight. By the end of dent, yellow dent kernels are canary yellow. White dent kernels are still white.

R6 – Physiological Maturity

Blacklayer has formed at the bottom of the kernel, severing the flow of plant solutes to the kernel (Figure 3.6). This occurs soon after the milk line disappears. Biomass accumulation is complete. Using a thumbnail, you can lightly scrape away the base of the kernel to see a black or dark brown layer. The kernel is at about 30% to 35% moisture at this point. Field drydown of the kernel is a function of physics. Temperature, relative humidity, and wind speed will determine how fast or slow corn kernels dry down in the field. Normally, corn kernels that reach R6 in late August will dry down faster than corn kernels that reach R6 in mid-October.

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Chapter 4

Corn Hybrid Selection

Chad Lee and Richard C. Kenimer

It's the final minutes of a basketball game and the other team needs to foul to try to get back into it. The coach has the option between two point guards. Both shoot 80% from the line. One has made eight of 10 free throws all season, and the other has made 80 of 100 free throws. Which one do you choose? Which one has been more consistent?

When it comes to corn hybrids, you want the excellent and consistent performers. Corn hybrid selection has the potential to gain the producer the greatest yield increases without necessarily paying more per acre to get them. Corn hybrid trials conducted at the University of Kentucky routinely identify differences of 20 to 40 bushels per acre. Other trials have similar yield differences. Simply picking the right hybrids can make a 20- to 40-bushel difference before the seed is ever planted.

Look for Hybrids that Consistently Perform Well

Seed companies, universities, and other companies all report on hybrid performance. Consistent corn yield is extremely important to selecting hybrids. Corn hybrids that yield well on average across many locations are most likely to be the best performers next season. Most hybrids will not yield in the top ten percent at every location. But the ones that yield in the top ten percent most consistently are good candidates for selection.

To use the basketball example above, the hybrid that yields well at multiple locations is like the player who has 100 attempts, while the hybrid that yielded well at one location is more like the player with 10 attempts. A hybrid that has yielded well across multiple locations displays more consistency. Results from more locations give us more confidence in how those hybrids will perform next year.

Corn hybrids with relative maturities from 110 to 120 days usually perform best in Kentucky. Hybrids most grown in Kentucky range from about 112 to 116 days. The maturity rating is a relative rating, and the actual number of days needed will fluctuate year to year.

The University of Kentucky hybrid trials group hybrids by maturity and are conducted across multiple locations. Each location includes three replications of the same hybrid. For any single location, the yields are averaged across three replications and then analyzed for the predictability of yield differences. The yields are also analyzed across all locations. Normally, there are seven locations in the trial.

Kentucky corn hybrid trial site. Image by Richard (Cam) Kenimer.

Yield is the Most Important Trait, but Not the Only One

Corn farmers get paid for bushels of grain and the grain quality characteristics including test weight, moisture, cracked kernels, and foreign material. Rarely are farmers paid for anything more than these factors. As a result, yield and good grain quality are the most important factors when selecting hybrids. Other traits that influence yield and grain quality include test weight, stalk strength (or standability), disease tolerance, and husk cover. Some of the biotechnology traits can help defend yield potential and/or grain quality, but they do not necessarily increase yields by themselves. More on biotechnology will be discussed in the next session.

The University of Kentucky hybrid trials reports on yield, grain moisture at harvest, test weight, and lodging. Yield, test weight, and lodging are all useful parameters. If ten hybrids have similar yields but four also have higher test weights, those four should be considered.

Diseases can reduce leaf area and minimize photosynthesis which ultimately reduces yields. For Kentucky, Gray leaf spot and Northern leaf blight are the two most common foliar diseases. If 10 hybrids all yield well and three have excellent tolerance to either gray leaf spot or northern leaf blight, then those three should be considered.

Grain moisture is helpful in determining the actual maturity of a hybrid. If all hybrids in a trial average 18% grain moisture, but one hybrid is at 22% grain moisture, that one hybrid likely matures later than the other hybrids in that group.

Corn lodging is an indicator of stalk strength or standability. Most modern hybrids do not lodge. However, in some years and with specific weather events, one or two hybrids may lodge. If a hybrid has a relatively high lodging number, then that could indicate a problem with the hybrid. Most hybrids that lodge do not yield well.

Biotechnology Traits

The incorporation of biotechnology into corn hybrids have allowed for much improved practices in some areas. The herbicide resistance traits have made no-tillage and minimum tillage systems easier to implement. Some of the insecticide resistance traits have greatly reduced yield losses from those insects. In particular, the Bt corn borer traits likely allow corn to be planted later in Kentucky without the yield penalties observed from non-Bt corn planted late. Corn hybrids without the Bt corn borer trait planted late are extremely vulnerable to corn borer infestations.

The current slate of biotechnology traits is useful in protecting corn against yield losses, but these traits alone do not make a poor hybrid a good hybrid. These traits are combined with traditional plant breeding to develop better hybrids. If a specific trait or traits are desired, then identify the hybrids that yield best with those traits.

Specialty Corn Markets

While most corn in Kentucky is yellow dent corn there are some specialty corn types that are of interest to Kentucky producers.

White Corn

White dent corn is hybrid corn with white kernels instead of yellow kernels. There is a strong market for white corn in Kentucky. White corn is milled for food. White corn hybrids may or may not have biotechnology traits incorporated into the hybrids. Most of these corn acres are contracted before planting. White corn hybrids typically are more susceptible to foliar diseases. Farmers are encouraged to scout crops, but expect to need to apply a foliar fungicide at some point in the season. The white corn trait is recessive and if pollen from a yellow corn hybrid fertilizes a white corn ovule, the resulting kernel will be yellow. As a result, farmers need to ensure that the white corn is isolated from yellow corn fields. This isolation is done either by adjusting planting dates to adjust pollination timings and/or harvesting border rows separately from the rest of the field. The border rows are used as a barrier to the rest of the field.

Non-Biotech Corn

There are some markets for corn that does not have any biotechnology traits. These hybrids are often labeled as “non-GMO”, which is a misnomer to signify a hybrid without biotechnology traits. (All corn hybrids and heirloom lines have been genetically modified through traditional plant breeding.) Farmers often contract these acres before planting.

Heirloom Corn

Some local markets are interested in growing corn types that would have been more common in Kentucky a century or more ago. These types are open pollinated and are not hybrids. These open-pollinated or “heirloom” corns will yield about 50% or less of modern hybrid corn. That yield reduction is calculated into the contracts. Heirloom corns can be grown in no-tillage conditions but are much more prone to lodging and foliar diseases. The additional management should be factored into the contracts as well.

Chapter 5

Corn Crop Management

Chad Lee

Field Preparation

Proper field preparation for corn planting begins with a soil test the previous fall. A soil test should be conducted every two years in Kentucky. Soil pH should be adjusted with agricultural lime in the fall. If the soil test calls for phosphorus, potassium, and/or zinc, those could be applied in the fall or in the spring before planting. Soil applications are the most economical timing for these. The only nutrient that should be applied after emergence in Kentucky is nitrogen fertilizer. That will be discussed in more detail in Chapter 7. Fields should be free of weeds at the time of planting. This is normally accomplished with burndown herbicides and no tillage or minimum tillage. More information about weed management is in Chapter 8.

For most Kentucky fields, no-tillage improves soil structure, reduces soil erosion, and gains water holding capacity. All these factors should improve yields.

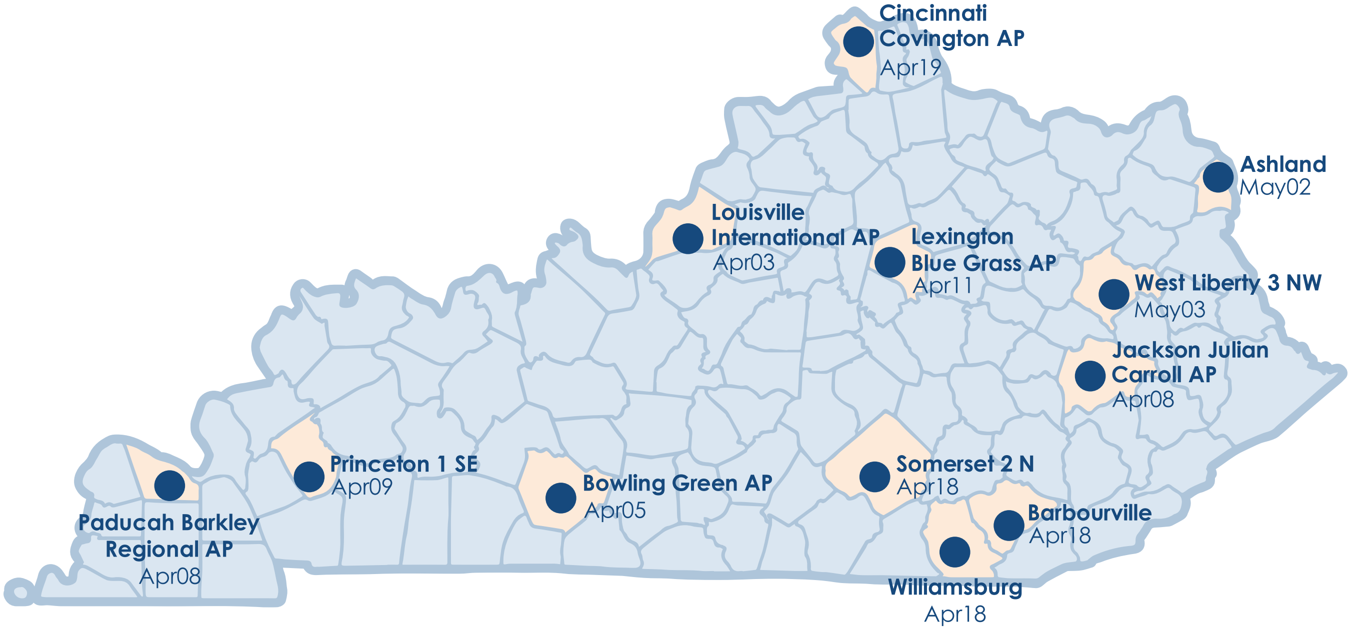
Corn Hybrid Maturities

Most hybrids are rated for maturity by a set number of days. Corn hybrids commonly grown in Kentucky range in rankings from 110 to 120 days. Most hybrids grown in Kentucky appear to be about 113 to 115 days in maturity and are commonly grown across Iowa, Illinois, Indiana, and Ohio.

We have some limited data that suggests most farming operations plant nearly all their corn acres in about 11 calendar days. If all corn hybrids are planted at about the same time, then spreading out maturities should help spread out the harvest window. In theory, using a range of maturities helps hedge against risk. Since we cannot predict when or whether dry weather will occur, we cannot predict when weather could limit yield. Corn is most sensitive to drought stress from just before tasseling to shortly after pollination. While corn of one maturity may be hurt by the dry weather, corn of a different maturity could be at a different growth stage and avoid the water stress.

Hybrids do not always mature according to their maturity ratings. In some years, we have observed hybrids of 114 and 120 days reach key growth stages at the same time. Even with these exceptions, planting hybrids with different maturities is a risk-management option.

Corn field in Trigg County, Kentucky. Image by Chad Lee.



Map of 50th percentile spring freeze dates.

Image 5.1. Young corn plants planted into a strip-tilled field with rye cover crop terminated about four weeks before corn was planted in Christian County, KY. Photo by Chad Lee

Corn Planting Dates

Current soil conditions, air temperature, and a favorable forecast may be more important than the calendar when planting corn in Kentucky. Soil temperatures at or above 50 degrees Fahrenheit for three or four days combined with a favorable forecast are a good guide for the start of corn planting.

Historically, these ideal conditions normally occur in April and May in Kentucky. Because of these historical conditions, corn traditionally has been planted from about April 1 to May 15 for most of Kentucky. Those historical dates were based on research data and the odds that soil conditions and weather were favorable for corn germination and growth. Yield losses were expected to occur when corn was planted around May 15 or later. However, current research and farm data suggest that corn planting could start as early as the last week of March and occur June 1 or later with little impact on yield, depending on the year.

Planting before April 1 increases the chances for a late spring freeze that can damage the corn plants and possibly result in a need for re-planting. Planting in June decreases

Current soil conditions, air temperature, and a favorable forecast may be more important than the calendar when planting corn in Kentucky.

Image 5.2. Corn following a rye cover crop that was terminated about three weeks before corn was planted in Hardin County, KY. Different nitrogen rates were tested in this field to better understand the relationship between cover crops effect on nitrogen needed by the corn crop. Photo by Chad Lee

the time to reach maturity and pushes corn reproductive stages later into the summer with fewer hours of sunlight.

Producers in Kentucky have provided planting dates and corn yields from 2003 through 2012 on more than 800 fields. Based on crop rotation, some fields may be repeated every other year. The resulting curve is weak (R2=0.24), implying that planting date has minimal influence on final yields. When the data was separated by regions of the state or by year, similar results occurred (data not shown). In Figure 5.1, some of the highest yields occurred from planting dates of March 26, May 11, May 24, May 26, and May 31. Planting early has larger variation in yields than planting later.

These data suggest that the weather at corn planting and the weather on the developing crop normally are more important than calendar, within some reasonable boundaries. In addition, the data suggest that yield losses from late planting are not as severe as they were 30 years ago. Reasons for this may include the wide use of Bt corn borer hybrids, better seed placement, better pest protection, and changes in weather. Whatever the reasons may be, the data help emphasize that soil conditions and weather are more important than planting date.

While the ideal planting date for corn may fluctuate year to year, the USDA Risk Management Agency considers April

Image 5.3. Corn kernels fill these ears and are about one-half milkline in the dent stage. Foliar diseases are present but unlikely to affect yields at this point. Photo by Chad Lee

Image 5.4. Corn at the R3 (milk) growth stage in Taylor County, Kentucky. Photo by Chad Lee

1 to May 31 to be the normal planting window for corn in Kentucky. To maximize crop insurance coverage, farmers are encouraged to plant corn in this window.

Corn Seeding Rates

A consistent trend in corn production of the past five decades is that newer hybrids require higher plant populations to maximize yield. The suggestions for corn seeding rates are in Table 5.1. Numerous studies have been conducted on corn plant populations and yield. Over the past ten years in Kentucky, studies have shown that if water is not limiting then corn can handle very high populations. However, if water is severely limiting, corn needs to be at very low populations. For situations in the middle (some water limitation during the season), corn yields well at a wide range of populations. Therefore, the planting rate suggestions are based in part on the risk of a soil becoming water-limiting during the reproductive stages of corn development.

Soils that are considered *low* for productivity are very shallow and often eroded slopes or heavy clays that are not tilled. These types of soils are at a high risk for having limited water during seed fill. To put this a different way, the odds of high yields occurring on these fields are low. As a result, the suggested seeding rates are 24,000 to 26,000 seeds per acre.

Soils in the *medium* productivity soils have about three feet of water-holding capacity. These soils generally slope less than 12% but are not level. These soils are prone to be water-limiting during corn reproductive development, but less likely than the low productivity soils. Suggested seeding rates for this group of soils are 26,000 to 30,000 seeds per acre.

Image 5.5. This corn was planted at less than one inch deep and the shallow roots are not picking up enough potassium (K). A mistake on planting can lead to other problems later. Photo by Chad Lee

Table 5.1. Suggested seeding rates for corn in Kentucky, assuming 95% emergence in 30-inch rows.

Soil Productivity	Target Seeds/A	Comments†
Low	24,000 to 26,000	Soils that are shallow, sloping, or non-tilled clays. Expected yields are less than 140 bu/acre on average.
Medium	26,000 to 30,000	Many soils in Kentucky with less than 12% slope and effective rooting depth to about 3 feet.
High	32,000 to 36,000	Deeper soils (river bottoms) with about 6 feet or more of rooting depth and excellent water-holding capacity. (No irrigation.)
Irrigated	32,000 to 42,000	The lower range is for limited water supply. The upper range is for fields at very low risk for water stress.

† Stalk strength is extremely important at the upper population range. Consult with local seed representatives on stalk strength and hybrids suited to the high populations.

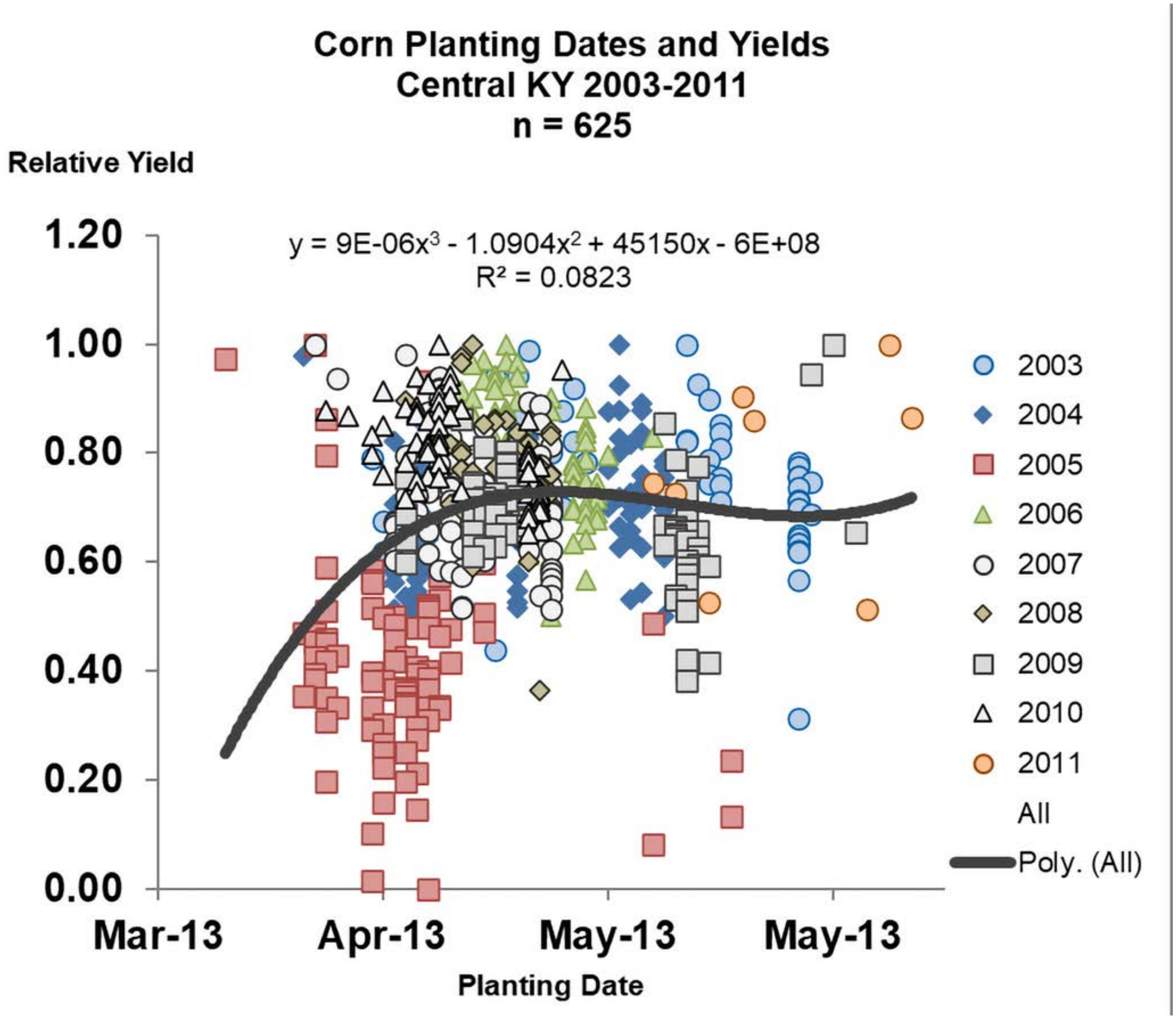


Figure 5.1. Corn yield and planting date have a very loose correlation in Kentucky. Each data point represents a single cornfield in a single yield. Six hundred and twenty-five individual fields were included in this analysis. For each farm and year, the highest-yielding field was set to 1 and every other yield from that same farm and year was set as a percentage of the highest yield. This allows us to analyze over different seasons.

Table 5.2. Seed-to-seed spacing for different seeding rates and row widths.

Target Rate	Row Width, Inches			
	15	20	30	36
Seeds/Acre	Seed-to-Seed Spacing, inches			
24,000	17.4	13.1	8.7	7.3
26,000	16.1	12.1	8.0	6.7
28,000	14.9	11.2	7.5	6.2
30,000	13.9	10.5	7.0	5.8
32,000	13.1	9.8	6.5	5.4
34,000	12.3	9.2	6.1	5.1
36,000	11.6	8.7	5.8	5.0
38,000	11.0	8.3	5.5	---
40,000	10.5	7.8	5.2	---
42,000	10.0	7.5	5.0	---

Highly productive soils that are not irrigated are deep with about six feet or more of rooting depth and have excellent water-holding capacity. These soils often occur in river and creek bottoms. The Memphis soil type fits into this category. Suggested seeding rates are 32,000 to 36,000 seeds per acre.

Irrigated soils have a wider range of suggested seeding rates of 32,000 to 42,000 seeds per acre. The lower range of these suggested seeding rates are for soils with low water-holding capacity, while the higher seeding rates are for soils with better water-holding capacity. The higher range are for soils where there is very little risk of water limitations. Consult with your seed sales representatives for guidelines on hybrid strength.

Many fields in Kentucky have soils in the low, medium, and highly productive categories. These fields are excellent candidates for variable rate seeding. The irregular shapes of many of these fields provide more reasons to have section control on planters to prevent overlapping rows.

In all these systems, we are assuming proper soil pH, adequate soil fertility, no soil compaction, no weed competition, and diseases and insects below threshold values. All these seeding rates are suited for corn in 30-inch, 20-inch, and twin rows (8-inch twin rows on 30-inch centers). For corn in 36- or 38-inch rows, populations can go to about 32,000 seeds per acre but not above or the resulting plant-to-plant spacing will get too close (Table 5.2).

Neighboring states have different results for corn seeding rates or plant populations. Indiana, Tennessee, and Ohio report ideal seeding rates while Illinois reports ideal plant populations. In Indiana, the most recent data suggest that seeding rates of 33,000 seeds per acre (final stand of 31,400 plants per acre) is ideal for most fields (Nielsen et al., 2014). Under severe drought stress 21,000 to 25,500 plants per acre may be better. For Tennessee non-irrigated fields, a seeding rate of 30,000 seeds per acre (targeting 27,000 to 28,000 plants per acre) is recommended (McClure, 2009). In Ohio, suggested seeding rates of 31,000 to 33,000 seeds per acre are recommended for most environments, while 24,000 to 26,000 seeds per acre are recommended for fields with low yield potential (Thomison, 2011). Illinois identified final plant populations of 25,000 to 30,000 plants per acre maximized yields in non-irrigated southern Illinois locations while 35,000 to 40,000 plants per acre were needed in non-irrigated northern Illinois (Nafziger, 2013).

Current University of Kentucky research tested irrigated corn up to 60,000 seeds per acre in 15-inch rows. With final stands at least 95% of seeding rates, yields were steady to increasing from populations of 40,000 to 60,000 seeds per acre. The most economical populations in those irrigated studies were about 40,000 to 45,000 seeds per acre.

Uniform Depth Placement

Corn should be seeded at about 1.5 to 2.0 inches deep for most Kentucky soils. Corn should not be planted less than 1.5 inches deep. In soils with higher sand content, corn could be seeded as deep as 3.0 inches but not deeper. The uniformity of depth greatly influences the uniformity of emergence. Several studies have demonstrated that corn plants germinating a day or two later than the majority will become “weeds”: not producing much seed of its own and limiting the seed production of neighboring plants. While much attention is given to uniform spacing, uniform depth may be more important than uniform spacing.

Setting the depth is a balance between having enough force (or weight) to cut the furrow and not so much as to

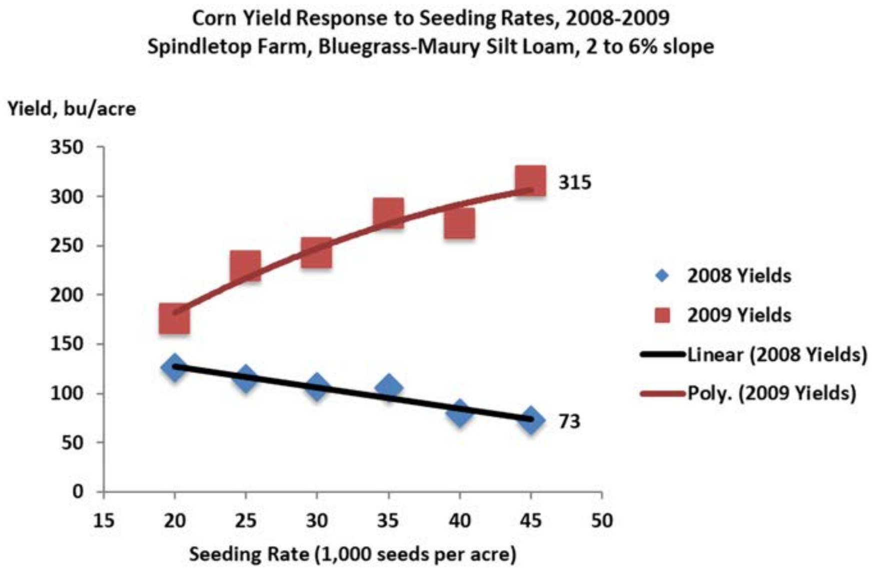


Figure 5.2. Yield response of four corn hybrids to seeding rate in 2008 (dry year) and 2009 (timely rainfall). Data are from Spindletop Farm, Lexington, KY, on a Bluegrass-Maury silt loam with four hybrids: DKC63-42, DKC63-45, DKC64-44 & DKC65-47.

cause sidewall compaction. If sidewall compaction is severe, then the corn will not fully recover and yield will be lost.

Consult the owner's manual of your planter to learn how to properly set depth without increasing the risk for sidewall compaction.

Uniform Spacing

Corn spacing refers to the distance between two plants in the same row. For corn in 30-inch rows as a set population of 30,000 seeds per acre, the seed-to-seed spacing should be 7 inches (Table 5.2). If all seeds germinate, then the plant-to-plant spacing is also 7 inches. Most replicated studies demonstrate that if most corn plants are plus or minus 1-inch from the desired plant spacing, then yields are not affected. Yields are reduced if two or three plants are within 2 inches of each other. (note: find Nielsen's spacing studies). These are referred to as "doubles" and "triples". In the above example, if a seed does not germinate, then that leaves a "skip" between two plants. Generally, skips are less damaging to overall yield than doubles and triples.

Consult your owner's manual to learn how to set your planter and the ideal planter speed. Planters operated faster than recommended will drop seed less uniformly.

Starter Fertilizer

Most research in Kentucky has not identified a yield increase from starter fertilizers. A meta-analysis of data from across the Midwest and Mid-South (but not Kentucky) identified a 5% yield increase on average from 2x2 (2 inches beside the row and 2 inches below the soil surface) and/or in-furrow starter fertilizers containing nitrogen. Starter fertilizers will usually make young corn plants looks greener and appear healthier. If starter nitrogen is factored into the total nitrogen management plan, starter fertilizers can be a viable option. Be cautious about the salt indexes of fertilizers applied in-furrow. If too much fertilizer is applied in-furrow, it could damage the seed. More information about fertilizer rates and placements occurs in Chapter 7.

In general, the window for excellent conditions to plant corn is narrow in Kentucky. With that in mind, the planter should not be stopping more to fill fertilizer tanks than it stops to fill the seed hoppers.

Row Cleaners

Getting uniform depth when planting can be a challenge when heavy residue is present. That residue could be from the preceding cash crop or from a cover crop. Row cleaners set properly can move residue away from the seed furrow and improve seed placement uniformity. Proper settings usually mean that the row cleaners are moving a residue out of the seed furrow but moving minimal, if any, soil. If a farmer wants to use the row cleaners to lightly till the soil, then the row cleaners penetrate less than 1 inch into the soil.

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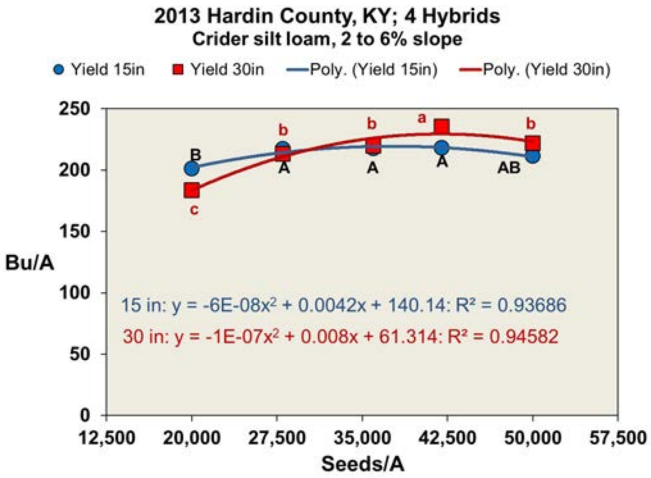

Figure 5.3. Corn hybrid yield response to seeding rate in 2013 (adequate rainfall). The field was no-tillage. The hybrids were Pioneer P1319HR and P1498HR.

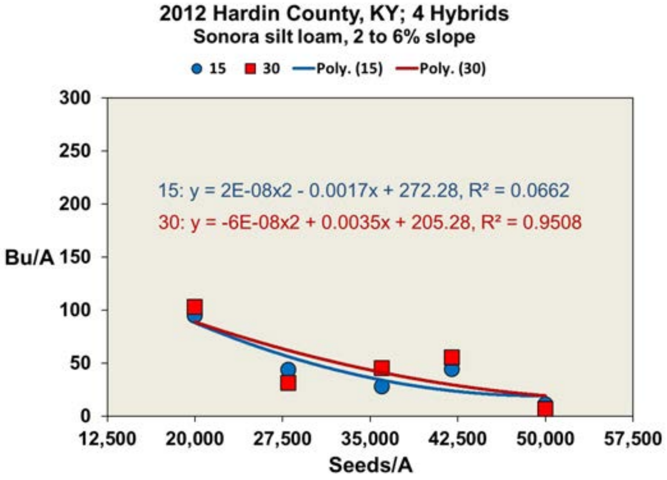

Figure 5.4. Corn hybrid yield response to seeding rates in 2012 (dry season) in Hardin County, Kentucky. The four hybrids were Pioneer brands.

Irrigated corn research trials at Princeton, Kentucky. Image by Carrie Knott.

Chapter 6

Irrigation Principles and Tools

Chad Lee, Carrie Knott, Ole Wendroth, and Montserrat Cortasa Salmeron

Nearly all the agronomic management for a corn crop occurs before July 1 in most years. Yet, corn yield in Kentucky is extremely dependent on temperature and rainfall in July and August (Figure 6.1). If 2012 is excluded (a year of extreme drought), the temperature and rainfall in July and August across Kentucky typically explain whether the state corn yield will be greater than or less than Kentucky's trend line yield (Figure 6.2). Thus, a Kentucky farmer must make most important decisions involving management and anticipated yield before they know the yield potential of the corn crop and how weather late in the season will support high yields. Irrigation can help alleviate these risks, stabilizing and potentially improving yields.

About 83,000 acres of farmland are irrigated in Kentucky, which equates to only a little more than 1% of the harvested grain crops. Irrigation can lead to higher yields compared to rain-fed conditions when properly managed because corn yields are reduced when insufficient rainfall occurs. In Kentucky it is common for yield to be reduced by up to 23% when rainfall is insufficient and in extremely dry years yield loss of 50% or more can occur in specific fields. Managing irrigated crops differs substantially from managing rain-fed crops. Although irrigation can help avoid water stress and maximize corn production and profitability, it comes with the risk of over-irrigation, which can reduce yields by caus-

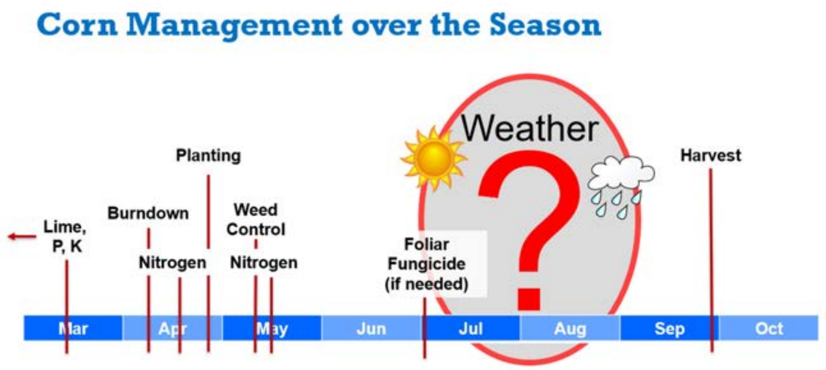

Figure 6.1. Typical timings of corn management practices in Kentucky.

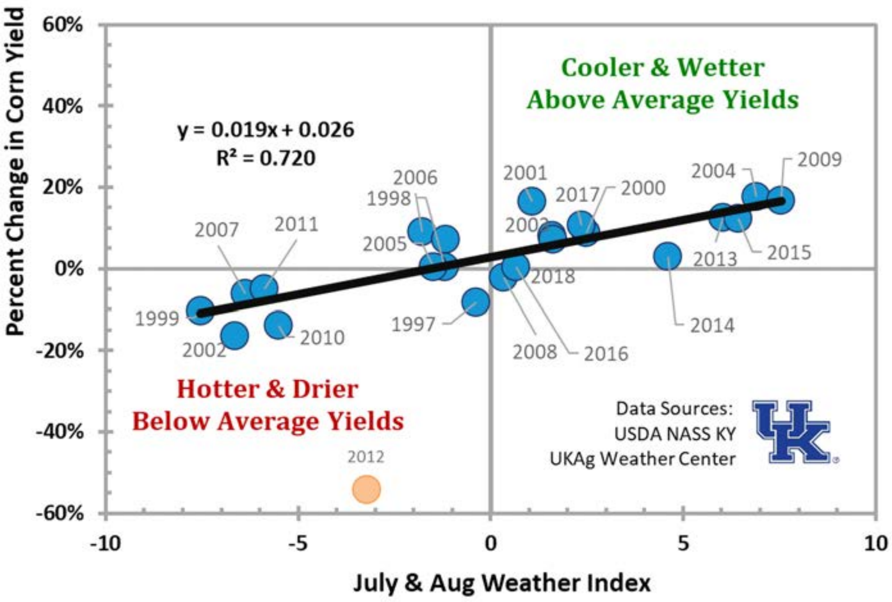

Figure 6.2. Cooler, wetter July and August weather results in greater corn yields in Kentucky while hotter, drier July and August results in lower corn yields. The July and August weather is expressed as an index of rainfall deviation from normal plus the inverse of temperature departure from normal. The percentage of yield change was calculated as the deviation from the historical yield trend. Since corn yields generally increase over time, the best way to compare among years is to compare departures from the yield trend.

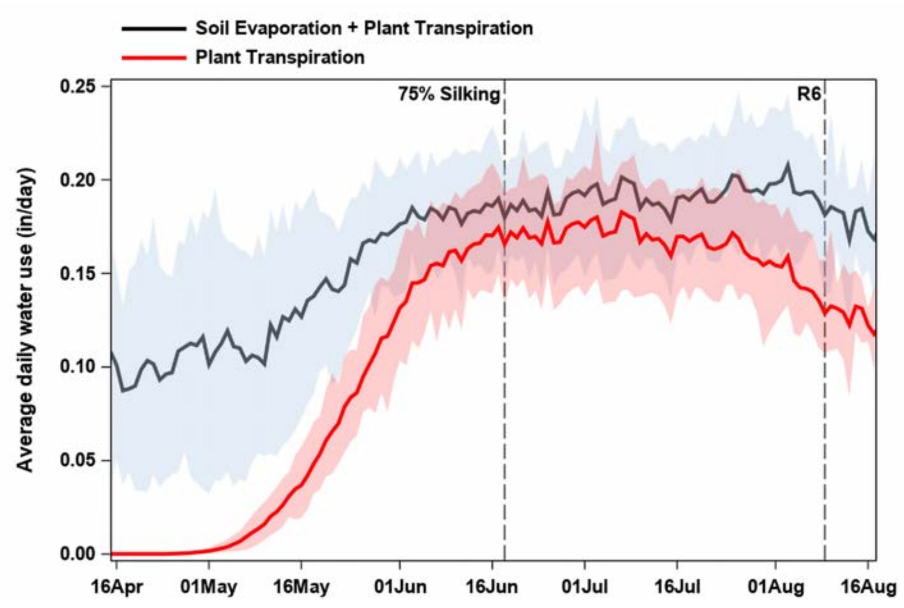

Figure 6.3. Average daily evapotranspiration (soil evaporation + plant transpiration) and plant transpiration of a full-season corn hybrid grown in Princeton, KY, planted on April 15. Data were obtained from the DSSAT-CERES crop simulation model using weather data from 1990-2020. The shaded areas indicate the 90% confidence interval, i.e., in nine out of 10 years the actual ET for corn grown in Princeton, KY, will fall within the shaded area.

ing nutrient losses, waterlogging damage, oxygen deficiency, surface runoff and, in particularly extreme cases, soil erosion. Therefore, understanding when and how much to irrigate is an essential key to profitable corn production while protecting the environment.

Corn Water Use

During early corn developmental stages, the average water required for evapotranspiration (ET) in Kentucky under no water stress is typically about 0.10 inches per day (Figure 6.3). Most of the water loss occurs through soil evaporation because corn plants are small and a large portion of the soil between corn rows is exposed to direct sunlight. As corn develops and reaches reproductive growth stages, average water use increases to almost 0.20 inches per day (Figure 6.3). By silking, nearly all water loss is transpiration, or water loss from the plants, because the soils are shaded by the crop.

These crop stage-dependent water use values are helpful for generalized recommendations only. The actual corn water use depends upon many environmental conditions: sunlight, air temperature, relative humidity, and wind speed. Therefore, estimates of average water use in corn vary from one region to another, from one field to another, or even within the same field depending on topography. For example, average water use of corn in Nebraska will likely be greater than that in Kentucky because relative humidity in Nebraska is lower and wind speed greater than in Kentucky, causing a larger water deficit in the atmosphere.

Water use can also vary from one year to another based upon environmental conditions, as shown by the range of estimated water use for corn planted in Princeton, KY, in Figure 6.3 (variability across years is indicated by the shaded area). For example, corn water use may range from about 0.20 inches per day in early May assuming hot and dry conditions. In contrast, if conditions are cool and wet for that same time corn water use may be less than 0.05 inches per day. Therefore, even when generalized estimates of corn water use by growth stage exist for specific regions it is critically important that actual environmental conditions are considered for irrigation scheduling.

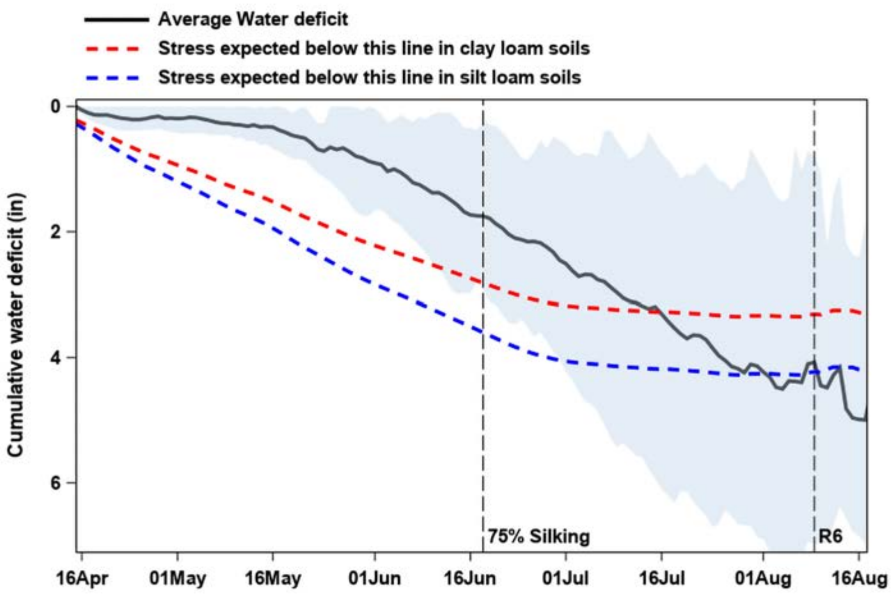

Figure 6.4. Average cumulative water deficit calculated from the difference between actual evapotranspiration (ET) and precipitation of a full-season corn hybrid grown in Princeton, KY, planted on Apr 15. Evapotranspiration was estimated from simulations over 30 years (1990-2020) with the DSSAT-CERES crop model. The shaded area indicates the 10-90% percentile interval. The dashed lines indicate the thresholds below which crop water stress would occur in a silt loam soil (blue) and a clay loam soil (red) with typical crop soil available water as described in Table 6.1. The estimated thresholds consider an increase in crop rooting depth over the season up to 31.5 inches, and that water stress would occur when the soil water storage is depleted to 60% of the plant-available water capacity.

Typical Water Deficit for Corn Grown in Kentucky

In a typical year, corn grown in Kentucky uses about 5.1 inches of water in July and about 5.0 inches of water in August. The 30-year average precipitation across Kentucky is slightly more than 4 inches each month in July and August. However, if every day of these two months were clear and sunny, corn water use would increase to 6.9 and 6.8 inches for July and August, respectively. If plant available water stored in the soil falls below 60% of the plant available water capacity, then the corn crop will likely experience periods of water stress that can negatively impact final grain yield.

In Kentucky, water deficits commonly occur during the corn growing season (Figure 6.4). On average, the crop has a 2- to 4-inch water deficit during reproductive growth stages, when water deficits can result in the most damage to final grain yield. However, corn may experience water stress only in some cases, depending on the cumulative water deficit on any given year and the plant available water.

Soil Water Holding Capacity

Another important consideration when determining when and how much to irrigate is the ability of soils to store water that is available to the growing corn crop. Soils in Kentucky are forest-based. This means they are shallower than the grass-based soils of northern Iowa, Illinois, and southern Minnesota. A Crider silt loam soil, which is the Kentucky State soil, with minimal slope will hold about 9.9 inches of water at field capacity in a soil profile that consists of 1 ft of silt loam over 1.5 ft of clay loam. From these 9.9 inches, only 6 inches are available for use by plants, in this case corn plants (Table 6.1). Assuming a maximum daily water use of 0.24 inches, 6 inches will theoretically be enough to sustain a corn crop for 25 days before the plant-available water is entirely depleted. However, water stress would occur already at 10 to 11 days because this is how long it would take for the plant available soil water to be depleted down to 60% when precipitation does not occur. Shallower soils will hold less water and deeper soils will hold more. If Kentucky experiences a very hot July and August combined with about two weeks of no rain, corn could suffer water deficits with the shallow soils experiencing it first.

Extreme situations of rapid water depletion can occur in fragipan soils depending on the depth of the fragipan layer. Approximately 2.7 million acres in Kentucky have fragipans (Karathanasis et al., 2017). In most cases, the fragipan is at 20 to 24 inches depth, reducing the plant available water holding capacity considerably due to the reduced rooting depth.

Remember, plants will already be under water stress conditions even if the soil water content is substantially above the permanent wilting point. As a rule of thumb and as shown below, it is appropriate to turn on the irrigation when the water storage is depleted to 60% of the plant-available water capacity.

Even though Kentucky receives more than enough rainfall over the course of a year to support corn production, it is not uncommon for corn fields to have a water deficit during the growth stages that reveal the greatest water demand of the crop (Figures 6.3 and 6.4). Irrigation can help mitigate water stress during those periods to avoid water deficits. However, there are management practices that will increase soil water retention. After about four years of no-tillage, a soil will hold about 1 to 2 inches more water (Blevins et al. 1971). Thus, no-till can help provide a buffer against dry conditions. This is likely part of the reason for yield increases in no-till fields in the Ohio River Valley. Storing an extra inch or two of water is not as helpful in Iowa or Illinois where the soil at field capacity is holding 12 to 15 inches, already.

Irrigation Management Tools

Tools that help producers decide when and how much to irrigate can greatly increase the productivity, and ultimately

Table 6.1. Typical soil water content at field capacity (θFC) and permanent wilting point (θPWP), plant-available soil water capacity (PAWC), and plant available water storage (PAWS) for soil layers of different thickness in different soil types. (Modified after Wendroth et al., 2017)

Soil Type	Soil Water Content at		Plant Available Soil Water Capacity (PAWC) (v/v)	Plant Available Soil Water Storage (PAWS) in a…		
	Field Capacity (θFC) (v/v)	Permanent Wilting Point (θPWP) (v/v)		4 in-layer (inch)	1 ft-layer (inch)	3 ft-profile (inch)
Silt Loam	0.33	0.10	0.23	0.92	2.76	8.28
Clay Loam	0.33	0.15	0.18	0.72	2.16	6.48
Sand	0.09	0.05	0.04	0.16	0.48	1.44
Example: 1 ft Silt Loam over 1.5 ft Clay Loam				1.0*2.76 inches + 1.5*2.16 inches= 2.76 inches+3.24 inches = 6 inches		

the profitability, of corn production. Yield can be reduced when too little water or when too much water is provided to the corn crop while it is growing and filling grain. If too much water is applied, profitability can be reduced due to lower yields, which are a consequence of nutrient losses, particularly nitrate losses.

There are many irrigation scheduling tools that estimate crop water deficit and can help decide when irrigation should be used. Three of the most common irrigation tools are the checkbook method, the daily water balance method, and sensor-based methods.

Checkbook Method

The checkbook method is by far one of the simplest irrigation scheduling tools available to decide when and how much irrigation water to apply. This method is a simplified version of the water balance method in which the difference among weekly precipitation, plant available soil water storage (PAWS; Table 6.1) and expected crop water use results in the total amount of supplemental water needed.

For example:
During the blister (R2) growth stage about 1.40 inches water are needed per week: 0.20 inches per day x 7 days. At the beginning of the week plant available soil water storage was expected to be about 1.5 inches. Recall, plants only have access to 40 % of the plant available water before water stress occurs; therefore depletion down to 60% of 1.5 inches is 0.6 inches. Only 0.1 inches rainfall occurred for the week.

Subtract rainfall and 60% depletion of PAWS from crop water needs to find the amount of irrigation needed to avoid water deficits and crop stress.

1.40 inches – 0.1 inches – 0.6 inches = 0.70 inches of irrigation water is needed

Although the checkbook method is the simplest to implement, the main disadvantage of this method is that it is the least accurate method to estimate water needs. This is because the checkbook method relies on long-term averages of crop water needs (ET) that may or may not reflect current growing conditions. This can lead to inaccurate estimations of irrigation needs and could result in yield limiting conditions.

Water Balance Method

The water balance method also involves calculations to determine irrigation needs. However, it is more complicated to apply than the checkbook method because it requires daily estimates of ET. This method calculates the cumulative water deficit after accounting for precipitation to fulfill ET requirements. Irrigation is provided when the crop reaches a specified water deficit depending on the soil and irrigation rate.

The estimates of ET in this method can be obtained based on the formula below (example uses the FAO56 single crop coefficient approach).

Daily Crop Evapotranspiration (ET): $ET_a = K_c \text{ x } ET_0$

The term "ET_0" is the reference evapotranspiration which equals actual ET under well-watered conditions. ET_0 can be obtained from weather stations located at different sites in Kentucky from the UKAg Weather Center (http://weather.uky.edu/php/cal_et.php). The term "K_c" is a crop coefficient that is dependent on growth stage and soil water content. Kc multiplied by ET_0 provides an estimate of the actual crop ET. In corn, K_c is approximately 1.20 when the crop has a full canopy and decreases to 0.35-0.6 by physiological maturity. The K_c early in the season will be lower than 1.2 but can be variable depending on row spacing, plant population, environmental and irrigation management conditions (e.g. under frequent rainfall or sprinkler irrigation events, K_c may approach 1 or 1.2).

The water balance method can provide good estimates of crop ET to identify irrigation requirements and is the standard method used by many in the southeastern U.S. to

ET (Evapotranspiration): A measure of the amount of water used from a landscape (corn field). Water use includes soil evaporation and crop transpiration. Typically measured in inches (or mm) of water per day.

Plant Available Water Capacity (PAWC): The amount of plant-available water that can be stored in the soil profile, measured in inches (or mm). If soil water storage falls below 60% of the PAWC, irrigation should be turned on to avoid water stress reducing production.

Plant Available Soil Water Storage (PAWS): The actual amount of water stored in the soil profile, measured in inches (or mm) that the plant is able to access for water uptake.

Soil Evaporation: Water that evaporates from the soil surface, measured in inches per day (or mm per day).

Transpiration: Water that transpires through plant leaves measured in inches per day (or mm per day) that cools the plant and allows for photosynthesis.

Field Capacity: The soil water content (measured in volume percent) or storage (inch or mm) to which the soil drains quickly due to gravity at two days after an extended rain period. In many cases, 1/3 bar or 33 kPa is assumed to be the soil water suction at field capacity. However, for Kentucky soils and climate conditions, 1/10 bar or 10 kPa is realistic, which implies a higher PAWC than at 1/3 bar.

Permanent Wilting Point: The soil water content (Vol. %) or storage (inch or mm) at which plants die because of irreversible wilting. The soil water suction at PWP is at 15 bars.

Soil Water Holding Capacity: Soil water content (Vol. %) or storage (inch or mm) at field capacity.

determine when and how much to irrigate, particularly in Arkansas, Mississippi, Texas, and Louisiana. The method is not widely used in Kentucky because user-friendly tools to estimate daily ET rates are not available.

The UKAg Weather Center has developed a simplified version of this method with the "Irrigation Manager" tool (available at http://weather.uky.edu/php/cal_et.php). The Irrigation Manager estimates ET for each day based on weather and an ET model. It does not estimate ET for a specific crop such as corn or factor in the growth stage of corn. Since the corn crop and corn growth stage are not considered, little precision is gained compared to the checkbook method.

Sensor-Based Method

The sensor-based method to estimate irrigation needs is very accurate. Its accuracy is due in part to installation of specialized equipment in the field, some of which requires calibration. When properly calibrated, the soil moisture sensors measure the soil water status and can be used by the producer and/or irrigation model to determine how much the plant-available water is depleted. Moreover, this method provides triggers for turning on the irrigation or shutting it off and minimizes the risk of over- and under-application of irrigation water.

Soil water status is typically estimated in two different ways. One is the soil water potential, which can be measured with a tensiometer or an electrical resistance block, e.g., Watermark. The other is soil water content, which can be monitored with a TDR probe, capacitance probe, or with a volume-sample of soil. The measurements can be used to determine when to turn on the irrigation.

In general, the rule of thumb is to make sure that plant-available water stored in the soil does not fall below 60% of the PAWC. For a 3-ft deep soil (as displayed in Table 6.1) and assuming rooting depth is to 3 feet, irrigation needs to be turned on when plant-available water is 5 inches in the silt loam, 3.9 inches in the clay loam, and 0.9 inches in the sand. Remember, not all water in the soil is plant-available. The only water in the soil that is available for use by the plant is the water above the permanent wilting point and below field capacity in the depth range proliferated by roots.

In the following, we provide an example of a 3-ft deep soil profile with a 1.5-ft layer of silt loam on top of a 1.5-ft layer of clay loam. Based on the information in Table 6.1, the plant available water capacity in a 1.5-ft layer of silt loam is (1.5 ft * 2.76 inches =) 4.14 inches. The plant available water capacity in the 1.5-ft clay loam layer is (1.5 ft * 2.16 inches =) 3.24 inches, resulting in a total plant available water capacity of 7.38 inches in the 3-ft soil profile. Soil water content sensors were installed at the center of the depth interval that they represent: 0-9, 9-18, 18-27, and 27-36 inches (Table 6.2).

The measurements obtained in Scenario 1 signal that there is no need to irrigate because the depletion down to 73% is still above the 60% threshold. However, the measurements taken in Scenario 2 reflect a situation in which the plant-available soil water storage is already depleted to a value of 40% which is considerably below the recommended threshold. Irrigation should be turned on immediately to prevent the deficit from becoming more severe. The plant-available water storage was 2.97 inches while the threshold of 60% corresponds to 4.4 inches. Assuming a daily ET of approximately 0.2 inches, the irrigation should have been triggered approximately seven to eight days ago.

One limitation of this method arises from the question where to put the soil water content sensor (or water potential

Table 6.2. Two scenarios of measured soil water content at soil depths in a two-horizon soil profile. PWP denotes permanent wilting point, PAWC plant-available water content, and PAWS plant-available water storage.

Soil Type	Sensor Depth	Soil Layer	Total Soil Water Content		Plant Available Soil Water Content (PAWC)	Plant Available Soil Water Storage (PAWS)	Water Depletion
	(inch)	(inches)	Measured, v/v	Permanent Wilting Point (PWP, v/v)	(v/v)	(inch)	
	Scenario 1						
Silt loam	4.5	0 – 9	0.20	0.10	0.10	0.90	
	13.5	9 – 18	0.25		0.15	1.35	
Clay loam	22.5	18 – 27	0.30	0.15	0.15	1.35	
	31.5	27 – 36	0.35		0.20	1.80	
					Total:	5.40	73 %
	Scenario 2						
Silt loam	4.5	0 – 9	0.10	0.10	0.00	0.00	
	13.5	9 – 18	0.15		0.05	0.45	
Clay loam	22.5	18 – 27	0.28	0.15	0.13	1.17	
	31.5	27 – 36	0.30		0.15	1.35	
					Total:	2.97	40 %

Plant available soil water content is total soil water content minus water content at permanent wilting point.

Table 6.3. Advantages and Disadvantages of ThreeCommon Irrigation Scheduling Tools.

Method	Advantages	Disadvantages
Checkbook method	Does not require installation/equipment costs Easy to apply, only requires calculation of the difference among estimated crop water needs, precipitation, and plant available water	Not as accurate as other methods in estimating irrigation needs Does not account for actual crop water use
Daily water balance	Does not require installation/equipment cost Can be applied to any location with available weather data Can be accurate when used correctly	Requires computation Requires availability of weather data (minimum of daily minimum and maximum temperature, and precipitation).
Sensor-based	Most accurate when used correctly No assumptions for ET necessary	Requires installation cost Requires some maintenance Additional sensors required for different locations or soils

sensor). Farmers who know their fields and who know which zones fall dry at first need to make this decision based on their experience. An advantage of this method compared to the first two presented here is the fact that one does not need to make assumptions about ET because the soil water status is directly measured. The onset of irrigation is based on the measured water content. Remote access to this measurement simplifies the decision whether to turn on the irrigation system.

Variable Rate Irrigation

Producers understand that their fields are variable in slope, soil depth and soil type. This spatial variability is caused to a great extent by the Karst topography, erosion, and sedimentation processes leaving clayey soil at the surface in some backslope zones and deep silty horizons in other areas, such as footslopes within the same field. This variation is manifested in water infiltration rates that can be three to four times smaller in clayey zones than in silty zones, causing the problem of deciding on an optimum irrigation rate. Most irrigation systems on Kentucky farms provide spatially uniform irrigation rates. Modifying the pivot progressing speed will create partial differentiation of irrigation rate. Variable-rate systems in which irrigation nozzles can be controlled individually through GPS and an underlying irrigation map are expected to bring economic benefits and opportunities for environmental stewardship to our farms. Research will be focused on how to derive variable-rate irrigation maps specifically for Kentucky, what data are needed, and what the environmental benefits are.

Agronomic Modifications to Irrigation

Plant Population

If an adequate amount of water is available, increasing corn populations (up to a point) will increase total number of kernels per acre and increase yield. However, if water is limiting, the higher corn populations will add stress to the plants and will reduce yield by either harming pollination, increasing kernel abortion or decreasing kernel size. In many cases, low-density populations resulted in the highest yields in years with extremely dry weather. Conversely, with adequate water from rainfall or irrigation, populations of up to 45,000 plants per acre in 30-inch rows will result in high yields. In narrow rows, populations can rise to 50 or 55,000 plants per acre for maximum yield. See the chapter 5 (Crop Management) for more information. Planting a high population without irrigation carries the risk of losing yield if it is a dry year. Irrigation eliminates this risk.

Choice of Hybrid Maturity

The choice of hybrid maturity is another management decision that needs to be considered when adequate water is available from irrigation, or due to enough water supply from the soil. Results from three experiments conducted in Lexington and Princeton, KY, indicate that increasing hybrid maturity length increased corn yields to a greater extent under irrigation compared to rainfed conditions (Figure 6.5). The experiments conducted in Lexington during 2017 and 2018 were exposed to relatively low water stress which is unusual for this location. Thus, under irrigated conditions or moderate water stress in wet years, producers will benefit from full-season corn hybrids. In contrast, the experiment conducted in Princeton during 2017 was exposed to a relatively higher water stress compared to Lexington. Under conditions of water stress, yields across a wide range of hybrid maturities are more likely to be similar.

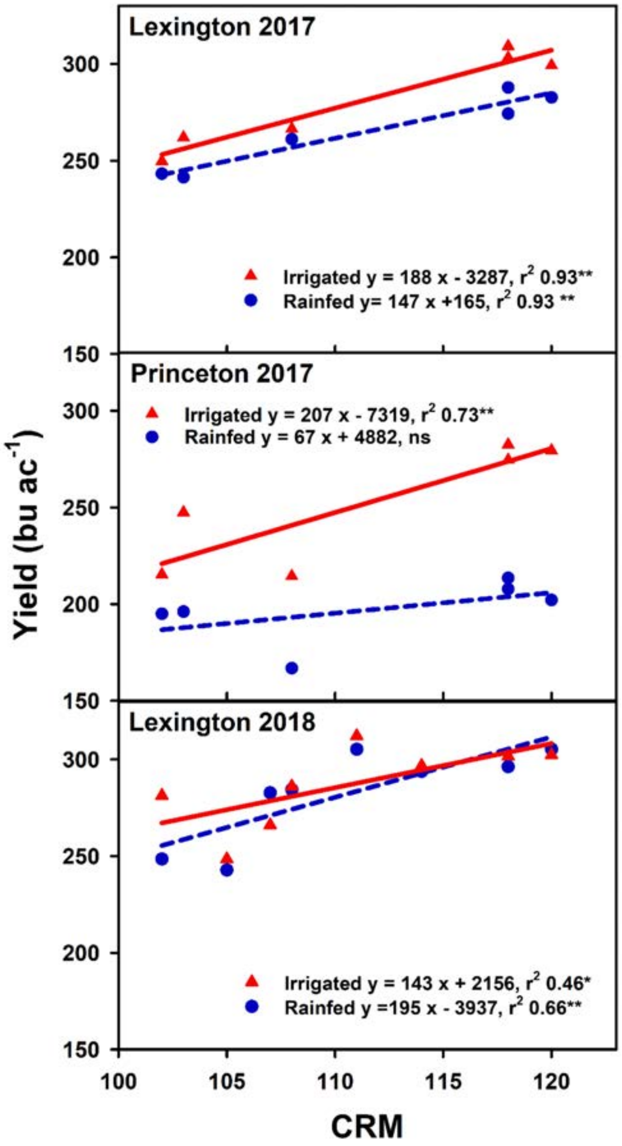

Figure 6.5. Corn yield under irrigated and rainfed conditions at three site-years across a range of corn hybrid relative maturities (CRM). These experiments were conducted by Salmeron et al., thanks to the support by the KY Corn Growers Association.

Nitrogen Management

Nitrogen management is discussed in greater detail in the nutrient management chapter. Ensuring adequate water with irrigation allows a producer to confidently apply nitrogen fertilizer when needed. Fertigation systems with appropriate black-flow preventers can help apply smaller doses of nitrogen to meet the crop's needs. An irrigation event of 0.1 inch per acre is approximately 2,700 gallons of water per acre. Thus, fertigation of nitrogen will not burn the corn plants.

Fertigation and high-clearance applicators allow a producer to better time N applications to when the corn crop needs nitrogen. This timing, combined with the yield protection of irrigation, allows a producer to manage nitrogen in a way that should greatly reduce the risk of nitrogen being lost.

Disease Management

A corn crop with adequate water for high yields is growing in an environment that favors foliar diseases like Gray leaf spot (caused by Cercospora zeae-maydis). Since the disease triangle includes the environment, pest, and host, the hybrids with tolerance to foliar diseases are the best way to manage this risk. After selecting suitable hybrids, a sound foliar fungicide strategy may still be needed in irrigated fields. See the Disease Management chapter for more information.

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Corn nitrogen rate trials with nitrogen-deficient corn in the foreground. Image by Hanna Poffenbarger.

Chapter 7

Fertility Program Components Resulting in Excellent Corn Nutrition

John H. Grove and Edwin L. Ritchey

A strong fertility program maintains soil nutrient levels that are adequate for nutrient uptake that supports the corn crop's full yield potential. Nutrient uptake is generally greater than nutrient removal, depending upon whether corn is harvested for grain or for silage, or whether some portion of the corn stover is removed after grain harvest (Table 7.1).

The fertility program should not cause excessive nutrient levels, given greater chance of financial loss, negative environmental (water, soil, or air) quality impact, or plant toxicity due to overapplication of certain nutrients (boron, copper, manganese, and zinc). This corn nutrient management chapter discusses the soil fertility management timeline, will include important University of Kentucky (UK) corn nutrition research, and will illustrate resulting nutrient management guidelines. The fertility program consists of soil and plant tissue sampling, considers nutrient application rates and alternatives in nutrient application timing, placement, and source management. This chapter on soil fertility and corn nutrition starts prior to planting, in the fall, and proceeds to corn maturity.

General Pre-Season Considerations

Late fall/early winter is a good time to consider impacts of the latest season's crop yield on soil fertility for the upcoming corn crop, to update soil test information, and to make early lime and fertilizer applications. Most growers soil test every two or three years. However, if the most recent crop for a field was very good, or very poor, an 'out-of-cycle' soil test can help you avoid under- or over-fertilizing the next corn crop. Do not combine yield information with tabular grain nutrient concentration data to calculate the next crop's fertilizer needs. UK research has shown that these nutrient removal estimates are of little value in determining nutrient needs. False positives (putting on more fertilizer than needed) and false negatives (putting on less fertilizer than

Table 7.1. Corn (200 bushel per acre yield level) nutrient uptake, harvest tissue concentrations and removal (determined using information from IPNI, 2014; Purdue Extension, 2013; TFI, 1976).

	Corn Nutrient Uptake (lb/acre)					
Whole Plant at	Nitrogen	[1]Phosphate	[1]Potash	Sulfur	Zinc	Boron
Physiological Maturity	270	108	274[3]	30	0.65	-

	Harvest Tissue Concentration (dry weight basis)					
Plant Part	Nitrogen	Phosphorus	Potassium	Sulfur	Zinc	Boron
	%				ppm	
Grain	1.40	0.34	0.53	0.17	25	10
Stover	0.95	0.15	1.70[2]	0.15	40	-

	Harvest Nutrient Removal (lb/bu)					
Plant Part	Nitrogen	[1]Phosphate	[1]Potash	Sulfur	Zinc	Boron
Grain	0.66	0.37	0.30	0.08	0.0012	0.0005
Stover	0.45	0.16	0.97[2]	0.07	0.0020	-
Silage (lb/wet ton)	9.7	3.1	7.3	1.1	-	-

	Harvest Nutrient Removal (lb/acre)					
Plant Part	Nitrogen	1Phosphate	[1]Potash	Sulfur	Zinc	Boron
Grain	132	74	60	16	0.24	0.09
Stover	90	32	194[2]	14	0.41	-
Silage[3]	263	84	198[2]	30	-	-

[1] P_2O_5 = phosphate = P x 2.29; K_2O = potash = K x 1.20.

[2] Considerable variation in reported K/K_2O values due to differences in leaching of K from stover between corn physiological maturity and grain harvest.

[3] 200 bu grain/acre = 27.04 wet tons silage/acre, assuming a silage moisture content of 65%.

needed) are quite frequent. Changes in nutrient availability due to soil processes (leaching, fixation, erosion etc.) are not considered, either. Don't guess – soil test and follow recommendations. A timely fall soil testing program allows early, appropriate applications of lime, phosphorus (P), potassium (K), and zinc (Zn).

Irrigated Corn Production – Irrigated corn is important to producers making the investment to deliver additional water when needed. Most of what is written in the remainder of this chapter on corn nutrition is appropriate to both dryland and irrigated corn, but the irrigation investment means that special attention should be paid to certain aspects:

1. First, soil test irrigated fields every year to monitor soil nutrient levels. As water is not likely to become limiting, nutrient removal will often be greater.
2. Second, maintain those soil nutrient concentrations at "high," but not "excessive" soil test levels. Research has not shown any need for "extra" soil nutrition for irrigated corn but letting soil nutrition fall to deficient levels can cause avoidable economic loss.
3. Third, split needed fertilizer N into two applications, delaying the larger portion (65-80%) until at least the V5-V6 growth stage to optimize N use efficiency and recovery by growing corn. If rainfall is excessive, be prepared to make a "rescue" N application.
4. Fourth, visually assess the growing crop weekly for signs of nutrient stress—use good spot/bad spot plant tissue analysis and soil tests to confirm an observed stress. Use field-wide tissue analysis to monitor for "hidden hunger/no symptom" nutrient concentrations.
5. Fifth, fertigation—application of nutrients over the top of the growing crop—provides more flexibility in fertilizer timings.

Organic Corn Production – Organic corn is economically important to those growers producing corn as part of their organic production system. Again, most of what is written in this corn nutrition/soil fertility chapter is appropriate to both conventional and organic corn, but there are important differences that cause added management attention.

1. First, soil test organic corn fields ahead of each corn crop to monitor soil nutrient levels. Corn produces a lot of biomass with a large nutrient uptake requirement.
2. Second, maintain soil nutrient concentrations in the "medium-high" soil test category to avoid excessive nutrient amendment expenses. Nutrient management is more expensive, and the probability of a positive return on investment (ROI) falls more rapidly with the larger expenditures needed to reach greater soil test levels in organic crop production.

3. Third, organic corn N nutrition needs special management attention. Corn needs a good N supply, but N is often difficult to manage in organic production systems. Intensive tillage is often used to stimulate N release from soil organic matter and organic soil amendments (residues, green cover crops, composts, manures, but not biosolids—not allowed in organic corn production). But tillage also impacts other soil processes that can affect nutrient loss mechanisms (erosion, biological immobilization, and denitrification).
4. Fourth, the usually greater per bushel price for organic corn grain suggests that additional effort to monitor the growing crop will be of value. Visually assess the growing crop weekly for signs of nutrient stress—use good spot/bad spot plant tissue analysis and soil tests to confirm any observed stress. Take field-wide plant tissue samples to monitor for "hidden hunger/no symptom" nutrient concentrations. See also Ritchey (2015).
5. Fifth, relying solely on animal manure for N, P, and K will eventually result in excessive P values that could be an environmental concern. Producers using rock phosphate as their P source will need a more acid soil pH, between 5.5 and 5.7, to maintain P availability.

Soil Testing – A regular soil sampling program is the best first tool to guide the corn nutrition program. Soil test results generate recommendations for rates of lime (soil pH management), N, P, K and Zn. Soil test B is available by special request as B is sometimes needed. In rare cases, S or magnesium (Mg) may be necessary, but there is no valid available soil S test for Kentucky. UK corn N rate recommendations (AGR-1; Ritchey and McGrath, 2020) are determined after many site-years of corn field research. Field cropping history, soil drainage class and tillage are also used to adjust N rate recommendations.

Soil Sampling – When sampling, keep in mind that a few ounces of sampled soil are being tested to determine lime and fertilizer needs for millions of pounds of field soil. This means that the sampling protocol should ensure the sample sent to the laboratory is as "representative" as possible. To be "representative," sampling should consider both the sampled area and the sampling depth. The primary tillage system greatly impacts the recommended sampling depth. No-till fields should be sampled to a depth of 4 inches. All other fields should be sampled to the depth set by the primary tillage tool (disc, chisel plow, etc.), usually 6 to 8 inches. Soil samples can be collected at any time during the year, but September to December (fall/early winter) or February to April (late winter/spring) are best in order to get timely test results. There will often be a difference in test results depending on when samples are taken, so once a time of the year is selected for a field, sample that field at the same time in subsequent years. See Thom et al. (2003) Taking Soil Test Samples (AGR-16) for additional detailed information on soil sampling and the sample submission procedure.

Sampling for Variable Rate Lime/Fertilizer Application – Growers can separately sample areas within fields to delineate soil test differences in support of variable rate lime and fertilizer applications. Commonly done by dividing fields using a particular grid interval/cell size, research has shown that the most used method, the 330 by 330 ft (2.5 acre) cell size, is often inadequate. Smaller grid intervals give a better picture of soil test parameter variability, but analysis costs rise considerably. Some growers are now using "zone sampling," a procedure similar to long-standing UK recommendations to separately sample field areas different due to topography, drainage, previous field management, etc. Sampling zones can be derived from several mapped information sources, including satellite, airplane, drone, or sensor images; topographic data; yield monitor data; or some combination of these.

Nutrient Stratification – Lime and fertilizer applied continuously to the surface of minimum and no-till fields causes immobile nutrient (P, K, Ca, Mg, and Zn) buildup in the top 1 to 3 inches of soil, with less effect on deeper soil test values. This "stratification" has not been a problem in Kentucky no-till corn production. Surface residues over no-till soil cause a convergence of greater nutrient levels, conserved moisture, and corn root development. But nutrient stratification is why UK recommends that no-till fields be sampled to a 4-inch depth. Also, if most or all fertilizer N is surface applied, continuous no-tillage results in greater soil acidity (lower pH) in the top 1 to 2 inches of soil. Surface acidity reduces the activity of some herbicides, particularly the triazines, and may need occasional monitoring with a separate 2-inch-deep soil sample.

Soil Test Lab Procedures Should Not Impact Lime Rate Recommendations – Soil lime requirements are usually determined by measuring the pH of a suspension of soil in a buffer solution (to determine total soil acidity). Soil solution acidity (small part of total soil acidity) is found by measuring the pH of a suspension of soil in distilled water or a dilute salt solution. Different buffers may be used by different private/public labs, but due to good calibration generally result in the same lime rate recommendation (for a given target pH), if lime quality is considered. UK lime rate recommendations assume a relative neutralizing value (RNV) of 100%. Lime quarry RNV reports are available, and growers can adjust the recommended rate according to the RNV of their purchased lime. Other labs may assume lime quality is less than 100% effective, resulting in higher lime rate recommendations on soil test reports.

Soil Test Lab Procedures Do Impact Rate Recommendations for P, K, Zn, B, and Mg – Available soil nutrient levels are determined by chemical extraction from soil, and extractants/extraction procedures are chosen so the numerical results are reasonably well correlated to plant yield and/or nutrient uptake. Further, the numerical result can be calibrated in terms of the nutrient rate to be applied so that the soil delivers sufficient nutrition to the corn crop. Correlation and calibration results are specific to the extractant/extraction procedure. Different laboratories use different extractants/extraction procedures. Most used extractants (for soil test P and K) are:

1. Mehlich-3, used by UK Soil Testing and many others.
2. Mehlich-1, widely used by private and public labs in the Southeastern US.
3. Bray P1 (for soil test P) and neutral, normal, ammonium acetate (for soil test K), used in several northern and western Corn Belt states.

UK's fertilizer P and K rate recommendations are correlated and calibrated for Mehlich-3 soil test P and K values, respectively. The Mehlich-1 extractant gives lower soil test P and K values, so using UK's recommendations for soil test values determined by Mehlich-1 extraction could result in greater than needed fertilizer P and K rate recommendations.

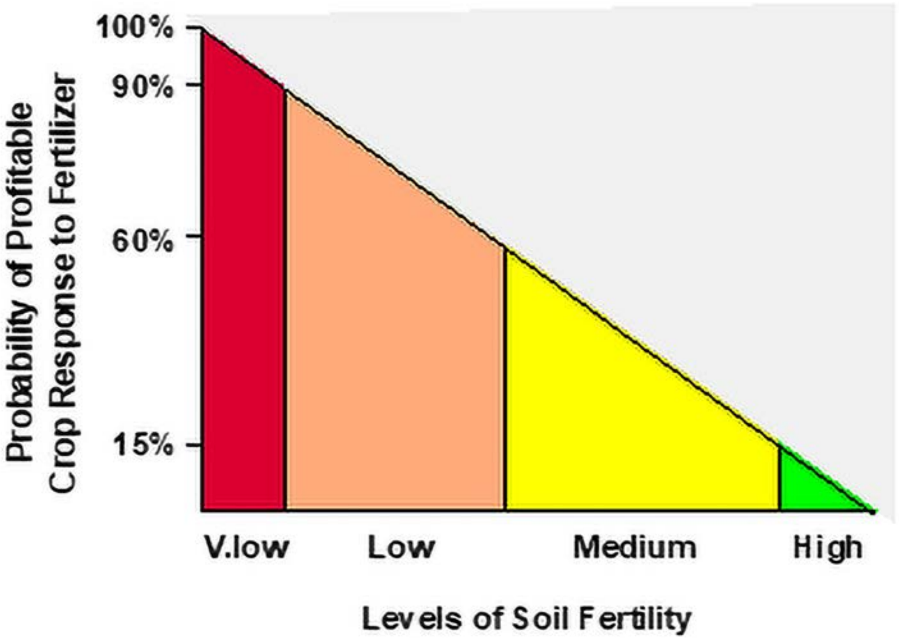

Figure 7.1. The relationship between the expected probability of a profitable response to applied fertilizer P or K and the soil test level for those same nutrients. Courtesy Frank Sikora, UK Regulatory Services. A Very Low soil test has about a 90% or greater probability of corn responding (yield increasing) to applied fertilizer. A High soil test has about a 15% or less probability of corn yields increasing to applied fertilizer.

Soil Testing for Other Secondary Macronutrients (S, Ca) and Micronutrients (Cl, Cu, Fe, Mn, Mo) – Though UK has soil test research sufficient to make fertilizer rate recommendations for Zn, Mg and B, this is not the case for the other secondary macro and micronutrients listed above. Some private soil testing laboratories will analyze the soil for S, calcium (Ca), chloride (Cl), copper (Cu), iron (Fe), manganese (Mn) and molybdenum (Mo) and make fertilizer rate recommendations based only on that information, regardless of whether any correlation and calibration research for Kentucky cornfields exists. Following such recommendations greatly increases the likelihood of adding unneeded fertilizer/spending unnecessary money. A better approach, when a deficiency in one of these secondary macro or micronutrients is suspected, is to follow recommendations according to results from analyses of both plant tissue and soil samples taken from field areas showing/not showing the deficiency.

Different Soil Test Labs Report Results in Different Units – Some labs report results in parts per million (ppm), while others report in pounds per acre (lb/acre). UK soil test report results are in lb/acre. If there is need to convert from one to the other, use one of the following formulas:

ppm x 2 = lb/acre; lb/acre ÷ 2 = ppm.

Different Philosophies Result in Different Fertilizer Rate Recommendations – Use of two/three different labs, all using the same extractant/extraction procedure and reporting results in the same units, does not guarantee the same fertilizer rate recommendations. Differing philosophies are used by farm supply retailers, agricultural consultants, and individual soil test labs to interpret soil test values and make fertilizer rate recommendations in Kentucky. Those philosophies include Crop Sufficient Level of Available Nutrients, Nutrient Balance-Basic Cation Saturation Ratio, and Maintenance. Each philosophy is based on different assumptions about crop nutrition and/or soil nutrient needs.

Crop Sufficiency Philosophy: UK recommendations are designed to result in a crop sufficient level of available nutrients, and the expected crop response at any given soil test level, with normal to good seasonal weather, is what determines the fertilizer rate recommendation. The sufficiency approach means that there is a soil test level at which further addition of that nutrient is not recommended, regardless the yield level (i.e., 300 lb soil test K/acre and 60 lb soil test P/acre will support 300+ bu corn/acre).

Maintenance Philosophy: With this philosophy, nutrients removed at harvest are replaced, often with P and K applications to soils with very high soil test P and K levels. "Maintenance" is often used in combination with "crop sufficiency" which uses soil testing as a basis for recommendations. However, the probability of an economic return to the fertilizer investment falls well below 50% when soil test P and K reach the boundary between medium and high (Figure 7.1). A yield response to the extra maintenance fertilizer is not to be expected though the fertilizer is added to maintain soil test levels. UK does recommend some 'maintenance' P and K, until the upper boundary for the high soil test category is reached, in recognition of the difficult trade-offs between:

a. Avoiding economic loss due to insufficient P or K availability in some parts of the field area (given the challenge of getting a representative soil sample).

b. Avoiding economic loss due to over-application of soluble P and K fertilizers that are vulnerable to loss (runoff, erosion, and chemical fixation).

Nutrient Balance-Basic Cation Saturation Ratio Philosophy: The theory behind these recommendations is that there is a desired 'balance' among the soil-borne nutrients which, if met, results in maximum crop yield. This approach has been widely tested across the Corn Belt, including Kentucky, and has been thoroughly repudiated by numerous years of field research (McLean, 1977; Murdock, 1992; Olson et al., 1982). There is no evidence that achieving a balance among the soil nutrients has any value as regards plant nutrition.

For any fertilizer recommendation philosophy to have value in Kentucky, there must be a body of field research on Kentucky soils/under Kentucky weather conditions. All these philosophies or combinations of philosophies were evaluated in Kentucky for corn production (Murdock, 1992). All resulted in excellent crop yields with good weather. In most all cases, there was no difference in yields, but there were always large differences in recommended amounts and kinds of fertilizer, resulting in large differences in fertilizer cost. Those philosophies resulting in high fertilizer costs gave no yield advantage. Crop sufficiency fertilizer recommendations cost the least, gave equivalent yield and resulted in a much greater ROI.

Pre-Plant Soil Fertility Management Decisions and Their Execution

The pre-plant period is from the harvest of the previous crop until corn planting. During this time, several soil fertility management decisions are executed, particularly those related to soil pH/acidity/liming and soil P, K, and N nutrition. Generally, liming to control acidity is done earliest, in the fall after harvest of the prior crop if possible. Larger increases in soil P and K fertility (larger proportion of the next corn crop's P and K requirement), if needed, may be done anytime in this window, depending on fertilizer P and K availability and pricing. Smaller portions of corn's P and K needs are generally met later, at or just after planting. N timing is the opposite—fall N fertilization for corn is not recommended anywhere in Kentucky—and spring corn N applications should not begin until 3 weeks prior to the expected start of corn planting.

Soil Acidity and Corn – Corn is less sensitive to soil acidity than wheat and soybean, with an optimal soil pH range of 6.2 to 6.4 in Kentucky. At pH 7.0 or above, Mn and Zn may become deficient. In Kentucky, especially the central Bluegrass, Zn deficiency has been observed at these pH levels, and especially when soil test P is high. Corn experiences little or no yield reduction between pH 5.5 and 6.0, but fertilizer efficiency, especially for P, is often reduced. The reduction in P availability ranges from 0 to 25%. Between pH 5.0 and 5.5, visible stress symptoms may not be evident, plant growth will probably look normal, but yield will likely be decreased around 10%. This yield loss is often due to reduced recovery-availability-efficiency (hidden hunger) of P, but corn's Ca, Mg, N, S, K, and Mo nutrition can also be negatively impacted in this pH range. Added fertilizer efficiency will generally be reduced in this pH range and added fertilizer P efficiency will likely decline by at least 25% relative to that observed at pH 6.5. At soil pH values below 5.2 corn can suffer Mn toxicity, and aluminum (Al) toxicity if soil pH is below 4.8. This further reduces crop recovery of soil nutrients and water. At very low soil pH values (4.0 to 5.0), availability of many nutrients is considerably lower and corn yield is strongly reduced.

Table 7.2. Rate of 100% effective (RNV = 100) limestone (ton/acre) to raise soil pH to 6.4 (Table 6 from Ritchey and McGrath, 2020).

Water pH of Sample	Buffer pH of Sample								If Buffer pH is Unknown
	5.5	5.7	5.9	6.1	6.3	6.5	6.7	6.9	
4.5	4.50	4.25	4.00	3.50	3.00	2.50	2.00	1.50	2.75
4.7	4.50	4.25	4.00	3.50	3.00	2.50	2.00	1.50	2.75
4.9	4.50	4.25	3.75	3.25	2.75	2.25	1.75	1.25	2.75
5.1	4.50	4.25	3.75	3.25	2.75	2.25	1.75	1.25	2.75
5.3	4.50	4.25	3.75	3.25	2.50	2.00	1.50	1.00	2.25
5.5	4.50	4.25	3.50	3.00	2.50	2.00	1.50	1.00	2.00
5.7	4.50	4.00	3.50	2.75	2.25	1.75	1.25	1.00	1.75
5.9		4.00	3.25	2.50	2.00	1.50	1.00	0.75	1.25
6.1			2.75	2.00	1.50	1.00	0.75	0.50	1.00

Pre-Plant Soil Acidity Management/Timing – Agricultural lime (ag lime) is calcium carbonate ($CaCO_3$) with various amounts of magnesium carbonate ($MgCO_3$). Ag lime neutralizes soil acidity, raises soil pH, and adds Ca (and Mg). Ag lime can be applied any time field conditions permit but should be applied at least six months before planting the target crop. Fall is usually a good application time. Ag lime will begin dissolving immediately. Fall weather is usually better for spreading lime while avoiding soil compaction. With adequate moisture, a small pH change might be measured in four weeks, but 6 to 12 months are needed for a significant amount of ag lime to react and really raise soil pH.

Pre-Plant Soil Acidity Management/Ag Lime Rates – Enough lime should be applied to raise soil pH to 6.2 to 6.4. The buffer pH, together with water pH, determines the ag lime rate needed (Table 7.2). The ag lime rates recommended in Table 7.2 assume:

a. Ag lime quality as measured by Relative Neutralizing Value (RNV) is 100.
b. Thorough mixing of ag lime to a 6-inch depth, except in no-till fields.
c. Total reaction time of 4 years, unless faster reacting sources like hydrated/slaked lime (calcium hydroxide) or burnt/unslaked/quick lime (calcium oxide) are used.

Continued use of acid-forming fertilizers, especially N, can lower the final soil pH obtained. When applying more than 4 ton/acre, half should be applied before primary tillage (e.g., chisel plowing) and the second half after primary tillage, but followed by secondary tillage (e.g., vertical, disc or field cultivator tillage).

Pre-Plant Soil Acidity Management/Lime Sources – Ag lime, both calcitic (mostly calcium carbonate) and dolomitic (contains significant magnesium carbonate), is the most common liming agent used in Kentucky. Ag lime quality is derived from both chemical purity (calcium carbonate equivalence, CCE) and fineness. Kentucky lime law specifies the minimum ag lime standard – 80% CCE and ground fine enough so that 90% passes a 10-mesh screen and at least 35% passes a 50-mesh screen. RNV estimates the ag lime fraction that dissolves in 3-4 years, considering both purity and fineness. Ag lime with an RNV of 80 will require a lower rate to reach a desired pH than an ag lime with an RNV of 60. The ag lime RNV measured on Kentucky quarry samples ranges widely, between 30 and 90%. Remember that the ag lime rate recommended in Table 7.2 assumes an RNV of 100.

Ag lime RNV is determined by UK Regulatory Services, on behalf of the Kentucky Department of Agriculture, and results for Kentucky and nearby out-of-state quarries are posted on the Regulatory Services website (http://www.rs.uky.edu/soil/AgLimeReports.php). Other liming agents are sometimes used. These are usually industry by-products or are finely ground ag lime suspensions. Use rates should be based on CCE and fineness. With suspensions, the actual weight of ag lime in the mix matters. One ton of a suspension may contain only 0.5 ton of lime – the rest is water and suspension agent. Specialty bagged liming products (superfine limestone, pelletized lime, hydrated lime, ground oyster shells, etc.) are more expensive, but are convenient to use. Care should be taken to avoid over-liming small areas with these products.

Pre-Plant Soil Acidity Management/Ca Salts Are Not Liming Agents – In the soil, ag lime dissolves to form Ca^{2+} and carbonate (CO_3^{2-}) ions (Reaction 1). Then, the CO_3^{2-} anion (the base), neutralizes acidity (hydrogen, H^+) held on soil clay and organic matter (OM) to form water (H_2O) and carbon dioxide (CO_2), while each Ca^{2+} takes the place of 2 H^+ on soil clay and OM cation exchange sites (Reaction 2). The reaction's mass balance shows that 100 lb of pure $CaCO_3$ is needed to neutralize 2 lb of acid H^+, explaining why lime rates are in ton/acre, not lb/acre.

Reaction 1: $CaCO_3 \Rightarrow Ca^{2+} + CO_3^{2-}$
Reaction 2: Clay or $OM\text{-}2H^+ + Ca^{2+} + CO_3^{2-} \Rightarrow$ Clay or $OM\text{-}Ca^{2+} + H_2O + CO_2$

The chemical reactions show that the "base" that neutralizes the "acid" is CO_3^{2-}, not the so-called "basic cation", Ca^{2+}. Bases that neutralize acids are carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), hydroxide (OH^-), and oxide (O^{2-}). The usual "basic cations", which merely accompany the base anions, are Ca^{2+}, Mg^{2+}, potassium (K^+) and sodium (Na^+). Other anions, like chloride (Cl^-) and sulfate (SO_4^{2-}), are salt anions, not base anions. Products consisting of calcium chloride ($CaCl_2$; liquid road salt/tire ballast) or calcium sulfate ($CaSO_4.2H_2O$; gypsum) are salts, not liming agents/lime replacements. These Ca salts are Ca sources but have no acidity neutralizing value.

Pre-Plant Soil Acidity Management/When Lime Will Again Be Needed – Soil acidity is the result of naturally occurring ongoing processes, mostly organic matter and plant residue decomposition and soil weathering/hydrolysis/leaching. Acid forming fertilizers, especially ammoniacal N fertilizers, accelerate soil acidification and cause soil pH to fall. For these N sources, Table 7.3 gives pounds of RNV 100 ag lime needed to neutralize generated acidity, per pound N applied. The rate of decline depends on soil buffer capacity – greater buffer capacity slows pH decline. Although corn tolerates moderately acid soils, reduced tillage/no-till corn growers applying N mostly to the soil surface need to remember that the upper 1 to 2 inches of soil can become very acid (pH below 5) within 3 to 4 years. Once this happens, Mn and Al toxicity can occur and triazine herbicides are rapidly deactivated. Because different factors determine when the next lime application will be needed, the best soil acidity management program for corn involves a soil test every two or three years, with the occasional shallower (2-inch depth) soil sampling of reduced tillage/no-till fields.

Pre-Plant P and K Management for Corn – Pre-plant P and K applications are particularly important so that adequate P and K are available for plant uptake during the first half of the growing season. By the time kernels start filling rapidly (10-15 days after silking), corn will have taken

Table 7.3. Lime needed to neutralize the acidity generated by various fertilizer N sources.

Fertilizer N Source	Source N Concentration	Amount of 100% RNV Lime Needed
	%	lb lime/lb N applied
Ammonium Nitrate	34	1.8
Urea	46	1.8
Anhydrous Ammonia	82	1.8
Urea-Ammonium Nitrate Solutions	28-32	1.8
Ammonium Sulfate	21	5.3
Diammonium Phosphate	18	1.8

Table 7.4. Recommended rates of phosphate and potash (lb/acre) as related to soil test P and K, respectively (Table 13 from Ritchey and McGrath, 2020).

Category	Test Result: P	P_2O_5 Needed	Test Result: K	K_2O Needed
Very high			>420	0
High	>60	0	355 - 420	0
			336 - 354	0
			318 - 335	0
			301 - 317	0
Medium	46 - 60	30	282 - 300	30
	41 - 45	40	264 - 281	30
	37 - 40	50	242 - 263	30
	33 - 36	60	226 - 241	40
	28 - 32	70	209 - 225	50
			191 - 208	60
Low	23 - 27	80	173 - 190	70
	19 - 22	90	155 - 172	80
	14 - 18	100	136 - 154	90
	9 - 13	110	118 - 135	100
	6 - 8	120	100 - 117	110
Very low	1 - 5	200	<100	120

up about 45-50% and 90-100% of its P and K requirement, respectively. When soil test P and K levels are medium-high, soil P and K reservoirs provide the majority of corn's P and K nutrition. The annual amount of corn P and K uptake from fertilizer is not likely to exceed 15-20%, or 25-40%, of applied P and K, respectively. Corn grown after a 5 to 7 years old sod may respond less to P fertilizer than soil test P results suggest because organic P levels are higher, and more P will be mineralized from sod residues. Organic P levels are not assessed by soil test procedures such as Mehlich-3 extraction. Both P and K are considered relatively immobile soil elements since each reacts with soil in ways that usually minimize leaching losses. Soil K is held at cation exchange sites on clay-sized particles and organic matter. Soluble fertilizer P forms less soluble compounds with soil calcium, iron, and aluminum. Topsoil erosion losses of P and K are of greater concern in Kentucky.

Soil test-based fertilizer P and K rate recommendations are shown in Table 7.4. When recommended rates are relatively large, most of the P and K fertilizers are applied pre-plant, including both fall-early winter and late winter-early spring application timings. Pre-plant fertilizer P and K is usually broadcast uniformly over the soil surface. Variable rate fertilizer P and K application is popular, often done with an air-flow spreader to improve uniformity. The rest is usually applied at-planting, in some form of 'starter' fertilizer. At very low to low soil test P or K levels, large amounts of fertilizer P or K are needed. Agronomic efficiency of these high fertilizer P and K rates can be improved by pre-plant broadcasting one-third to one-half the total recommended rate. Then, at-planting, band only one-half of the remaining recommended rate. The total recommended rate of P or K is decreased by one-quarter to one-third. Time of application can be determined by economics (e.g., fertilizer price), application equipment availability, or potential losses in plant availability. Fall pre-plant application is favored when prices are lower, application equipment is generally available, soil compaction potential is low, and conditions do not favor nutrient losses. Planting a winter cover crop that will take up soluble P and K can reduce nutrient losses from fall-early winter fertilizer applications.

All the fertilizer P sources in Table 7.5 can be applied pre-plant, and all are equally agronomically effective when used at recommended rates and properly applied. Cost/value of the N contained in DAP, MAP and APP can be substantial (20 to 30%), likely N loss may preclude fall application, and TSP becomes the best choice. All pre-plant fertilizer K sources for corn (Table 7.5) are equally effective. Pre-plant application of organic P and K sources, especially broiler chicken litter, but including swine manure, other animal manures and biosolids (treated sewage sludge) may be used in addition to, or in place of, fertilizer P and K. The nutrient content of these materials will vary, so a laboratory analysis is needed to guide application rates. For municipal/industrial sludges, laboratory analysis will also determine the toxic element (nickel, cadmium, chromium, etc.) concentrations to prevent excessive soil loading with these elements.

Pre-Plant Secondary Macronutrient and Micronutrient Management for Corn – Among the secondary macronutrients, Ca and Mg are generally provided via ag lime additions and S is generally sufficient – as yet there has been no verified corn S deficiency in Kentucky. Sulfur sources are given in Table 7.5. Ammonium thiosulfate (ATS) is compatible with UAN. All S sources can be applied at any time pre-plant/at-plant, except elemental sulfur, which is best applied in late fall-early winter. Elemental S must be oxidized by soil microbes and this biological process takes time. Gypsum is often cheaper than other S sources, partly because gypsum can come from mines or one of several by-product sources (dry wall manufacture, water treatment plants, and coal-fired power plants).

The micronutrients B and Zn, needed in some Kentucky corn fields, can usually be applied at any time from early pre-plant to at-plant. Some fertilizer B and Zn sources are found in Table 7.5. Soluble Zn salts (sulfate, chloride, and nitrate) and Zn chelates have good plant availability. Zinc oxide and ammoniated Zn products are not recommended due to their poor solubility. Poultry litter contains significant Zn and can often meet crop needs. Fertilizer B sources include borax, tetraborate (Granubor), boric acid, and octaborate (Solubor). Borax and tetraborate are better suited to dry application, while boric acid and octaborate are solids intended for dissolution in liquid fertilizers. Fertilizer Zn rate recommendations are found in Table 14 of Ritchey and McGrath (2020). Fertilizer B recommendations are made by UK extension soil scientists, after a UK soil B test.

Pre-Plant N Management for Corn – Nitrogen is the nutrient most often needed for corn production (Table 7.1). Of the total uptake, 50 to 60% of the N is in the grain. The rest is in leaves, stalks, roots, husks, and cobs. Soil N, most all in organic matter, is usually too low to supply corn's N

Table 7.5. Common fertilizer sources: chemical formula, physical form, and nutrient analysis.[1]

Fertilizer Source Name and Chemical Formula	Form	Total N	Available Phosphate	Soluble Potash	Sulfur	Boron	Zinc
		N %	P_2O_5 %	K_2O %	S %	B %	Zn %
NITROGEN FERTILIZERS							
Anhydrous ammonia (AA) NH_3	compressed liquid[2]	82	0	0			
Urea $CO(NH_2)_2$	dry	46	0	0			
Ammonium nitrate (AN) NH_4NO_3	dry	33.5 - 34	0	0			
Nitrogen solutions (UAN) Urea + AN + Water	liquid	28 - 32	0	0			
Chilean nitrate ($NaNO_3$)	dry	16	0	0			
Ammonium sulfate (AS) $(NH_4)_2SO_4$	dry	21	0	0	24		
PHOSPHORUS FERTILIZERS							
Diammonium phosphate (DAP)[3] $(NH_4)_2HPO_4$	dry	18	46	0			
Monoammonium phosphate (MAP) $NH_4H_2PO_4$	dry	11	52	0			
Ammonium polyphosphate (APP) $(NH_4PO_3)_n(OH)_2$	liquid	10 - 11	34 - 37	0			
Triple superphosphate (TSP) $Ca(H_2PO_4)_2$	dry	0	44 - 46	0			
POTASSIUM FERTILIZERS							
Muriate of potash (MOP) KCl	dry	0	0	60 - 62			
Potassium sulfate (SOP) K_2SO_4	dry	0	0	50	18		
Potassium nitrate (NOP) KNO_3	dry	13	0	45			
Sulfate of potash magnesia (Sul-Po-Mag/K-Mag) $K_2Mg(SO_4)_2$	dry	0	0	22	22		
SULFUR FERTILIZERS							
Calcium sulfate (gypsum) $CaSO_4 \cdot 2H_2O$	dry				16 - 19		
Elemental sulfur S	dry				90 - 99		
Ammonium thiosulfate (ATS) $(NH_4)_2S_2O_3$	dry	12	0	0	26		
BORON and ZINC FERTILIZERS							
Borax $Na_2B_4O_5(OH)_4 \cdot 8H_2O$	dry					11	
Sodium tetraborate pentahydrate (Granubor) $Na_2B_4O_7 \cdot 5H_2O$	dry					15	
Boric acid H_3BO_3	dry					17	
Disodium octaborate tetrahydrate (Solubor) $Na_2B_8O_{13} \cdot 4H_2O$	dry					20.5	
Zinc chelates Zn EDTA, etc.	dry						8 - 14
Zinc sulfate monohydrate $ZnSO_4 \cdot H_2O$	dry				17.5		35.5

[1] Table 7.5 developed by Chad Lee who adapted portions of this table from: http://agguide.agronomy.psu.edu/cm/sec2/table1-2-11.cfm

[2] Compressed liquid converts gas in the field.

[3] DAP is the most common form of P fertilizer in Kentucky.

Table 7.6. Fertilizer N rate (lb N/acre) recommendations for dryland corn (Table 12 from Ritchey and McGrath, 2020).

Cover Crop	Tillage[3]	Soil Drainage Class[2]		
		Well-Drained	Moderately Well-Drained[4]	Poorly Drained
Corn, sorghum, soybean, small grain, fallow	Intensive	100 - 140	140 - 175	175 - 200
	Conservation	125 - 165	165 - 200	
Grass, grass-legume sod (4 years or less), winter annual legume cover	Intensive	75 - 115	115 - 150	150 - 175
	Conservation	100 - 140	140 - 175	
Grass, grass-legume sod (5 years or more)	Intensive	50 - 90	90 - 125	125 - 150
	Conservation	75 - 115	115 - 150	

[1] Nitrogen rate for irrigated corn should be increased to 175 to 200 lb N/A.
[2] Soil drainage class examples are given on Page 2.
[3] Intensive tillage has less than 30% residue cover, and conservation tillage has more than 30% residue cover on the soil at planting.
[4] Poorly drained soils that have been tile drained should be considered moderately well-drained.

requirement. Most soils contain considerable organic N. A soil with 3% organic matter has between 3,000 and 3,500 lb organic N/acre. But only a small portion, 1 to 5% (30 to 175 lb N/acre), is mineralized into plant available inorganic N forms (ammonium-N, nitrate-N) each season. Inorganic N also comes from mineralization of fresh plant residues, early terminated cereal cover crops, legume cover crops, and forage grass and legume sods. Cropping history is an important consideration when estimating fertilizer N requirements (Table 7.6). Soil N availability to young corn is variable and generally unpredictable, because changes in seasonal weather impact organic N release as well as the fate of added fertilizer N. Pre-plant levels of organic matter or soil nitrate-N are not reliable indicators of soil N availability to corn in Kentucky.

Recommended fertilizer N rates are also affected by tillage, soil drainage, irrigation, and application timing (Table 7.6). New UK research shows that an additional 25-35 lb N/acre is needed when no-till corn follows a winter cereal rye cover crop that was fully grown/headed out when terminated. This additional N should be in the first N application when N is split applied. Fall-early winter application of fertilizer N for corn is never recommended in Kentucky because of the moist and warm seasonal weather and use of a nitrification inhibitor (discussed below) does not prevent sizeable overwinter N losses that occur.

Pre-plant N applications in the late winter-early spring period should be as close to corn planting as possible (including at-planting). The pre-plant N application will be some portion of the recommended rate—modified by fertilizer N source, soil conditions (especially temperature and moisture), recent/likely weather and soil properties (especially drainage) and considering resources (equipment, time) available for a later N application. Delaying 60 to 80% of the recommended N allows greater synchrony between N availability and corn root development.

Fall applied bulk blends often contain N, depending on DAP or MAP (Table 7.5) inclusion. Some fall applied N is immobilized into organic matter and/or taken up by winter cover crops and weeds. Otherwise, fall applied N has little value to the coming corn crop and should not be counted towards the corn fertilizer N rate recommendation. But when blends are applied in late winter-early spring, closer to planting, their N can be subtracted from the recommended N rate.

Corn fertilizer N sources come in both solid and liquid forms (Table 7.5). All can be used pre-plant/at-plant and one or more N loss inhibitors (stabilizers) may be used. Anhydrous ammonia (AA) is injected as a supercooled liquid—released from the applicator into a depressurizing converter that keeps 70% to 85 % of the AA as a liquid during application, making for accurate metering and calibration. The applicator must be cleaned and maintained to prevent uneven application. When released into soil, liquid AA immediately changes to a gas—AA must be injected 4 or more inches deep and immediately covered to prevent ammonia gas loss. In no-till soils, loss prevention usually requires a winged or beaver tail shaped piece of steel above the delivery tube outlet on the injection knife, but a solid or spoked closing wheel, or an inverted disc, may also be needed to close/cover the injection knife opening/slit.

When injected into the soil, ammonia (NH_3) reacts with water and becomes ammonium-N (NH_4^+). The ammonium-N stays near the injection band, moving very little, so roots must grow closer to the band to take up the N. Small corn plants can be N deficient if root growth is slowed by cool, wet conditions or sidewall compaction. If some N is applied as starter or in-row fertilizer, the potential for temporary N deficiency is often eliminated. Pre-plant/at-plant AA applications can occur 0 to three weeks before corn planting, which is four to seven weeks before significant corn root development (V5). Conversion of AA to nitrate-N (NO_3^{2-}) can reach 75% during this period. Nitrate-N is vulnerable to leaching and denitrification losses due to rainfall and wet soil conditions. To counter these losses, a nitrification inhibitor is recommended and nitrapyrin and pronitridine are both compatible with AA.

Urea is a solid N source that quickly dissolves in soil moisture and hydrolyzes to form ammonium-N. Consequently, urea's soil behavior is like that for ammonium-N except for the greater possibility of ammonia volatilization loss. During hydrolysis, soil pH near the urea granule increases significantly ($pH > 9$), favoring ammonia formation. Urease, an enzyme widely found on both living vegetation and dead crop residues, catalyzes urea hydrolysis and ammonia volatilization. Under certain conditions, one or both mechanisms can cause a large fraction (up to 40%) of urea-N to be lost. Factors affecting loss are temperature and moisture, tillage/degree of vegetative cover, soil contact, and ambient soil pH. Rainfall (0.25 inches or more) or tillage incorporation within two days of application results in minimal volatilization.

Urea applied before May 1, when soils are generally cool and moist will generally experience less volatilization loss due to urease. Usually broadcast, pre-plant/at-plant urea-N is converted to nitrate-N very thoroughly prior to significant corn root development (V5). To reduce nitrate-N losses to leaching and denitrification during this time a nitrification inhibitor may be recommended and dicyandiamide, nitrapyrin, or pronitridine may be used.

Urea-ammonium nitrate (UAN) solutions—one half the UAN-N comes from urea and the other half is from ammonium nitrate—can be injected, surface broadcast or surface dribbled. UAN solutions are also broadcast as the carrier in "weed and feed" mixtures. The 28% N solution is used for the earliest, coldest, applications because of reduced salt-out potential. Volatilization losses from surface-applied UAN are smaller than from urea because only half the UAN-N is from urea. UAN injection minimizes volatilization and immobilization by microbes as crop, cover crop, and weed residues are decomposed. As one-quarter of UAN-N is nitrate-N, losses to leaching and denitrification can be a bigger problem with this N source when the soil is already wet and further rainfall occurs. Nitrification inhibitors, including dicyandiamide, nitrapyrin, and pronitridine can reduce these losses.

Other fertilizer N sources include ammonium nitrate (AN), ammonium sulfate (AS); and Chilean nitrate (nitrate of soda). Chilean nitrate can provide up to 25% of organic corn's N requirement. These fertilizer N salts dissolve readily in moist soil and are excellent N sources but are not favored for at-plant application. Ammonium sulfate is an excellent source of sulfur, and ammonium-N is not subject to volatilization loss, but this source acidifies the soil more, per pound of N, than any other N source (Table 7.3). Animal manures, especially poultry litter, are used to provide nutrients to corn and are applied pre-plant. When applied in the fall-early winter, their value as an N source is reduced by overwinter losses of the soluble N they released. AGR-146, Using Animal Manures as Nutrient Sources, and AGR-165, The Agronomics of Manure Use for Crop Production, provide guidelines for estimating N values for most animal waste materials found in Kentucky. Where these and other organic N sources are likely to provide a substantial amount of N to the corn crop, a presidedress soil nitrate test (PSNT, see below) will also be useful to guide the need for additional post-emergence N. Applying manures as the sole source of corn N is likely to build soil P levels to unacceptably high levels. Avoid this by using manure as a source of P (or K) and use other N sources to provide the bulk of corn N nutrition.

Pre-Plant Soil/Fertilizer N Losses with Wet Weather/Wet Soils – Kentucky soils lose some nitrate-N every year, but when heavy rain or flooding occurs within a month of N application, serious losses are likely. Nitrate-N is an anion, not attracted to soil cation exchange sites, and is very soluble in water. This causes nitrate-N to be mobile in soil and susceptible to leaching. Leaching occurs in moderately well-drained, well-drained and tile-drained soils with long and/or intense rainfall. Leaching is the less common cause of N loss from Kentucky soils. When soils become saturated with water, denitrification converts nitrate-N to gaseous N (N2 and N2O) forms via a rapid biological transformation. Denitrification is the most important N loss pathway in poorly drained and somewhat poorly drained soils and is the most common cause of N loss in Kentucky. These losses result in a higher recommended fertilizer N rate on somewhat poorly drained and poorly drained soils (Table 7.6).

The quantity of N lost from wet soils depends on the fertilizer N source, the time between N application and the start of waterlogging, and the length of time the soil is saturated. Upland well-drained soils wet from constant rains probably will not lose much N because two to three days of saturated conditions are needed to start denitrification and these soils usually do not remain saturated between rains. Imperfectly drained soils flooded for one to two days can stay saturated even longer for several reasons (usually soil compaction), but the N loss amount will not be as great as one might assume. Since only nitrate-N is lost, first estimate the amount of applied N converted to nitrate-N when flooding starts. Table 7.7, above, gives estimates of the proportion of fertilizer N as nitrate-N at 0, three, and six weeks after application for important N sources, with and without nitrapyrin. Denitrification causes 3-4% of nitrate-N to be lost each day of saturation. UK research trials found a corn yield increase of 11

Table 7.7. Fraction of fertilizer N converted to nitrate-N at different times after application (Murdock, 2001).

Fertilizer N Source	Weeks After Application		
	0	3	6
	Fertilizer N as Nitrate-N (%)		
Anhydrous Ammonia	0	20	65
Anhydrous Ammonia + Nitrification Inhibitor[1]	0	10	50
Urea	0	50	75
Urea + Nitrification Inhibitor [1]	0	30	70
UAN solution	25	60	80
Ammonium Nitrate	50	80	90

[1] NI = nitrification inhibitor, nitrapyrin, that slows transformation of ammonium-N to nitrate-N.

bu/acre from side-dressing more N under these conditions. Alternatively, soil nitrate-N is found by sampling (10-12 cores per sample) the area(s) in question to a depth of 12 inches and getting a nitrate-N soil test done.

Pre-Plant/At-Plant Nitrification Inhibitors – There are two types of inhibitors, nitrification inhibitors and urease/volatilization inhibitors—they are unrelated to each other and are helpful in two different situations. Some commercial products are a combination of both types but should not be bought unless both types of loss are anticipated. When fertilizer N is applied pre-plant/at-plant to wet soils, soils that are less than well-drained, and significant rainfall is anticipated, a nitrification inhibitor should be considered. Generally, pre-plant/at-plant conditions are too cool and moist to cause much volatilization loss from urea or UAN, so a urease inhibitor is not usually considered at this time. Nitrification inhibitors only work with N sources that contain or generate ammonium-N, like AA, urea, UAN, ammonium nitrate and ammonium sulfate – the inhibitors "stabilize" the ammonium-N. Nitrification inhibitors slow nitrification, the transformation of ammonium-N to nitrate-N, for three to four weeks. Inhibitor economics must be weighed against other management tools that can achieve the same objective: 1) add more N (35 lb N/acre) to offset the loss; 2) add less N (35 lb N/acre) and splitting the N application, making a second application containing at least one-half of the recommended N rate when corn is at growth stage V4 to V8; or 3) use slow release/encapsulated N (usually polymer coated urea).

At-Plant Soil Fertility Management Decisions and Their Execution

At-Plant Corn Nutrition – During corn planting, the highest priority is getting seed into soil—at the proper depth, with good seed-to-soil contact, and without sidewall compaction. At-planting corn nutrition should be a secondary concern, only important if the producer anticipates either stressful conditions or in-field soil nutrient status variation that might be dealt with by at-planting fertilization. There are basically five at-planting fertilizer addition options:

1. Seed treatments (micronutrients, microbial products).
2. Seed furrow (in-furrow, pop-up) placement (N, P, micronutrients, microbial products).
3. One (2x2) or two (2x2x2) band placement approximately 2 inches to the side, and 2 inches below, the seed (N, P, K, micronutrients). This approach is particularly useful when reducing the large amounts of fertilizer P or K needed because of very low to low soil test P or K levels, where only one-third to one-half the total recommended rate was applied pre-plant, and agronomic efficiency is being raised by at-plant banding of one-half of the remaining recommended rate.
4. Surface bands dribbled off the planter frame anywhere from above the seed furrow to several inches to the side of the seed furrow (N, P, micronutrients).
5. A separate trip across the field to broadcast needed fertilizer (usually N).

Evaluation of placement options, products and product combinations continues, but several research conclusions are in. First, no yield improvement due to seed/seed box/in-furrow applied microbial products has been observed. As the biology field science improves, benefits are anticipated. Some seed is sold with a microbial product coated on the seed – may explain the lack of response observed to applying additional products of this kind. Second, there has been no reported benefit of 2x2x2 (2 bands) placement over 2x2 (1 band) placement, except when high band fertilizer rates could cause salt injury. Dividing high rates between 2 bands prevented injury. Third, a "starter effect" (improved initial corn growth) is likely to result from either in-furrow or 2x2 band placement, when corn is planted early into cold, damp soil. Regardless the soil test nutrient levels, at-planting banded fertilizer will usually increase early growth and vigor under these soil conditions. This may look dramatic early, but "starter fertilizer" rarely increases Kentucky corn yields if populations are adequate, the soil contains sufficient nutrients, and physical conditions permit corn root growth. Field

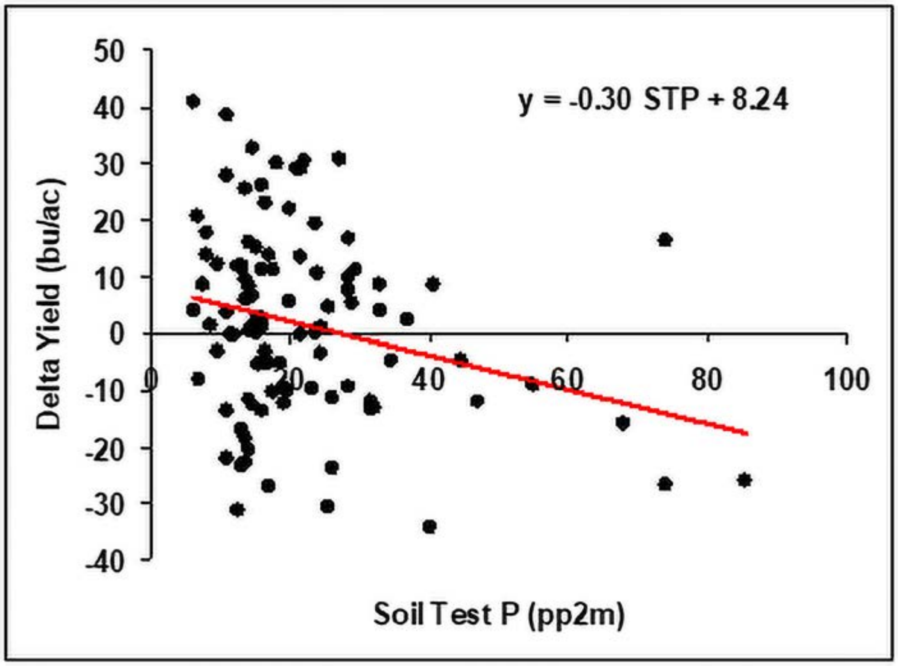

Figure 7.2. Corn yield increment due to use of an in-furrow starter fertilizer containing P, as a function of soil test P. Pair-wise comparisons across the field (Grove, personal communication.). The probability of a positive yield increase was greatest when soil test P was low.

soils testing medium to high contain sufficient nutrients such that in/near row fertilizer is not likely to increase yield. Figure 7.2 shows this trend—a decreasing yield response to in-furrow starter as soil test P increased.

A few corn starter responses in Kentucky are responses to the Zn and B in some starter fertilizer formulations, but much of the “starter effect” in Kentucky corn fields is an N response. Cold, damp soils do not readily mineralize N from soil organic matter. Remaining responses are most often due to P. Cold, damp soils limit P diffusion to emerging roots and the speed of root growth. In Kentucky, starter K shows little benefit unless root zone compaction is a problem.

Fourth, the yield increases sometimes observed with starter fertilizer are often small and uneconomical. The consistency and amount of yield increase depends on the soil (especially soil drainage), tillage system, planting date, and weather (Table 7.8). Conditions causing prolonged corn stress early in the growing season increase the chances, and size of, any positive yield response. A positive yield response is larger, and more consistent, for early planted no-till corn on less than well-drained soils. Not as consistent, smaller, positive yield responses to starters are found with early planted no-till corn on well-drained soils. Responses will be small, often non-existent, in warmer years and with later planting.

With in-furrow/pop-up fertilizer, no more than 10 to 15 lb/acre each of N and P_2O_5 are recommended. Greater rates can cause salt injury, reducing seed germination. If fertilizer is banded 2x2, amounts of N plus K_2O should be limited to 100 lb/acre. As soil clay content decreases, the fertilizer rate causing injury decreases. A starter N source containing urea adds additional risk due to greater concentrations of ammonia-N from urea placement.

At-Plant Secondary Macronutrient and Micronutrient Management for Corn – Most of the information on these nutrient elements was discussed previously (see Pre-Plant Secondary Macronutrient and Micronutrient Management for Corn), and there are few at-planting concerns. Less prone to leaching than nitrate-N, sulfate-S will leach in some Kentucky soils, and applied S is better timed at-planting. Choices include either liquid or solid S sources (Table 7.5) but ATS should not be used in liquid 2x2 or pop-up/in-furrow formulations (Note: sulfates have a lower salt index than chlorides and nitrates).

Table 7.8. Expected corn yield increase to starter fertilizer (Murdock, 2001)†.

Tillage	Soil Drainage	Consistency of Increase	Expected Increase (bu/acre)
tilled	all types	occasional	0 - 1
no-tilled	well-drained	sometimes	1 – 6
no-tilled	not well-drained	most of the time	5 - 7

† 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 be a negative response.

Zinc and B sources (Table 7.5) are often applied in starter fertilizers. Soluble Zn salts (sulfate, chloride, and nitrate) and chelates are commonly used. Starter Zn rates can be greatly reduced (up to 80%) relative to broadcast Zn, though starter Zn will likely need to be repeated each time corn is grown in a Zn responsive soil (Ritchey and McGrath, 2020). The B sources like borax and tetraborate are suited to dry 2x2 application, while boric acid and octaborate can dissolve in liquid formulations used in both 2x2 and in-furrow applications.

Post-Emergence Soil Fertility Management Decisions and Their Execution

Post-Emergence Corn Nutrition Management – After corn emerges, soil fertility assessment shifts focus. The growing plants are monitored, both visually and via tissue sampling, for nutrient element deficiency/sufficiency/toxicity. Any soil sampling has a specific diagnostic focus. That said, the important/largest second N application occurs relatively early in this period. The growing corn and usually drier soil begin to impact N rate, timing, placement, and source options. Other needed nutrients, most often B and Zn, may be provided via foliar applications.

Split/Delayed Fertilizer N Management for Corn – Corn N is applied any time from about 3 weeks before planting to near tasseling, but application timings are caused by the seasonal mix of weather, soil, and N source. These are grouped into four N application windows: 1) pre-plant/at-plant; 2) pre-emergence to V2; 3) early post-emergence (V3 to V6); and 4) late post-emergence (V7 to V8). Any fertilizer N applied after V8 is a “rescue” application as some portion of yield potential may have already been lost – or that loss is anticipated. The most effective method of increasing corn N recovery is delayed/split fertilizer N application. The practice works because young corn plants (up to V6) require little N, and much of that N can be supplied by soil organic matter mineralization. Early in the season, soils are typically wettest and most prone to N loss, especially somewhat poorly and poorly drained soils. The virtue to delayed/split N application is improvement in N use efficiency/minimization of weather driven N losses, (leaching and denitrification). Later N applications are more likely to avoid wet soil conditions.

Early (V2-V3) post-emergence N applications may still carry some risk of leaching and denitrification loss if soils are already wet and more heavy rainfall is anticipated. In this case, a nitrification inhibitor (see above) may be needed for fertilizer N use efficiency. Under these conditions, when either AA or UAN is injected, only a nitrification inhibitor is

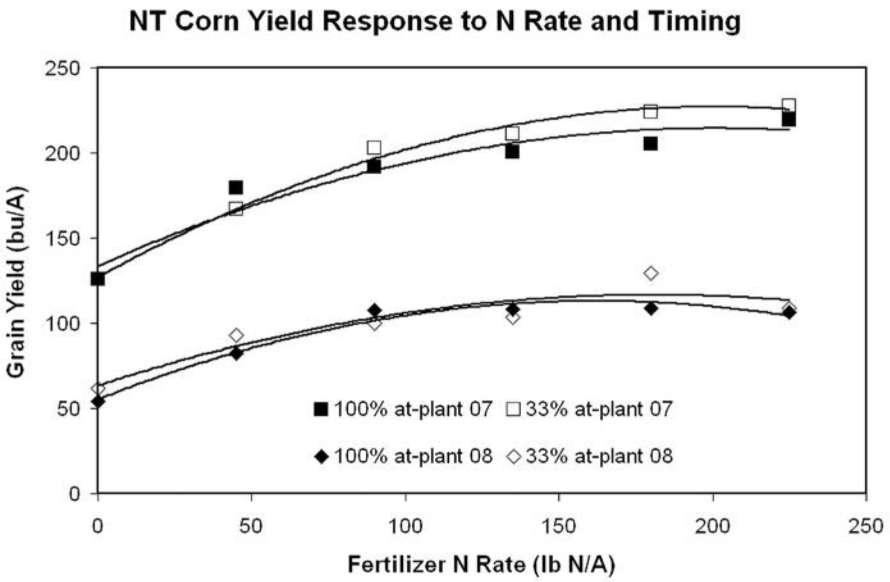

Figure 7.3. No-till corn yield response to N rate and split N application for two different seasons.

needed. Surface application of UAN or urea to no-till fields may require a product that combines both volatilization and nitrification inhibitors. Though volatilization losses (see below) are of particular concern in no-till soils, denitrification, leaching, and immobilization losses can also be greater, so recommended fertilizer N rates are also somewhat greater for no-till corn production.

In a wet season, delayed/split N is often beneficial on well-drained soils. Figure 7.3 shows corn yield as a function of fertilizer N rate and split application (100% at-plant versus 33% at-plant and 67% sidedress) for two years (2007 and 2008). In the drier and lower yielding year, 2008, there was no benefit to split application. The opposite was true in the wetter, higher yielding 2007 season—a benefit of 10 to 15 bushels/acre.

The second N application is usually made between the V3 and V8 growth stages, contains the larger portion (50-80%) of the recommended N rate in order to maintain available N supply/meet the N need of rapidly growing corn. A presidedress soil nitrate test (PSNT, see below) may be used to guide the second application rate, especially when forages or legume cover crops were grown previously, or where animal manures have been applied. Another alternative is to use a proprietary soil N release model (Adapt-N, Encirca, Corteva Fields, etc.) to guide the second dose N rate. Research indicates these models need to be well calibrated, at least by region, to be effective. The later N applications can be guided by applicator mounted canopy sensors which measure some canopy color/growth characteristic, sometimes relative to a reference strip, and use a mathematical equation to convert that measurement into an on-the-go fertilizer N rate application. Though commercially available, research has yet to confirm the value of this approach in Kentucky corn production.

First consider the field soil's drainage class. Well-drained and moderately well-drained soils with red, red-yellow, and red-brown subsoils (Baxter, Crider, Pembroke, etc.) can be fertilized with most/all of the recommended N at any time – if the weather is not unusually rainy. Moderately well-drained, somewhat poorly-drained, and poorly-drained corn soils with gray-brown, gray-yellow, and gray subsoils (Belknap, Calloway, Newark, Sadler, Stendal etc.), even if tile-drained, should most always receive delayed/split N fertilizer management. As a general guideline for these wet-natured soils, if two-thirds or more of the recommended fertilizer N rate is applied 4 to 6 weeks after planting (V4-V6), the total N rate can be reduced by 35 lb N/acre (Ritchey and McGrath, 2020).

Any fertilizer N source (Table 7.5) can be used to make the second/delayed application. The application can be injected, or surface dribbled between corn rows or broadcast over the crop (top-dressed). Injection is required with AA use and is favored for UAN application to avoid volatilization and immobilization losses. Subsurface N application in no-till corn production can reduce the amount of N required by 10-15% compared to surface broadcast N. Research has found no yield benefit to splitting the dribble band in half and placing UAN close to each row (sometimes called "y-drop").

Post-Emergence Urea-N Volatilization Management – Injection is not favored when time is limited, and/or corn acreage is large in relation to available equipment. Top-dressing is less favored when the crop is larger than V4-V5 due to leaf burn, but soil surface applied urea or UAN to no-till fields carries additional risk—urease driven ammonia-N volatilization. Generally, volatilization losses are about 5% or less if urea or UAN is applied to a tilled soil surface, though the loss can be higher if soil pH is 7.0 or greater. With urea/UAN applied to a no-till soil surface after May 1, the N loss can range from 0 to 35%, but the average is about 10%. Higher losses occur if soil is warm and moist but drying due to a good breeze just after urea/UAN application. Losses are greater with urea than UAN as only half the UAN-N is urea-N. Dribble banded UAN exhibits less volatilization than broadcast UAN as the UAN contacts less soil/residue urease. Losses are much less with half-inch of rainfall within 48 hours of application.

Urease/volatilization inhibitors can improve N use efficiency from surface applied urea or UAN. These reduce/delay ammonia-N volatilization losses. Economics of inhibitor use are more favorable with UAN surface applied to no-till corn after May 1—expected soil and weather

Table 7.9. Urease inhibitors shown effective under field conditions in peer-reviewed research.

Abbreviation	Chemical Name	Commercial Products[1]
NBPT	N-(n-butyl) thiophosphoric acid triamide	Agrotain; various
NPPT	N-(n-propyl) thiophosphoric acid triamide	Limus (also contains NBPT)
Duromide	undetailed derivative of NBPT	Anvol (also contains NBPT)
ATS/CaTs	Ammonium or calcium thiosulfate	various

[1] Listing of a commercial product is not an endorsement of that product.

conditions favor volatilization. Active urease inhibitor ingredients are in Table 7.9. NBPT is off-patent, formulated into several products, and widely available. NBPT alone will often control volatilization (at the proper active ingredient rate). Some commercial products combine NBPT with other urease inhibitors to extend/improve volatilization inhibition. Thiosulfates are less effective, and their urease inhibition is considered incidental to their use as an S source.

Pre-Sidedress Soil Nitrate Test (PSNT) – The biological transformations of N and unstable soil inorganic N levels makes precise prediction of the amount of N needed to optimize returns difficult. This is the reason that meaningful soil tests for N availability are not found for most Kentucky crops. One exception is the PSNT, taken just prior to V4-V8 post-emergence N application. The PSNT measures N contributions from organic matter, prior crop residue and/or legume cover crops, and previous manure applications. Soil cores are taken to a 12-inch depth, centered between corn rows. About ten cores are taken in each field area of particular interest.

The PSNT is usually determined in a soil test laboratory, but there are field PSNT 'quick tests' available. Interpretation of results, in terms of the UK recommended sidedressed N rate, is shown in Table 7.10, above. PSNT results below 11 ppm N and above 25 ppm N are easily interpreted. Results between 11 and 25 ppm N are difficult to interpret because of variation in observed research results. Interpolation gives an increasing sidedress N rate of 6.25 lb N/acre for each ppm of PSNT nitrate-N as the test value falls from 26 ppm N (0 lb N/acre) to 10 ppm N (100 lb N/acre). Given the response variation (Figure 7.4), risk-averse producers might want to use a somewhat higher sidedress N rate after completing the interpolation.

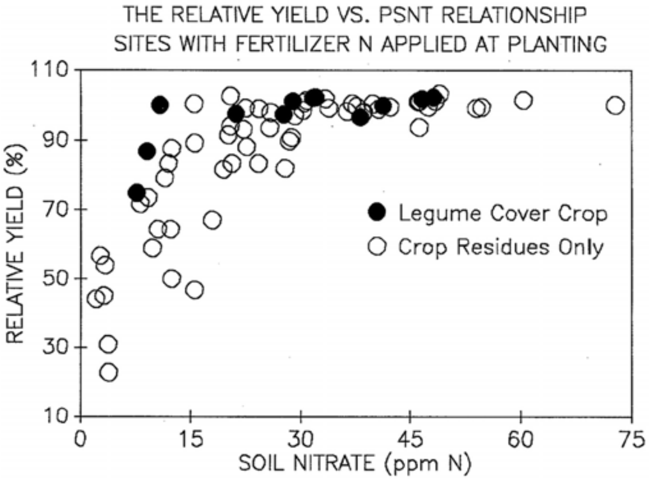

Figure 7.4. Relative corn yield as related to the PSNT value, for Kentucky (compiled from Grove, 1992). Corn yield approaches 100% when soil nitrate values reach 25 ppm N. See Table 7.9 for sidedress fertilizer rate recommendations according to the PSNT value.

Post-Emergence Management of Nutrients Other Than N for Corn – Application of other macronutrients (usually P or K; maybe S or Mg) and micronutrients (B or Zn) after emergence is often described as a 'rescue'. These are usually due to deficiency symptoms in the growing crop and/or plant tissue and soil sample analyses that confirm nutrient need and guide rescue rates. There will often be some negative yield impact of early deficiencies, but the sooner nutrient needs are met, the lower the impact. Because macronutrient needs are relatively large, post-emergence applications involve broadcast top-dressed dry materials. Some dry sources are salty and leaf burn should be expected—the smaller the corn, the less effect the leaf burn. Liquid P/K sources can be injected/ dribbled, but liquid sources are usually more expensive, especially for K. Broadcast foliar P/K applications are not recommended because needed rates can cause serious leaf damage. Lower foliar P/K rates that can be applied are insufficient for a deficient crop – may give temporary greening of the corn canopy, but little else. Micronutrients can either be soil or foliar applied. Needed rates are low and both uniform application and rapid crop uptake are desired, so water soluble B and Zn sources (Table 7.5) are often foliar applied.

Table 7.10. Interpreting PSNT results.‡

PSNT Nitrate-N (ppm N)	Soil Nitrogen Status	Interpretation
less than 11	low	High probability N is deficient. Corn will likely respond to full sidedress application. Recommend 100 to 150 lb N/acre.
11 – 25	medium	Intermediate N availability. Corn may or may not respond to sidedress application. Recommend 0 to 100 lb N/acre.
more than 25	high	High probability N is adequate. Corn will likely not respond to sidedress application. Recommend 0 lb N/acre.

‡ Taken from UK Regulatory Services Pre-Sidedress Soil Test Report Form.

Post-Emergence Corn Nutrition Monitoring – The growing crop should be regularly (usually weekly) visually assessed for any nutrition problems as a part of the larger scouting protocol. What follows are pictures, both small plants and large leaves (if available), and brief descriptions of likely symptoms for corn. Nutrient deficiency symptoms in small plants indicate one of three things: 1) initial soil nutrient supplies are too small; 2) root zone conditions are unfavorable for nutrient recovery by roots; and 3) early diagnosis and understanding will determine whether these symptoms are temporary or yield-threatening. When understood and dealt with quickly (when the deficiency is not likely to be temporary), young plant (through V5) deficiencies are usually not yield-threatening. As the crop gets larger, deficiency symptoms will indicate that a portion of the corn's yield potential has been lost. Remember that genetics plays a role in symptom expression—not every hybrid will exhibit the same symptom for a particular nutrient deficiency.

Post-Emergence Corn Nutrition/Visual Deficiency Symptoms – Nutrient deficiencies impact tissue color and appearance, and similarities among individual nutrients exist. Figure 7.5 shows that nutrient deficiencies are associated with their location on the plant (i.e., whether symptoms are primarily observed on older, more mature tissue versus younger, newly formed tissue), but symptoms can spread to the whole plant as deficiency severity increases.

In many cases, visual nutrient deficiency symptoms are not clear, are confused with one another, or are confused with other problems, including a poor growing environment (too cold, wet, dry, or compacted soil) or pest and/or disease pressure. Corn production specialists should be familiar with nutrient deficiencies commonly found in their region.

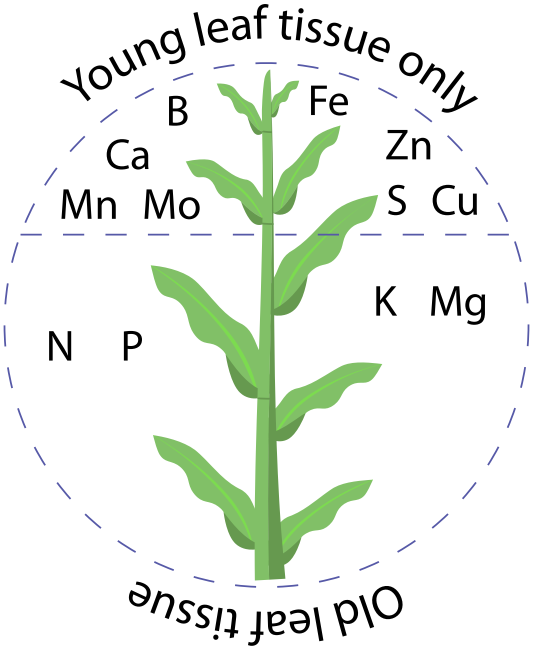

Figure 7.5. Expected location of deficiency symptoms for each nutrient. Source: International Plant Nutrition Institute

Image 7.1. Nitrogen deficiency in corn. International Plant Nutrition Institute (a-c) and Mississippi State University (d).

Nitrogen Deficiency

Young corn exhibits whole plant chlorosis/yellowing (Image 7.1a). With N deficiency after stalk elongation, N is translocated from older lower leaves to newer leaves or the ear, causing lower leaves to have a characteristic "V" shaped yellowing (Image 7.1b). The open end of the "V" is at the leaf tip and yellowing narrows along the leaf midrib towards the stalk (Image 7.1c). Corn growth and yield effects can range from severe (stunted, chlorotic plants which may be barren), to mild (normal-appearing plants with ear tips that do not have fully formed kernels (Image 7.1d). N deficiency can occur anywhere corn is grown in Kentucky.

Image 7.2. Phosphorus deficiency in corn. International Plant Nutrition Institute (a, b)

Phosphorus Deficiency

Stunted corn is a first sign of P deficiency (Image 7.2a), due to reduced internode length (Image 7.2b). Corn leaves may be distorted and dark green, and purple or red-purple on outer edges of lower leaves. The greater anthocyanin pigment is due to sugar accumulation in deficient plants, especially at low temperatures. P deficiency can occur anywhere in Kentucky except on the naturally high P soils of the inner and outer Central Bluegrass regions.

Image 7.3. Potassium deficiency in corn. International Plant Nutrition Institute (a, b)

Potassium Deficiency

K is mobile and deficiencies first appear on older leaves as scorching, yellowing, or firing/tissue death along leaf edges (Image 7.3a, b). K deficient corn grows slowly, stalks are weak, lodging often occurs, has less disease resistance and is more susceptible to moisture stress. Seed size is reduced. Symptoms can occur with dry or compacted soils when roots are stunted - even if soil test K values are high. K deficiency often signals that something else is wrong. Deficiency can occur anywhere in Kentucky but is less common in the Pennyroyal regions.

Image 7.4. Sulfur deficiency in corn. International Plant Nutrition Institute (a, b)

Sulfur Deficiency

Deficient plants show greater yellowing of younger leaves as S is somewhat immobile in the plant (Image 7.4a). Leaves of some hybrids exhibit pale green to yellow interveinal striping (Image 7.4b). S deficiency can be confused with N deficiency, especially on young plants where initial symptoms are a pale green to yellow green color on most leaves. S deficiency has yet to be confirmed in Kentucky but is expected due to reduced atmospheric S deposition.

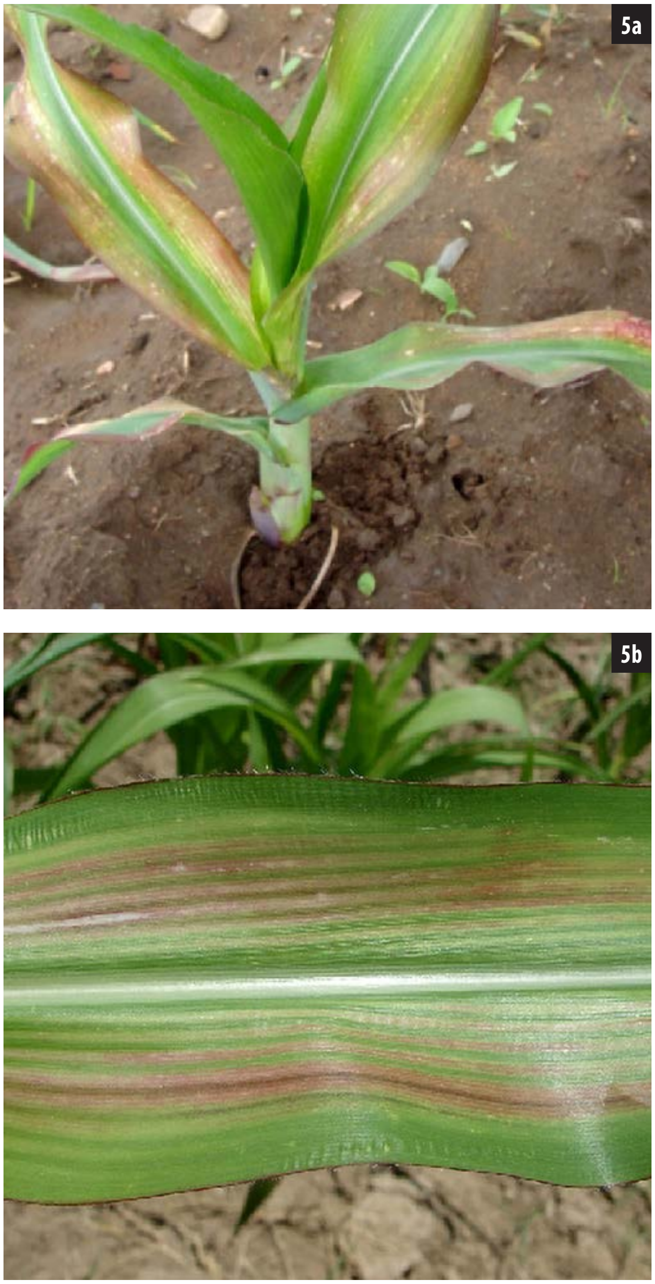

Image 7.5. Magnesium deficiency in corn. International Plant Nutrition Institute (a, b)

Magnesium Deficiency

Magnesium is mobile in plants, and deficiency appears first on older leaves as yellowing or interveinal chlorosis (Image 7.5a). This deficiency is sometimes confused with others that cause leaf striping, especially manganese toxicity on acid soil. Greater deficiency severity causes symptoms to appear on younger leaves, and necrosis (dead spots) development (Image 7.5b). Severely deficient corn leaves may be brittle, thin, and cup or curve upwards, with reddish-purple color at edges, tips and along veins. Mg deficiency has yet to be observed in Kentucky corn.

Image 7.6. Zinc deficiency in corn. International Plant Nutrition Institute (a, b)

Zinc Deficiency

Corn plant growth is stunted with increasing Zn deficiency, caused by short internodes. Corn looks compressed or "rosette" (Image 7.6a, b). If the stalk is split lengthwise, a brown-black discoloration is usually present at the lowest nodes near the base of the stalk. Zn leaf deficiency occurs in youngest leaves, but symptoms vary with hybrid. Sometimes there is a more general whitening (Image 7.6a), and sometimes an interveinal yellow to white chlorosis (Image 7.6b) that can be confused with other nutrients. Corn Zn deficiency is aggravated by high soil pH (above 6.8) and high soil P levels, making the problem common in the Inner Central Bluegrass.

Image 7.7. Boron deficiency in corn. International Plant Nutrition Institute (a); Pride Seed (b); U.S. Borax (c).

Boron Deficiency

Boron is immobile in the plant and deficiency symptoms appear as abnormal growth of the youngest leaves and growing points. Corn leaves may not unfurl properly and can be dimpled in a "zipper-like" pattern (Image 7.7a). Ears do not pollinate properly (Image 7.7b, c). Visual deficiency symptoms are relatively rare, but "hidden B hunger" can occur most anywhere in Kentucky and is more likely in the Western Coalfields and Cumberland Plateau regions.

8a


8b


Image 7.8. Manganese deficiency in corn. International Plant Nutrition Institute (a, b).

Manganese Deficiency

Manganese is immobile—deficiency appears as reduced/stunted growth (Image 7.8a) with visual interveinal chlorosis on younger, upper leaves (Image 7.8b). Leaves become pale green, then pale yellow. At this time, Mn deficiency can be confused with Fe, Zn or S deficiency. As Mn deficiency becomes severe, brown, dead areas appear. Soils with a high pH (above 7) should be prone to Mn deficiency, but Mn deficiency has not been confirmed on corn in Kentucky.

9


Image 7.9. Manganese toxicity in corn. Murdock (2001).

Manganese Toxicity

Manganese toxicity causes stunted development and leaf interveinal chlorosis/yellowing. The interveinal chlorosis is often expressed as a string of necrotic/dead spots (Image 7.9) and can be confused with Mg deficiency. Mn toxicity is most likely when soil pH is 5.2 or less. In Kentucky, corn Mn toxicity is rare, but has been confirmed.

Image 7.10. Iron deficiency in corn. International Plant Nutrition Institute (a, b)

Iron Deficiency

Iron deficiency typically occurs on younger leaves due to immobility in plants, but as severity increases, chlorosis spreads to older leaves (Image 7.10a). Initial interveinal chlorosis is pale yellow, but severe deficiency may "bleach" the entire plant white (Image 7.10b). This deficiency may be confused with Zn, S or Mn deficiency. High pH (above 7.5) soils are prone to Fe deficiency. These pH levels are rare in Kentucky and Fe deficiency has not been reported.

Post-Emergence Corn Tissue Sampling and Analysis/Sufficiency Concentrations – In the absence of deficiency symptoms a plant tissue sampling and chemical analysis (PTSCA) program can inform evaluation of a field's nutrition management. First, PTSCA is combined with soil testing to confirm a deficiency diagnosis and determine whether nutrient supply or root recovery problems are driving the deficiency. Second, routine PTSCA can find yield limiting problems that are not visually apparent (hidden hunger). Routine PTSCA can identify protocols resulting in excessive nutrient concentrations, suggesting possible economic loss.

For PTSCA to confirm observed nutrient deficiency/abnormal growth, collect one sample from the affected area and another from a nearby area of 'normal' looking corn. A representative soil sample should be collected from the affected area and another sample taken from an adjacent 'normal' area. Take soil cores near plants that were tissue sampled, in each area.

For routine PTSCA, randomly sample plants/leaves throughout a uniform field/field area. Collect tissue samples in a new, clean, brown/white, kraft paper bag. Dusty, soil covered leaves and plants should be avoided. If leaves have a light dust cover, gently remove with a soft brush, or quickly dip in and out of clean water. Do not use soap solution or prolong the rinse because some nutrient elements will be leached out of the tissue. Do not include damaged, diseased, or dead tissue in the sample. Sample a definite plant part. For corn at least 6 but no more than 12 inches tall, cut 10-20 plants 1 inch above the surface. For corn taller than 12 inches but not tasseled, take the first mature leaf (complete leaf collar) below the whorl from 10-20 plants. Fully developed plants should be sampled at 50% silking. Take the ear leaf (leaf just below the ear) from 10-20 plants. See also Schwab et al. (2007), AGR-92, Sampling Plant Tissue for Nutrient Analysis. Do not take samples after silks have turned brown as post-silking nutrient sufficiency data are not available. Table 7.11 summarizes nutrient levels that would be considered sufficient. Levels below those shown might be insufficient for optimal yield.

Post-Maturity Corn Nitrogen Assessment: Corn Stalk Nitrate Test – When corn matures, a final evaluation of the field's N management program is possible using the corn stalk nitrate test (CSNT). The CSNT is a laboratory determination of nitrate-N concentration of corn stalk segments taken after physiological maturity. The CSNT is based in the observation that stalk N is depleted under N stress, is maintained when N is adequate, and is accumulated when N is excessive. All corn producers might initially benefit from the CSNT on a few fields every year, or on many fields in a year with unusual weather. If results are usually 'optimal' (Table 7.12), then less testing investment is needed. If results are usually low, marginal or excessive, then the field's N management program should be adjusted. On-farm research with different N management treatments might benefit from the CSNT. Producers growing corn on manured soils, or after alfalfa, should consider the CSNT. To view sampling, see this video (https://youtu.be/N7wBn3dIG-w. The bulletin

Table 7.11. Plant tissue concentrations showing corn nutrient sufficiency.*

	Type of Sample		
Nutrient	**whole plants more than 6, but less than 12 inches tall**	**leaf below whorl, plants more than 12 inches tall**	**ear leaf at tasseling before silks turn brown**
N	4.0 – 5.0 %	3.0 – 4.0 %	2.8 – 4.0 %
P	0.40 – 0.60 %	0.30 – 0.50 %	0.25 – 0.50 %
K	3.0 – 4.0 %	2.0 – 3.0 %	1.8 – 3.0 %
Ca	0.30 – 0.80 %	0.25 – 0.80 %	0.25 – 0.80 %
Mg	0.20 – 0.60 %	0.15 – 0.60 %	0.15 – 0.60 %
S	0.18 – 0.50 %	0.15 – 0.40 %	0.15 – 0.60 %
Fe	40 – 250 ppm	30 – 250 ppm	30 – 250 ppm
Mn	25 – 160 ppm	20 – 150 ppm	15 – 150 ppm
Zn	20 – 60 ppm	20 – 70 ppm	20 – 70 ppm
Cu	6 – 20 ppm	5 – 25 ppm	5 – 25 ppm
B	5 – 25 ppm	5 – 25 ppm	5 – 25 ppm
Mo	0.1 – 2.0 ppm	0.1 – 2.0 ppm	0.1 – 2.0 ppm

* From Schwab et al. (2007), AGR-92. Sampling Plant Tissue for Plant Analysis.

Table 7.12. Interpreting CSNT results.**

CSNT Nitrate-N (ppm N)	Plant Nitrogen Status	Interpretation
less than 250	Low/ Deficient	High probability that N is deficient. Visual signs of N deficiency are usually apparent.
250 – 700	Marginal	N availability is close to "optimal" but could result in lower yields that will cause economic losses.
700 – 2000	Optimal	High probability that yields are not limited by N availability. Visual signs of N deficiency on lower leaves are often observed in this range.
more than 2000	Excessive	High probability that N is greater than needed for maximum yields.

** From Murdock and Schwab (2004), AGR-180, Corn Stalk Nitrate Test.

AGR-180, Corn Stalk Nitrate Test (http://www2.ca.uky.edu/agcomm/pubs/agr/agr180/agr180.pdf), also describes sampling.

Summary

A good corn nutrition management program starts early (the previous fall), with planning for the upcoming season using the latest soil test results and last season's plant tissue analysis and yield monitor data. Plan execution (right nutrient rate, source, timing, and placement) will involve management/monitoring decisions pre-plant, at-plant, and post-emergence/in-season. A comprehensive management program will maximize profitability, yield, and quality—especially in the absence of other limiting factors—and provide valuable information for next year's plan.

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Chapter 8

Weed Management

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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 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.

Weed and Corn Interactions

Weeds typically cause corn yield loss through competition for resources including light, moisture, and nutrients. Yield loss due to weed competition is dependent on the weed species present. Some species, such as giant ragweed, are very strong competitors and can cause high yield losses if not controlled. Others, including some annual grass species, are weakly competitive, but can still significantly reduce corn yield when present at high populations during early crop development. Theoretically, a weed's competitive potential can be used, in part, to develop an economic threshold – the density at which it makes economic sense to control weeds. However, because of variable competitive potential, and because a field rarely contains just one weed species, it can be difficult to determine a critical weed density at which control becomes economically justified.

In addition to crop yield loss, weeds can cause crop quality losses, harvesting difficulties, and contribute to the weed seed bank. Weeds with a vining growth habit such as morningglory and honeyvine milkweed can interfere with corn harvest at low plant populations. Other weed species such as smooth pigweed, Palmer amaranth, waterhemp, and common lambsquarters can produce thousands of seeds from a single plant. Therefore, controlling even low populations of such annual weeds can be a good strategy. This is especially true for weeds such as Palmer amaranth, waterhemp, and Italian ryegrass that are likely herbicide resistant and pose major threats to rotational crops such as soybean and wheat. It is also desirable to control light infestations of perennial weeds and newly introduced annuals before they become a serious problem. Table 8.1 provides information about a number of weeds commonly found in Kentucky corn fields.

Timing is also a critical aspect of weed and corn interactions. Most weed-corn competition studies indicate that,

Italian ryegrass in corn stubble. Image by Travis Legleiter under normal environmental conditions, weeds emerging and growing with corn for the first 2 to 4 weeks after corn emergence do not reduce corn yield if they are then removed. In addition, if the corn is kept weed-free for 4 to 6 weeks after emergence, weeds that emerge later are not likely to reduce yield relative to the cost of treatment. ***In general, the critical weed free period for corn under normal environmental conditions is from 2 to 6 weeks after planting***. However, as discussed above, late emerging weeds may cause harvest problems, reduce crop quality, or contribute to the weed seed bank depending on the weed species.

Life Cycles of Weeds

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 and understand the life cycle of weedy plants, their growth habit, and their potential impact on the crop.

Weeds can be grouped into three major categories based on their life cycle. Knowing the life cycle of a weed may help you determine when it might be problematic and how and when to best manage it.

1. Annuals complete their life cycle in one growing season and reproduce only by seed. Summer annuals, such as large crabgrass and waterhemp, germinate in the spring and set seed in late summer or fall. These summer annual weeds are more likely to directly compete with the corn. Winter annuals typically germinate in the fall and complete their reproductive cycle in the spring or early summer. Therefore, winter annual plants, such as common chickweed and Italian ryegrass are generally more of a concern at the time of planting and during the early stages of corn growth in no-till corn production. Winter annual control prior to seed production is warranted in fields that also produce winter annual crops such as wheat.
2. 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 as well as seed production. They reproduce only by seed and sometimes complete their life cycle within one year. Plants that grow for the full two years can become quite large and competitive and should thus be controlled early in their growth.
3. Perennial plants are capable of living and growing for more than two years. Depending on the species, reproduction can be by seed and/or by vegetative structures such as rhizomes, stolons, tubers, taproots, or creeping roots. These vegetative structures are mostly belowground and can be spread through tillage, planting, and other operations that move soil. For example, johnsongrass plants frequently encountered in corn fields emerge from seed but are also capable of emerging from rhizomes. Plants emerging from rhizomes or other vegetative structures will often be much larger than those emerging from seed. Perennial weeds are of concern in Kentucky's crop production systems due to the predominate no-tillage practices.

Weed Scouting and Field History

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. Many herbicides will control some species better than others, so proper weed identification is crucial to selecting the right product. Additionally, an effective postemergence control strategy for weeds often depends on proper identification when weeds are less than 4 inches tall. Photos of a few of the common weeds in Kentucky corn fields are included in this chapter. Training and a skilled eye are often needed to properly identify weeds during these early vegetative growth stages, and field scouting should begin within 1 to 2 weeks of corn planting and continue at weekly intervals for 8 to 10 weeks into the growing season.

A history of previously known weed problems in a field greatly aids in preparing an overall weed control strategy before the growing season starts. 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.

Cultural Practices and Mechanical Weed Control

Overreliance on any one weed control tactic can lead to shifts in predominant weed species, with those that are less affected by that tactic becoming dominant in the production system. For example, relying solely on a limited number of herbicide active ingredients can lead to herbicide resistance. Thus, in addition to scouting, a good program of integrated weed management should employ a variety of crop and weed management tools to deal with weed problems. These include preventing the introduction of new weeds and limiting the number and spread of weed seeds and vegetative structures. Mechanical methods, or cultivation, can also contribute to weed control. Early-season cultivation tools, including rotary hoes and spring tine harrows, can be effective in controlling early flushes of weeds and can be used through corn emergence. Specialized minimum tillage cultivators with wide sweeps and narrow shanks are capable of functioning in high crop residue and contribute to weed control between corn rows after corn emergence. Adequate timing and soil conditions are crucial for effective weed control with cultivation. Additionally, maximizing crop competitiveness through cultural practices such as planting at the optimal time and using adequate seeding density allows the corn to compete better with weeds by reducing weed emergence and growth. More information on corn cultural management is found in Chapter 5.

Crop rotation can also be an effective tool for managing some problem weeds. It helps limit the population density of some perennial or difficult-to-control weeds that accumulate in continuous crop production systems. For example, johnsongrass can be more 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. Variable timing of harvest may also kill weeds prior to seed dispersal, effectively reducing the buildup of these seeds in the soil. Rotation to crops other than corn and soybean also allows for more opportunities to rotate herbicides, which in turn helps prevent the development of herbicide resistance in some weed species.

Cover crops are an additional cultural practice that not only improve soil characteristics, but can also provide suppression of winter annual or early emerging summer annual weeds. Cereal rye has been shown to provide the greatest potential for weed suppression, especially of marestail (horseweed). However, the use of cereal rye prior to corn planting requires additional management to avoid issues related to nitrogen immobilization and disease pressure. More information about using cover crops in corn production can be found in Chapter 13.

Impacts of Tillage on Weed Control

Management practices used in Kentucky and surrounding states emphasize reducing tillage in a corn, soybean, and wheat rotation. Reduced and no-tillage systems offer both benefits and challenges regarding weed management.

No-tillage practices can provide numerous benefits for weed control. Tillage mixes weed seeds throughout the soil. Seeds closer to the surface will germinate over time. If there is no tillage to bring additional seeds to the surface, and if new seed inputs are limited, the soil seed bank can decline. Furthermore, leaving the soil undisturbed for several years may lead to rotting and/or predation of seeds on the soil surface. However, this assumes that weed control practices are successful and weeds are controlled prior to seed production.

While the reduction in large-seeded weeds is often noticeable in no-tillage systems, the lack of soil disturbance also promotes the development of populations of certain weed species. The fact that no-tillage limits the amount of soil disturbance that can break down the outer coating of weed seeds may explain why such weeds as common cocklebur and burcucumber are observed to a lesser extent in no-tillage compared to more intensive tillage situations. Small-seeded annual broadleaf weeds and annual grasses generally increase in prevalence in no-tillage systems. Species such as Palmer amaranth and waterhemp can predominate in no-tillage fields due to their small seed size and superior ability to emerge from the very top layers of soil. These two species can become especially problematic due to the lack of tillage and heavy reliance on herbicides in a no-till system. Larger-seeded weed species often do not emerge as well from the soil surface.

The occurrence of some annual weed species such as marestail (horseweed) and Italian ryegrass are also noticed more frequently under no-tillage conditions. These species can emerge during the late fall or early spring months and maintain active growth throughout the corn growing season. Both species, if not managed properly, can often escape control with spring burndown herbicides. Thus, both species can easily invade fields where tillage is not used to destroy existing plants in the spring.

The incidence and severity of perennial weeds can also occur in no-tillage corn production systems due to the lack of soil disturbance. Weeds such as common pokeweed and curly dock are examples of perennials with large fleshy tap-roots that grow well in a no-tillage environment. Honeyvine milkweed and trumpetcreeper are warm-season perennial vines with creeping roots that can thrive in such an environment as well. Johnsongrass is a perennial with rhizomes (underground stems) that likely poses the greatest risk to corn in a no-till cropping system, due to the potential development of herbicide resistance which would limit herbicide options.

Reducing tillage leaves previous crop residue on the soil surface, with more residue remaining following a wheat or corn crop relative to crops such as soybean. Surface crop residues can intercept herbicide sprays – this is an important consideration for soil-active herbicides that must be mixed into the surface soil layers to be effective in preventing weed emergence (see next section for more information on these herbicides). Either rainfall or mechanical incorporation can move herbicides into the soil and close proximity to germinating weed seeds. In no-till, rainfall is the primary avenue for this movement off crop residues and into the soil; mechanical incorporation can still be used in tilled systems. Some herbicides intercepted by crop residue may be subjected to loss by processes such as photodecomposition or by volatilization. In general, research data has not indicated a major reduction in performance of soil-active herbicides as a result of crop residue left on the soil surface, as long as a timely activating rain event is received. 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. Cover crop residues can act in a similar manner; see Chapter 13 for more specific information.

Another noted effect of more residue on the surface is the change in surface soil characteristics. 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 and lack of soil inversion. These two factors can change the effectiveness and the persistence of some herbicides. For example, the triazine herbicides, such as atrazine, tend to persist less and may provide less weed control in a no-tillage system compared to conventional tillage. Timely applications of lime will help raise soil pH and alleviate some of these concerns. On the other hand, overapplication of lime may result in high soil pH levels (pH 7.0 or above) that can cause herbicide carryover concerns to other rotational crops. Routine soil testing can help manage pH for optimal herbicide efficacy.

Herbicide Weed Control

Herbicide Use and Timing

Herbicides are the primary method of weed control in most corn production systems. 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 and are effective during weed seed germination, whereas foliar-active herbicides control weeds after they have emerged from the soil and are applied postemergence (POST) to the weeds. There are numerous formulations available that contain both soil and foliar active herbicides allowing for an application that controls both emerged weeds and keeps future weeds from emerging (that is, provides residual control).

Soil-active herbicides are usually applied to the soil surface before the crop and weeds emerge (i.e., preemergence [PRE]), although many soil-active ingredients such as atrazine, acetochlor, and S-metolachlor can also be applied after corn emergence but before weeds emerge. Herbicides applied to the soil surface are dependent on an activating rainfall or irrigation event to move the herbicide into the weed seed zone (see above).

In no-tillage systems herbicides are usually needed for vegetation control prior to crop emergence (i.e. preplant foliar or “burndown”). Paraquat (e.g. Gramoxone), glyphosate (e.g. Roundup PowerMax), dicamba, 2,4-D, saflufenacil (e.g. Sharpen and Verdict), and glufosinate (e.g. Liberty) are often used to "burndown" the existing vegetation. In many cases, the green vegetation present among the previous crop residue consists of cool-season annuals and perennials, along with some early-emerging summer annual weeds. Depending on its timing, this application can also be used to terminate cover crops (see Chapter 13). Burndown applications typically occur in the spring up to 30 days prior to planting. In some cases, such as when planting into a perennial grass or legume crop, burndown applications can be more effective when applied in the fall prior to corn planting. Numerous herbicide products are available that contain both foliar and soil active ingredients that allow for burndown of existing vegetation and provide residual herbicide control of germinating weeds.

Postemergence herbicide are applied after corn emergence or during the corn growing season. Certain weeds, especially warm-season perennials including johnsongrass, will not be readily controlled by preemergence herbicide treatments and thus postemergence applications are essential. In addition, if soil-active herbicides are not used to prevent summer annual weed emergence, or they are not effective due to environmental conditions, these summer annuals may need to be treated with timely postemergence herbicides. Postemergence herbicide actives include acetolactate synthase (ALS) inhibitors (e.g. nicosulfuron, rimsulfuron, etc.), hydroxyphenyl pyruvate dioxygenase (HPPD) inhibitors (e.g. mesotrione, tembotrione, topramezone, etc.), glyphosate, glufosinate, 2,4-D, and dicamba. Many postemergence herbicide products include multiple active ingredients and often contain soil active herbicide chemistries such as atrazine and *S*-metolachlor. Because products can contain multiple active ingredients that act in different ways, it is critical to follow label instructions for optimal weed control and to avoid potential damage to sensitive areas and subsequent crops.

A herbicide program should be developed around known weed species in the target field to maximize applications to capture control of all species in the field. For example, a field with broadleaf signalgrass or morningglory pressure may benefit from delayed postemergence application or postemergence applications containing effective residual herbicides to control these late emerging seed species. In contrast, a field with horseweed (marestail) or giant ragweed pressure should be heavily managed early in the season for these earlier emerging weed species.

Herbicide Persistence and Carryover

Paraquat and glyphosate are either tightly bound to soil or rapidly broken down and offer no soil-residual activity, whereas atrazine can remain active in soil for a period of time. While persistence of herbicides in soil is beneficial regarding weed control, it is a concern when associated with carryover to rotational crops or other environmental impacts.

The risk of crop injury from herbicide carryover is primarily dependent on susceptibility of the rotational crops and the persistence of the herbicide. Herbicide persistence is affected by several factors including soil temperature, moisture, pH, and texture, and properties of the herbicide active ingredient. 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 imazethapyr (e.g., Extreme, Pursuit), chlorimuron-ethyl (e.g., Canopy, Classic, Synchrony), and fomesafen (e.g., Flexstar, Prefix) have potential to persist long enough to injure corn. Corn herbicides such as atrazine and HPPD-inhibitors have label precautions when rotating to wheat or soybean. Always check rotational restrictions on herbicide labels, particularly if you will plant tobacco or vegetable crops following corn.

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) soil organic matter (usually 2 to 3 percent), and 4) soils with medium pH levels (usually pH 6.0 to 6.8).

Environmental Precautions

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 and simazine-containing products have special label restrictions for use near ground or surface waters. Emphasis is placed on using low atrazine and simazine rates, buffer zones, and conservation tillage practices as strategies for minimizing the risk of contaminating water sources.

It is also important to practice good stewardship when making herbicide applications to reduce the potential for off-target movement. This can occur when environmental conditions such as wind speed and direction are conducive for direct spray particle movement or with certain herbicides that have the potential for volatility losses causing damage to near-by sensitive crops and vegetation. Furthermore, some product labels may have restrictive application buffer zones for protection of endangered species.

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 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 (UAN), 10-34-0, or ammonium sulfate (AMS) 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. 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 hard water antagonism of glyphosate products.

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 ALS-inhibiting or HPPD-inhibiting herbicides with organophosphate or carbamate insecticides. Refer to all herbicide labels prior to applying tank mixtures of herbicides and 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 or HPPD-inhibiting herbicides, may result in corn injury.

The risk of antagonism of weed control varies depending on specific products, methods of application, and environmental conditions. 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 Resistance

Herbicide-resistant Weeds

A major concern in weed management is the resistance of weeds to commonly used herbicides. Not all *Amaranthus* plants are created alike, nor are all johnsongrass plants the same. As with humans, there is broad 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 variable response to herbicides. The basis for herbicide resistance is the fact that genetic diversity allows biotypes within a species to survive an herbicide treatment that is generally known to be lethal to that plant species. The evolution of herbicide resistance is a natural process that can be accelerated by applying the same type of herbicide repeatedly and relying on few other tactics to kill weeds.

Examples of herbicide-resistant weeds documented in Kentucky corn fields include smooth pigweed and Palmer amaranth resistant to triazine herbicides (i.e. atrazine) and to ALS-type herbicides (Accent Q) as well as glyphosate resistance in Palmer amaranth and waterhemp. Additionally, ALS-inhibitor (Accent Q, Spirit) resistance in johnsongrass has been confirmed in Kentucky corn fields. The threat of glyphosate resistance in johnsongrass is likely imminent due to the current use of postemergence glyphosate applications as the primary method of control for this species in Kentucky corn. The potential for weed resistance to develop increases with a continuous use of a herbicide or herbicide products that have the same site 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.
- Avoid using the same herbicide or another herbicide with the same site of action (i.e., herbicides that inhibit the same process in target weeds) multiple times during a year or in consecutive years in a field. It is possible for a herbicide used in one crop to have the same site of action as a different herbicide used in another crop, especially

with the recent development of multiple growth regulator and HPPD-inhibitor resistant soybean varieties. Most herbicide labels now indicate the herbicide site of action group number on the front of the label. Herbicide site of action group numbers can also be found in "Herbicides, Formulations, and Manufactures" table in *Weed Control Recommendations for Kentucky Farm Crops* (AGR-6)

- Apply herbicides with different sites 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 equipment (especially tillage and harvest equipment) to avoid moving weed problems from one field to the next.

Herbicide-Resistant Corn Hybrids

Crops traditionally susceptible to some herbicides have been developed and are now available that are resistant to specific herbicides. Herbicide resistance in crops can result from biotechnology techniques that insert genes from another organism, typically soil bacteria. These are typically referred to as "genetically modified" or "genetically engineered." These traits can also result from mutations in a plants' genome – either naturally occurring or artificially enhanced. The majority of all modern resistance events have been achieved through biotechnology techniques. Table 8.2 lists herbicide resistance corn traits. There are instances in which multiple herbicide resistance traits are stacked within a single hybrid.

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

Table 8.1. Common weed species in Kentucky corn.

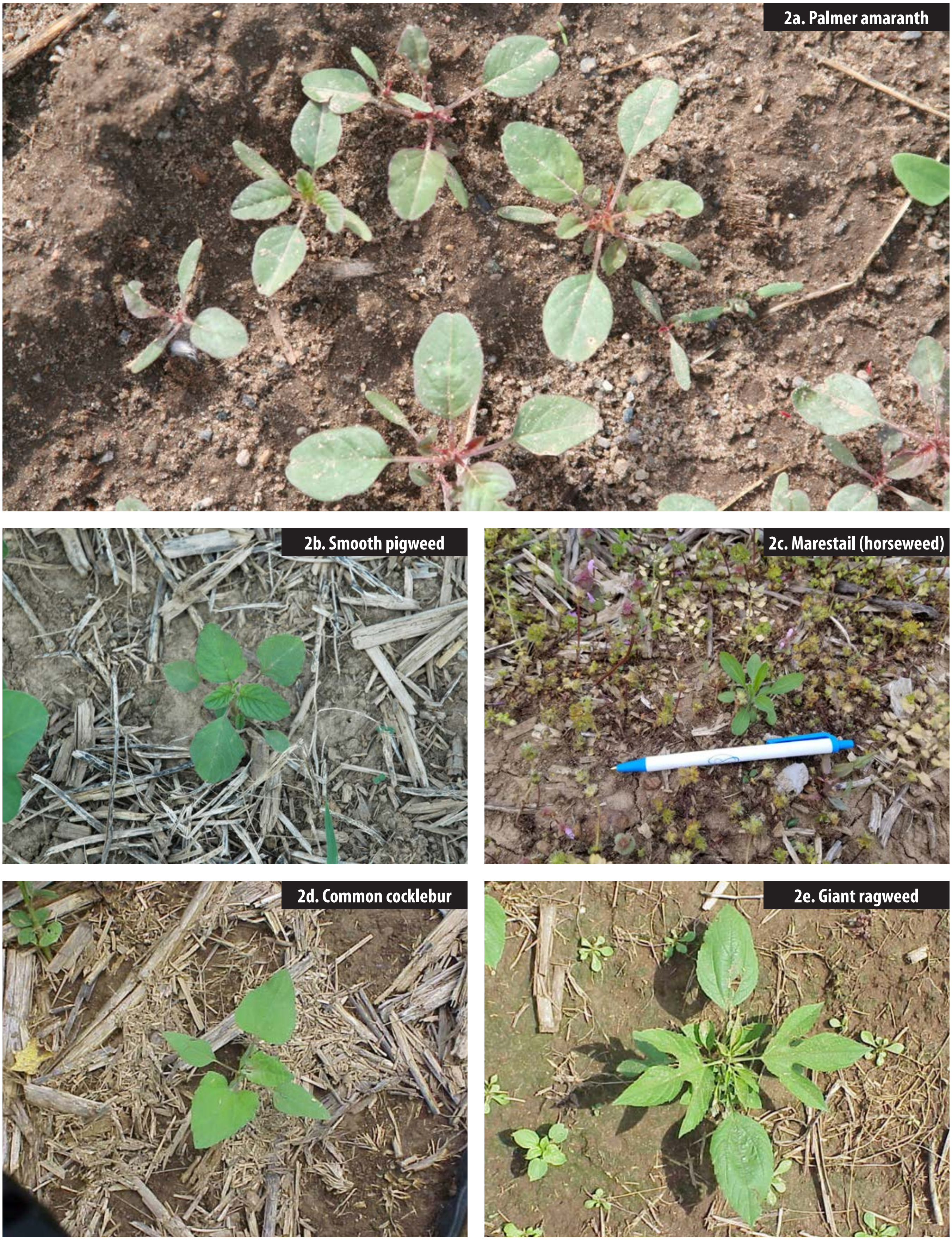
Weed Species	Life Cycle Primary Reproduction	Primary Emergence	Documented Herbicide Resistance in Kentucky[a] *(example herbicide)*	Notably Troublesome Characteristics
broadleaf signalgrass *Urochloa platyphylla*	Summer Annual *Seed*	Late Spring to Early Summer		Late emergence after corn planting
burcucumber *Sicyos angulatus*	Summer Annual *Seed*	Late Spring to Mid Summer		vining growth habit can lead to harvest issue
common cocklebur *Xanthium strumarium*	Summer Annual *Seed*	Late Spring to Mid Summer		Competitive at higher populations
large crabgrass *Digitaria sanguinalis*	Summer Annual *Seed*	Early Summer to Mid Summer		Late emergence after corn planting
fall panicum *Panicum dichotomiflorum*	Summer Annual *Seed*	Early Summer to Mid Summer		Late emergence after corn planting
giant foxtail *Setaria faberi*	Summer Annual *Seed*	Late Spring to Early Summer		Late emergence after corn planting
giant ragweed *Ambrosia trifida*	Summer Annual *Seed*	Early Spring to Early Summer	EPSPS - *glyphosate*	Highly competitive, early emergence
honeyvine milkweed *Cynanchum laeve*	Perennial *Creeping root, seed*	Spring		Vining growth habit can lead to harvest issue
Italian ryegrass *Lolium multiflorum*	Winter Annual *Seed*	Fall to Early Spring	EPSPS - *glyphosate*	Early emergence and herbicide resistance can lead to failed control prior to corn planting
johnsongrass *Sorghum halepense*	Perennial *Rhizome, seed*	Late Spring to Mid Summer	ALS - *nicosulfuron* ACCase - *fluazifop*	Perennial with limit herbicide options for control
lambsquarters *Chenopodium album*	Summer Annual *Seed*	Early Spring to Mid Summer		Drought stressed and/or mature plants can be difficult to control with postemergence herbicides. Prolific seed production.
marestail (horseweed) *Conyza canadensis*	Annual *Seed*	Early Spring to Early Summer & Late Summer to Late Fall	EPSPS - *glyphosate*	Extended emergence period, prolific seed production and herbicide resistance
morningglory (ivyleaf & pitted) *Ipomoea* (*hederacea* & *lacunosa*)	Summer Annual *Seed*	Early Summer to Late Summer		Late emergence, vining growth habit can lead to harvest issue; poor control with typical POST products
Palmer amaranth *Amaranthus palmeri*	Summer Annual *Seed*	Late Spring to Late Summer	ALS - *nicosulfuron* EPSPS - *glyphosate* PSII - *atrazine*	Extended emergence period, prolific seed production, and multiple herbicide resistance
smooth pigweed *Amaranthus hybridus*	Summer Annual *Seed*	Late Spring to Early Summer	ALS - *nicosulfuron* PSII - *atrazine*	Prolific seed production and herbicide resistance
common pokeweed *Phytolacca americana*	Perennial *Taproot, seed*	Mid Spring to Early Summer		Can cause staining of corn kernels particularly in popcorn
trumpetcreeper *Campsis radicans*	Perennial *Creeping root, seed*	Spring		Vining growth habit can lead to harvest issue
waterhemp *Amaranthus tuberculatus*	Summer Annual *Seed*	Late Spring to Late Summer	ALS - *nicosulfuron* EPSPS - *glyphosate*	Extended emergence period, prolific seed production, and multiple herbicide resistance
yellow nutsedge *Cyperus esculentus*	Perennial *Tuber, rhizome, seed*	Late Spring to Mid Summer		Perennial with limited herbicide management options

[a] **ALS** - acetolactate synthase Inhibitor; **EPSPS** - 5-enolpyruvylshikimate-3-phosphate synthase inhibitor; **PSII** – photosystem II inhibitor.

Table 8.2. Herbicide-resistant corn traits.

Commercial Launch Year	Trait Name	Herbicide Resistance *Trade Name products*	Method of development
1992	Clearfield or IMI-hybrids	imazethapyr *Pursuit* imazethapyr + imazapyr *Lightning*	Plant breeding and selection techniques
1995	Poast Protected hybrids	sethoxydim *Poast and Poast Plus*	Plant breeding and selection techniques
1997	Liberty Link	glufosinate *Liberty and several others*	Gene insertion
1998 2001	Roundup Ready Roundup Ready 2	glyphosate *Roundup PowerMax and several others*	Gene insertion
2019	Enlist	2,4-D *Enlist One* glyphosate *Durango and several others* 2,4-D + glyphosate *Enlist Duo* quizalofop *Assure II*	Gene insertion

Image 8.1. Palmer amaranth competing with corn for sunlight, water, and nutrients. Image by Travis Legleiter.



2a. Palmer amaranth

2b. Smooth pigweed

2c. Marestail (horseweed)

2d. Common cocklebur

2e. Giant ragweed

Image 8.2. Examples of common weed species in corn in the early vegetative stages when identification is essential for effective postemergence control. Image 8.2a, 2c, 2d, and 2e by J.D. Green. Image 8.2b by Erin Haramoto

2f. Honeyvine milkweed

2g. Yellow nutsedge

2h. Italian ryegrass

2i. Large crabgrass

2j. Johnsongrass

Image 8.2. Continued. Images 2f and 2i by J.D. Green. Images 2g, 2h and 2j by Travis Legleiter.

Chapter 9

Corn Diseases and Their Management

Kiersten A. Wise and Carl A. Bradley

Corn diseases can be economically limiting in Kentucky under favorable conditions. The likelihood that corn diseases will impact profitability in any given year or field depends on the disease triangle. The disease triangle tells us that corn diseases only occur when three factors are present at the same time: a susceptible corn hybrid, an organism that can infect corn (called a plant pathogen), and an environment favorable for disease development. The level of disease that ultimately develops is also dependent on these factors.

The field history of plant diseases can help aid in managing these disorders that are problematic in a particular area of a field of farm. Keeping a good field history and noting diseases that have been observed in the past help determine management practices that will minimize disease risk in future years.

Scouting fields and correctly identifying corn diseases are the first steps to preventing loss due to disease and creating a field history. Incorrect diagnosis may lead to costly and/or ineffective management methods. Several corn diseases have similar symptoms, and corn disease symptoms may also resemble disorders caused by other factors, such as herbicide damage, nutrient deficiencies, insect damage, etc. Sending samples to the local County Extension Agent for submission to the University of Kentucky Plant Disease Diagnostic Laboratory is the best way to identify disease, which will help provide the information needed to take management steps to prevent yield loss.

Successful corn disease management depends on altering the components of the disease triangle and taking steps to protect corn from factors that influence disease development. Corn diseases can be caused by bacteria, fungi, nematodes and plant viruses. Management practices vary depending on the causal organism and timing of infection and disease development. County Extension Agents should be consulted when developing a comprehensive corn disease management plan to tailor management options for a specific area or field based on field history and local conditions. In general, disease management should rely on a combination of the following:

Southern rust on a corn leaf. Image by Kiersten Wise

1. **Hybrid resistance**
    a. Select and plant hybrids that are resistant, partially resistant or less susceptible to diseases.
2. **Cultural practices**
    a. Rotate corn with soybean or other non-host crops
    b. Plant at recommended seeding rates and planting dates
    c. Manage residue that can harbor corn pathogens
    d. Irrigate according to agronomic guidelines and avoid frequent, short irrigation cycles
3. **Chemical practices**
    a. Use seed, in-furrow, or foliar-applied chemicals, if needed

Below is a list of commonly observed corn diseases and mycotoxins in Kentucky. Other diseases may occasionally be observed, and newly emerging diseases or diseases that are currently not common in Kentucky may become more prevalent with changes in environment, crop production practices, or hybrid availability.

Root and Seedling Diseases

Seedling Diseases

Causal Fungi and Oomycetes: *Pythium* sp., *Fusarium* sp., *Rhizoctonia* sp.

Symptom Timing: Planting to early vegetative growth stages

Conditions Favoring Disease: Soil conditions that delay germination and emergence favor infection and disease development. Seedling diseases are often associated with wet and/or heavy soils with poor drainage. Cool wet conditions at planting can lead to increased damage from seedling disease.

Symptoms: Seeds may rot or decay. Seedlings can be stunted, yellow, or wilt. Uneven stands or gaps in stands are often a first indication of a seedling disease issue. Affected plants may have brown discolored areas (lesions) on roots, and in some cases, a soft or decaying mesocotyl. Fusarium species can infect seedlings, occasionally progressing to the crown, resulting in a crown and stalk rot that is observed later in the season.

Management: Plant at the recommend time and avoid planting when soil conditions are cool and wet and unfavorable for rapid seed germination and early season growth. Fungicide seed treatments can provide some protection against seedling diseases.

Nematodes

Corn is a host for many different plant-parasitic nematodes. Typically, these nematodes are endemic to corn production areas. Nematodes known to affect corn that have been confirmed in Kentucky include: Dagger (*Xiphinema* spp.), Lance (*Hoplolaimus* spp.), Lesion (*Pratylenchus* spp.), Pin (*Paratylenchus* spp.), Ring (*Criconemella* spp.), Sting (*Belonolaimus* spp.), and Stunt (*Tylenchorhynchus* spp.). It is common to have more than one nematode species present in a field. Some species are more damaging than others, and yield loss will depend on population levels in a field.

Symptom Timing: Early vegetative stages through grain fill

Conditions Favoring Disease: Nematodes feed belowground on corn roots. The risk of damage is affected primarily by the number of nematodes present in a particular field. Nematode damage is typically most severe in soils with a high sand content, but yield loss can be observed with high nematode populations in other soil types. Continuous corn allows nematode populations to increase and become more damaging. Symptoms can be more prominent in dry conditions.

Symptoms: Symptoms of corn nematode damage range from minor to severe and depend on the type of nematodes present and their population level. General aboveground symptoms include patchy yellowing corn, stunting, early senescence, and unexplained yield reductions. Belowground symptoms include root pruning, root discoloration, and swelling. Plants may be infected by nematodes and show no symptoms.

Image 9.1. Pythium Seedling Blight. Image by Kiersten Wise.

Image 9.2. Anthracnose leaf blight. Image by Kiersten Wise.

Image 9.3. Common Rust. Image by Kiersten Wise.

Foliar and Aboveground Diseases

Anthracnose leaf blight

Causal Fungus: *Colletotrichum graminicola*

Symptom Timing: Early to mid-vegetative growth stages

Conditions Favoring Disease: The fungus that causes anthracnose leaf blight overwinters primarily in crop residue. Wet, humid weather favors infection and disease development. The leaf blight and stalk rot diseases can occur independently in a field, and the presence of anthracnose leaf blight does not necessarily result in stalk rot.

Symptoms/Signs: Lesions typically first appear on the lowest leaves in the plant canopy. Lesions are oval, expand across leaf veins, and are tan to brown with concentric rings visible in the lesion center. Lesions can grow together and blight large areas of leaf blade. Fungal structures called acervuli are often visible in the center of lesions. Acervuli have black spines that are visible with a hand lens, and the presence of these structures can help diagnose the disease in the field. Leaf lesions are rarely observed in the mid-upper canopy.

Management: Promoting residue decomposition through tillage or other methods and rotating away from corn will reduce the amount of the fungus available to infect future corn plantings. Select hybrids resistant for anthracnose leaf blight. Note that hybrids with anthracnose stalk rot resistance may not have leaf blight resistance and vice versa. Foliar fungicides with anthracnose leaf blight as a target disease are available.

Common Rust

Causal Fungus: *Puccinia sorghi*

Symptom Timing: Early vegetative growth stages through grain fill

Conditions Favoring Disease: The fungus that causes common rust does not overwinter in Kentucky. Spores are carried on wind currents from southern states each year and cause infection under mild, humid conditions. Leaf wetness contributes to infection and disease development. Hot, dry weather slows disease progress.

Symptoms/Signs: The first sign of common rust is the presence of small brick red or brown pustules on the leaf surface filled with rust-colored fungal spores. The spores create a “dusty” appearance and can leave reddish brown streaks on fingers or clothing when touched. These pustules can be found on the upper and lower surface of the leaf which can help distinguish the disease from southern rust. Pustules may also form on stalks and leaf sheaths. Leaf tissue around the pustules may die, leaving small tan to brown lesions of dead tissue.

Management: Most field corn hybrids have a moderate to high level of resistance to common rust; thus, common rust is rarely yield-limiting on hybrid corn and management is not often needed. Common rust in specialty corn production, such as sweet corn, seed corn, popcorn, or other high value corn, may require management under favorable conditions for disease development. Foliar fungicides are available for common rust management.

Image 9.4. Common Smut. Image by Kiersten Wise.

Common Smut

Causal Fungus: *Ustilago maydis*

Symptom Timing: Early vegetative growth stages through grain fill

Conditions Favoring Disease: The fungus survives for several years as spores in corn residue and in soil. Spores can infect any actively growing aboveground plant part. Injury from mechanical damage, insect feeding, hail, etc. can favor infection. Once infection occurs, galls develop, enlarge, turn powdery, and rupture to release spores.

Symptoms/Signs: Common smut is easily recognized by the white to silver galls that form on actively growing tissue. These galls are fungal growths covered by a white to greenish membrane that can split and release masses of black powdery spores. Galls are typically largest on ears and tassels. Galls on leaves are usually smaller and become hard and dry without rupturing.

Management: Yield loss due to smut is rare. Avoid damaging plants with equipment to reduce likelihood of infection.

Image 9.5. Crazy Top. Image by Kiersten Wise.

Crazy Top

Causal Oomycete: *Sclerophthora macrospora*

Symptom Timing: Mid vegetative growth stages through blister

Conditions Favoring Disease: The fungal-like pathogen that causes crazy top overwinters in soil or crop residue. Crazy top is most often observed in fields that flood after corn has emerged, or when ponding or heavy rain occurs early in the growing season. The pathogen produces swimming spores that infect the growing point of the corn plant. Grass weed species can also be hosts.

Symptoms: Crazy top symptoms vary, but almost always involve stunting or distortion of plant tissue. Tassels may appear bushy and/or resemble sprouted leaf tissue. Ear shoots can proliferate and leaves may be narrow and strap-like. Plants can tiller extensively and may not produce an ear or tassel.

Management: The disease rarely causes yield loss. Improving soil drainage can reduce conditions that favor disease development.

Image 9.6. Curvularia Leaf Spot. Image by Kiersten Wise.

Curvularia Leaf Spot

Causal Fungus: *Curvularia lunata*

Symptom Timing: Mid vegetative growth stages through grain fill

Conditions Favoring Disease: This fungus overwinters in corn residue and is splash- or wind-dispersed to new corn plants. Warm, humid conditions favor disease development.

Symptoms: Curvularia leaf spot starts as very small, round, tan lesion on leaves. Lesions often have a brown border and can be surrounded by a yellow halo. Symptoms range from a few lesions scattered across leaves, or lesions may densely cover large sections of the foliage.

Management: Curvularia leaf spot was first confirmed in Kentucky in 2018 and it is currently unknown what the impact on yield may be. Promoting residue decomposition through tillage or other methods and rotating away from corn will reduce the amount of the fungus available to infect future corn plantings. Anecdotal evidence suggests that some hybrids are more susceptible than others, however hybrid resistance ratings are not currently available for this disease. There are currently no foliar fungicides that list Curvularia leaf spot as a target disease on their labels.

Image 9.7. Diplodia Leaf Streak. Image by Kiersten Wise.

Diplodia Leaf Streak

Causal Fungus: *Stenocarpella macroscpora*

Symptom Timing: Mid vegetative growth stages through grain fill

Conditions Favoring Disease: The fungus overwinters primarily on crop residue but can also infect seed. Plants are infected during wet and humid weather, and infection can occur at any point in the growing season.

Symptoms/Signs: Small, round, dark brown-to-tan lesions are first observed on leaves. Dark concentric rings may be observed in the center of young lesions at the infection site on the leaf. These lesions expand lengthwise in long streaks and form elongated, elliptical lesions. In severe cases, lesions can coalesce to blight large areas of affected leaves. Symptoms can be observed on any leaf but are often first observed in the mid- to lower canopy. Small, round, dark fungal structures (pycnidia) often are observed within lesions.

Management: Diplodia leaf streak is not reported to cause yield loss in Kentucky as of 2020. Residue management through crop rotation or tillage can reduce the amount of fungus that overwinters. Anecdotal evidence suggests that some hybrids are more susceptible than others, however hybrid resistance ratings are not currently available for this disease

. There are currently no foliar fungicides that list Diplodia leaf streak as a target disease on their labels.

Image 9.8. Gray Leaf Spot. Image by Kiersten Wise.

Gray Leaf Spot

Causal Fungus: *Cercospora zeae-maydis*

Symptom Timing: Mid vegetative growth stages through grain fill

Conditions Favoring Disease: The fungus survives in corn residue and spores are splash or wind-dispersed to corn leaves. Leaves become infected during warm, humid conditions. Prolonged periods of high humidity increase disease severity.

Symptoms: Symptoms are usually first observed on lower leaves as small, gray to brown lesions. Lesions expand and take on a rectangular shape as they are restricted by leaf veins. Lesions can coalesce over time, blighting large areas of the leaf. Lesions on hybrids with resistance to gray leaf spot will often stay small and not expand into the classic rectangular shape associated with this disease.

Management: Planting a resistant hybrid is the most cost-effective way to manage gray leaf spot. Crop rotation and crop residue management can reduce the amount of the pathogen available to infect subsequent crops. Fungicides are available to manage gray leaf spot.

Image 9.9. Holcus Leaf Spot. Image by Kiersten Wise.

Holcus Leaf Spot

Causal Bacterium: *Pseudomonas syringae* pv. *syringae*

Symptom Timing: Early vegetative growth stages through grain fill

Conditions Favoring Disease: The bacterium that causes holcus leaf spot survives in crop residue and on alternative hosts, such as wheat, sorghum, and grassy weed species. Wet weather splashes bacteria onto corn leaves. Consequently, symptoms usually appear after spring rain events. Wind, hail, and other factors that injure plant tissue create entry points for the bacterium into its host, but holcus leaf spot can develop even in the absence of wounds.

Symptoms: Round, discrete lesions that are initially pale yellow to white and then enlarge and turn gray to brown or tan are present on leaves. Lesions have a water-soaked halo, and on certain hybrids, the margin of the lesion may appear brown or purple. Occasionally, lesions will coalesce into larger irregular shaped lesions that have a dry appearance. Symptoms can resemble damage from the contact herbicide active ingredient paraquat.

Management: Holcus leaf spot is not known to reduce yield, and management is not needed. Fungicide applications will not protect leaves against this bacterial disease.

Image 9.10. Northern Corn Leaf Blight. Image by Kiersten Wise.

Northern Corn Leaf Blight

Causal Fungus: *Exserohilum turcicum*

Symptom Timing: Mid vegetative growth stages through grain fill

Conditions Favoring Disease: The fungus survives in corn residue. Spores are spread by wind to plants and infection occurs during mild, wet weather.

Symptoms/Signs: Long, elliptical or "cigar-shaped," tan lesions are associated with this disease. Older lesions will have a "dirty" appearance. If viewed with a hand lens, spores (conidia) of the fungus that causes northern corn leaf blight can be viewed in the lesion which can be diagnostic of this disease in the field. Lesions can coalesce over time, blighting large areas of the leaf. Lesions on hybrids with single-gene resistance to northern corn leaf blight will be small and yellow and will not produce spores.

Management: Planting a resistant hybrid is the most cost-effective way to manage northern corn leaf blight. Single gene and multi-gene resistance to northern corn leaf blight exist, although company ratings may not indicate which resistance type a hybrid possesses. Crop rotation and residue management can reduce the amount of the fungus available to infect subsequent crops. Fungicides are available to manage northern corn leaf blight.

Image 9.11. Physoderma Brown Spot. Image by Kiersten Wise.

Physoderma Brown Spot

Causal Fungus: *Physoderma maydis*

Symptom Timing: Mid vegetative growth stages through blister

Conditions Favoring Disease: This fungus overwinters in corn residue and soil. Spores are dispersed by wind or water to young corn plants in spring. Infection requires sunlight, warm temperatures, and water. The fungus usually initiates infections within the whorl, leading to the banding pattern of symptoms on leaves. The disease is most severe in wet years or in irrigated fields when water remains in the leaf whorl for a prolonged period. Plants are most susceptible in the early vegetative growth stages and become more resistant with age. Physoderma brown spot incidence is usually highest in fields with conservation tillage and/or continuous corn.

Symptoms: The characteristic symptom of Physoderma brown spot is the appearance of round, purple to chocolate-brown spots in or near the mid-rib of the affected leaves. These spots can coalesce to form large dark blotches. Tiny, yellow to brown spots can cover leaves or appear in bands across leaf blades. Yellow or brown spots also may be observed on leaf sheaths, husks, or stalks. The fungus can also cause a stalk rot, which has been reported in several other states, including Iowa and Indiana, but the stalk rot phase of the disease has not yet been confirmed in Kentucky.

Management: Physoderma brown spot generally does not result in yield loss. Hybrids vary in susceptibility. Promoting residue decomposition through tillage or other methods and rotating away from corn will reduce the amount of the fungus available to infect future corn plantings. Foliar fungicides that list Physoderma brown spot as a target disease on their labels are available, but efficacy data for these products is limited.

Image 9.12. Southern Rust. Image by Kiersten Wise.

Southern rust

Causal Fungus: *Puccinia polysora*

Symptom Timing: Mid-vegetative growth stages through grain fill

Conditions Favoring Disease: The fungus that causes southern rust does not overwinter in Kentucky. Spores move northward from tropical areas each year and cause infection under warm, humid conditions. Leaf wetness contributes to infection and disease development. Dry and/or cool weather slows disease progress.

Symptoms/Signs: The first sign of southern rust is the presence of orange pustules filled with fungal spores on the upper leaf surface. The spores create a "dusty" appearance and can leave orange streaks on fingers or clothing when touched. These pustules are usually found on the upper surface of the leaf, which can help distinguish the disease from common rust which occurs on both the upper and lower leaf surfaces. Pustules may also form on stalks and leaf sheaths. Older pustules will become brown or black toward the end of the season.

Management: Hybrids vary in their level of resistance to southern rust. Choose less susceptible hybrids when available. Fungicides are available for management of southern rust.

Image 9.13. Trichoderma Ear Rot. Image by Kiersten Wise.

Ear and Stalk Rots

Ear Rots

Causal Fungi: *Aspergillus* sp., *Cladosporium* sp. *Fusarium* sp., *Nigrospora oryzae*, *Stenocarpella* sp., *Trichoderma viride*

Symptom Timing: Grain fill (dough and later)

Conditions Favoring Disease: Optimal conditions for ear rot development vary by causal fungi, but most infect corn at or after silking. Most of the causal fungi survive in soil and/or residue. Plant stress or wounding from insects, birds, or environmental factors such as hail, can provide infection points, or make ear rot damage worse. Lodged plants can bring corn into contact with the ground, leading to damage from ear rot fungi. Hybrids with tight husks that hold moisture or hybrids with ears that remain upright after maturity can also be more prone to ear rots. Wet conditions in fall that delay corn drying and harvest can make existing ear rot problems worse by allowing the fungi to continue to grow and spread. Most ear rot fungi will continue to grow until kernel moisture is below 15%.

Symptoms/Signs: Ear rots result in fungal growth on ears and kernels. Signs vary depending on the causal fungus:

- Aspergillus ear rot is a problem in hot, dry years and can be a significant issue under drought conditions. An olive-green mold is present on ears affected by Aspergillus ear rot.
- Diplodia ear rot is characterized by a white fungal mat of mold growth between kernels. Occasionally, the mat may be absent, and kernels will be brown and lightweight. Black fungal structures (pycnidia) are often present in the center cob tissue.
- Fusarium ear rot is associated with a white mold that can grow on individual kernels or small clusters of kernels. Affected kernels may also have a purple discoloration instead of, or in addition to, the fungal growth.
- Gibberella ear rot results in a pink to reddish fungal mat, often progressing from the ear tip.
- Penicillium ear rot results in a gray-blue powdery mold on and between kernels, often at the ear tip or where damage has occurred on the ear.
- Trichoderma ear rot is characterized by a blue-green mold that is on and between kernels. Kernel sprouting (vivipary) can occur on ears with Trichoderma ear rot.
- Other ear rots such as Nigrospora or Cladosporium ear rot can occur occasionally in Kentucky. Both produce a dark mold on kernels that is not often noticed until harvest. Both ear rots are more common when another stress such as hail or frost damage has impacted the crop.

Image 9.14. Aspergillus vs. Penicillium. Image by Kiersten Wise.

Mycotoxins

Mycotoxins are a byproduct of fungal infection and are not living organisms. Several of the fungi that cause ear rots produce mycotoxins in Kentucky, including *Fusarium* species (Fusarium and Gibberella ear rot) *Aspergillus flavus* (Aspergillus ear rot) and *Penicillium* sp. (Penicillium ear rot). Mycotoxins are extremely stable in grain and plants, and heat, freezing, and chemicals will not degrade these compounds. Mycotoxins are at higher levels in fines and foreign material in grain, and cleaning grain can help remove particles containing mycotoxins. However, this can concentrate fines, resulting in high concentrations of mycotoxins in screenings. Coring bins can also help reduce mycotoxins in stored grain. None of these practices remove mycotoxins directly from grain, but they remove grain affected by mycotoxins.

Testing for mycotoxins

Samples submitted for mycotoxin testing should be composed of several samples combined and taken from different areas within a silage mass or grain load or bin. Follow guidelines outlined by the USDA Grain Inspection Handbook for sampling methods to ensure that the sample to be tested accurately represents the grain or silage population. This handbook can be found at www.gipsa.usda.gov/GIPSA/. If sampling moldy silage for analysis, it is important to take a separate sample from an area that is not moldy and submit that also. Dry the sample below 15% moisture to slow fungal growth and mycotoxin production during shipping or freeze the sample and ship overnight on ice. It is important to test silage for mycotoxins, such as aflatoxin, since chemicals such as nitrates can cause similar animal feeding symptoms to those caused by mycotoxins.

Visual tests, such as the blacklight test, can be inconsistent to detect the presence of mycotoxins and therefore samples should always be sent to a professional laboratory for analysis.

Management: Select less susceptible hybrids. Rotate crops and manage crop residue. Fungicides are available for some ear rots, but efficacy data for these fungicides are limited. Anti-fungal products are available for Aspergillus ear rot management but must be used preventatively. If ear rots are observed in a field, affected areas should be harvested early and grain segregated to avoid mycotoxin contamination of non-infected grain. Silage and grain harvested with suspected ear rots should be dried to below 15% moisture. If grain or silage (with kernels present) is kept above this moisture content, molds and mycotoxins can continue to accumulate in grain. All grain contaminated by any ear rot fungus should be stored separately from good grain, and if stored long term, stored below 13% moisture to prevent further growth of fungi.

Stalk Rots

Causal Fungi: *Collectotrichum graminicola*, Fusarium sp., *Macrophomina phaseolina*, *Stenocarpella* sp.

Symptom Timing: Grain fill through harvest

Conditions Favoring Disease: Stalk rot fungi vary in the optimal conditions that cause disease. Some fungi infect early in the season, but symptoms may not be evident until late in the season. Most of the causal fungi survive in soil and/or residue. All stalk rots, with the exception of charcoal rot, are favored by warm, wet weather during grain fill. Charcoal rot is more severe when hot, dry weather occurs during grain fill. Many stalk rots are the result of another significant stress on the crop, such as drought or moisture stress, nitrogen deficiency, wounding, etc. Any stress that causes the plant to draw from stalk reserves for grain fill increases the risk of stalk rot issues. Stalk rots may also be abiotic in nature and not associated with a fungal pathogen.

Symptoms/Signs: Symptoms and signs vary depending on the causal stalk rot. In general, lower stalk tissue is weak and the internal tissue (pith) is shredded and often discolored. Lodging or stalk breakage is often the first indication of stalk rot. Distinguishing features of individual stalk rots are as follows:

- Anthracnose stalk rot: Dark brown to black discoloration on exterior of lower stalk. Pith is shredded and dark brown. Stalk death above the ear after pollination but before senescence is indicative of the top dieback phase of the disease.
- Charcoal Rot: Pith is shredded and silver colored. May contain tiny black fungal structures that can be viewed with a hand lens.
- Diplodia stalk rot: Small, dark-brown to black fungal structures (pycnidia) develop at the base of stalk. Shredded pith is tan to brown. Premature plant death can occur.
- Fusarium stalk rot: Pith shredded and white to pink-salmon-colored. The crown may also be discolored. Difficult to distinguish from Gibberella stalk rot.
- Gibberella stalk rot: Pith shredded and pink to reddish. Small black fungal structures develop on stalk near nodes and can be easily scraped off with a fingernail.

Management: Use hybrids resistant to stalk rots and that have good stalk strength ratings. Avoid excessive plant populations. Maintain balanced soil fertility and adequate nitrogen. Rotate crops and manage crop residue. Control insects that feed on corn and manage foliar diseases. Scout for stalk rot prior to harvest, and harvest early if 10 to 15 percent of the sampled population show disease or prematurely lodging.

Image 9.15. Fusarium Stalk Rot. Image by Kiersten Wise.

Chapter 10

Insect Pests of Field Corn

Raul Villanueva

Corn producers can rely on preventive Integrated Pest Management practices to reduce injury caused by arthropods (insects) and/or mollusks (slugs). These practices include:

- Planting time and crop rotation to disrupt pest cycles
- Selecting hybrids resistant to insects or diseases
- Weed control to eliminate alternative host of pests
- Judicious application of high specificity pesticides at the most effective time

Planting very early or very late can expose corn to greater risk of certain pest insects. While planting date is affected by weather conditions, farmers need to realize the effect of planting date on insect pressure. Continuous corn increases risks of certain insect species while crop rotations usually decrease those risks. Understanding the risks with corn planting date and crop rotations helps producers take appropriate steps such as scouting and judicious use of insect pest management tools.

The combination of all these activities can help producers prevent economic losses and continue with sustainable practices to grow corn. To achieve this, producers use crop growth information, pest intensity levels, crop development stage, pest history, weather conditions, grain price, expected yield, and cost of the control to determine the need for action.

The main goal of this section is to provide corn growers, consultants, and scouts reliable and up to date information on the identification of major pest, and basic information in their biology, phenology, and management in Kentucky.

Insect Resistance through Biotechnology

To manage key aspects to grown corn such as caterpillar pests, agricultural biotechnology has been producing highly resistant hybrids. In addition, these genetic improvements may include modifications in genetic traits that combine tolerance to herbicides (i.e. glyphosate or glufosinate) as well as insecticidal activity. For insecticidal activity, these hybrids use various genes from the soil bacterium *Bacillus thuringiensis* (Bt) to produce proteins that disrupt the digestive system of certain pests such as several lepidopteran species or corn rootworms. The Bt proteins are highly selective, and each one will affect only specific groups of insects (i.e. lepidopterans, beetles or mosquitoes). These proteins are nontoxic to mammals and other animals. Many biotech hybrids are commercially available and have been developed with the aim to control corn earworm, European and southwestern corn borers, and corn rootworms and suppress fall armyworm and black cutworm (Table 10.1). A

Corn earworm on a susceptible corn ear. Image by Chad Lee

Table 10.1. Summarized table of trades, events, proteins and insect targets and herbicide tolerances for 2021 (*). For an updated version of this table, check The Handy Bt Trait Table for U.S. Corn Production.

Trade name for trait	Event	Bt toxin or another trait expressed	Primary Insect Targets + Herbicide tolerance
Agrisure CB/LL †	Bt11	Cry1Ab + *PAT*	corn borer + glufosinate tolerance
Agrisure Duracade	5307	eCry3.1Ab	rootworm
Agrisure GT	GA21	EPSPS	glyphosate tolerance
Agrisure RW	MIR604	mCry3A	rootworm
Agrisure Viptera	MIR162	Vip3Aa20	broad caterpillar control, except for corn borer
Enlist	DAS40278	aad-1	2,4-D & 'FOPs'
Herculex I (HXI) or CB	TC1507	Cry1Fa2 + PAT	corn borer + glufosinate tolerance
Herculex RW	DAS-59122-7	Cry34Ab1/Cry35Ab1 + PAT	rootworm + glufosinate tolerance
Roundup Ready 2	NK603	Modified EPSPS	glyphosate tolerance
Yieldgard Corn Borer	MON810	Cry1Ab	corn borer
Yieldgard Rootworm	MON863	Cry3Bb1	rootworm
Yieldgard VT Pro	MON89034	Cry1A.105 + Cry2Ab2	corn borer and several caterpillar species
Yieldgard VT Rootworm	MON88017	Cry3Bb1 + EPSPS	rootworm + glyphosate tolerance
(None – part of Qrome)	DP-4114	Cry1F + Cry34Ab1/Cry35Ab1 + PAT	corn borer + rootworm + glufosinate tolerance
In SmartStax Pro	MON87411	Cry3Bb1 + DvSnf7 dsRNA + EPSPS	rootworm + glyphosate tolerance

*Adapted from "The handy Bt trait table for US corn production" (Chris DiFonzo). https://www.texasinsects.org/bt-corn-trait-table.html

† Mention of a trade name is not an endorsement.

list of commercially available hybrids can be found in the following publication: The Handy Bt Trait Table for U.S. Corn Production built and yearly updated by Dr. C. DiFonzo (Field Crops Entomologist – Michigan State University).

To cause insect mortalities by Bt corn hybrids, the Bt bacterium must be ingested by a susceptible insect. Then, 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 septicemia as bacteria multiply in its body. Even among Lepidoptera larvae, species differ in sensitivity to the Bt protein and already some species have been detected developing resistance to Bt. Producers should notice that not all parts of the plant necessarily contain the protein in equal concentrations.

The insects target by these proteins are black cutworm (*Agrotis ipsilon*), corn earworm (*Helicoverpa zea*), European corn borer (*Ostrinia nubilalis*), fall armyworm (Spodoptera frugiperda), the western and northern corn rootworms (*Diabrotica virgifera and D. barberi*), stalk borer (*Papaipema nebris*), southwestern corn borer (*Diatraea grandiosella*), true armyworms (*Mythimna unipuncta*), and western bean cutworm (*Striacosta albicosta*).

To avoid insect resistance corn producers must use recommended resistance management strategies (plant refuge areas with non-GMO corn, use seed blended with refuge seed, and/or use hybrids with more than one single trait-pyramids). Some caterpillar species have the high potential to develop resistance to corn containing single Bt. It is the producer's responsibility to use approved resistance management practices when using biotech crop technologies.

Scouting at Different Stages of Corn Development and Planting Time

If a suspicious insect problem is observed in a field, it is important to get it properly identified. Then determine how it is distributed, randomly through the field or to just certain areas such as field edges, along roads or streams, or crops adjacent to sites with problems. Additionally, evaluate healthy vs. injured plants, including roots, foliage, or stalks (both externally and internally). Handy tools for scouting agents should include magnification lens, a pocketknife, a trowel or small shovel, and a container (resealable bag or paper bags) to take samples for further identification. To monitor for insect pests in corn, chose random sites throughout the interior of fields. Your samples should be distributed to represent the entire field. Scouting methods differ among the key pests.

Pests that affect corn during earlier stages of development can be scouted through a random walking pattern (e.g., "zigzag"), looking for injury by pests that may include poor seedling emergence, injury to seeds, cut or lodged plants, poor vigor or stunted growth, presence of suckers, etc. Special attention should be given to monitoring of seedlings during periods of poor growing conditions or when corn is planted before early May. The cool weather and low soil temperatures after seedling emergence may expose young plants to cutworm and flea beetle damage over an extended period. 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. At minimum, sample three sites per fields smaller than 20-25 acres. For larger fields (>25 acres) add one site for each additional 10 acres. Large fields should be divided into units not larger than 25 acres. Use recommended scouting methods described below for specific pests so that scouting information can be compared with established treatment guidelines. Also, it is important to continue to scout field borders for "edge pests" (e.g., stink bugs, grasshoppers).

Major Pests

The Table 10.2 inserted below shows the main pests of corn in Kentucky as well as the time of occurrence during a growing season, and periods of highest occurrence that may reduce yield or cause economic damage.

Insects and Mollusks Affecting Corn

Insects affecting from emergence to the V5 stage may be checked while recording for plant stand counts up to the fifth leaf stage (V5). When plants are small, gaps in rows can be easily noticed, as well as fallen, cut, wilted, or stunted plants. If any of these are observed, it may be a sign of a pest problem. During the emergence and early seedling growth stage, examine areas with missing plants or gaps in rows by digging these areas to look for seed injury or depth of planting issues. At this stage seedcorn maggot, cutworms, wireworms, slugs, white grubs, or diseases can be causing emergence delays or plant stand reductions.

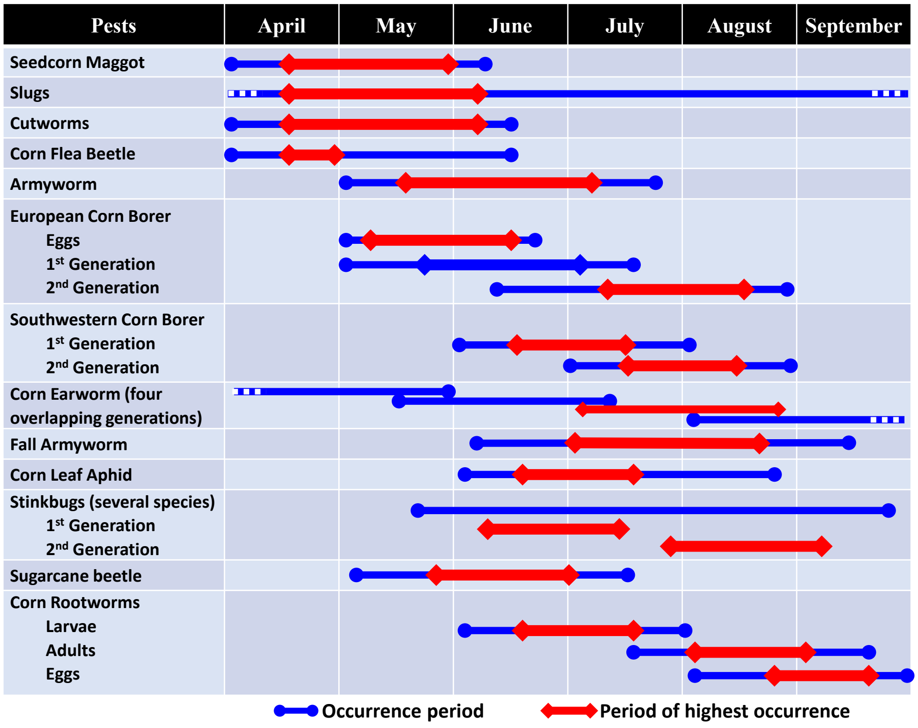


Table 10.2. Calendar for occurrence of key insect pests and slugs in Kentucky affecting corn

Seedcorn Maggot

Delia platura (Meigen) (Diptera: Anthomyiidae)

Description and injury: The immature form of this small fly is the seed corn maggot (larva). This stage causes damage to germinating seeds of corn as well as soybeans and other crops. The maggot has a whitish color and feeds on corn seed. This can cause stand reductions. Feeding on seed may cause poor to no germination or result in weakened seedlings that may die. The overwintering stage is the pupa. Adult flies emerge and mate early in spring, then female flies lay eggs within cracks in the soil, or under soil clumps. Crops planted early, when the weather is cool and wet for long periods of time, are potentially at greater risk to damaging or infestations. Also, soils with decaying organic matter, manure, or green plant material (cover crop or weeds), is highly attractive to female flies for egg laying. Any condition that delays seed germination may increase damage from seed corn maggot, with damage greatest in cool, wet springs.

Scouting and Monitoring: Damage can be detected by digging in areas where plants have failed to emerge. Serious damage may require replanting. If untreated insecticides seeds are used, systemic in-furrow insecticides aid in preventing infestations of seed corn maggots. Banded treatments should be incorporated lightly. There are no rescue treatments for this pest.

Economic threshold: Not available

Slugs and Snails

Monitoring: Intensive scouting for slugs and damaged plants should be conducted after periods of rain, when morning temperatures are temperate and weather is cloudy. Also, look for foliage for irregular holes with irregular margins to the lowest leaves of the plant (VE to V5); emphasis should be place on seedlings during periods of cool weather as seedlings are more vulnerable to damage. Scout for slugs during the day by examining around missing plants or plants with injury and on each side of rows (9 inches from the plant) in at least five locations of the field.

Economic threshold: not available.

Management: Ground beetle species (Coleoptera: Carabidae) have been observed preying on all stages of slugs (eggs, immature and adults) in laboratory tests at Princeton. These natural enemies can contribute to reduce slug populations. Emphasis should be placed on efforts to minimize reductions of ground beetles. Calendar-based insecticide sprays with broad-spectrum insecticides can reduce the numbers of ground beetles which can favor

Table 10.3. Rates of metaldehyde (Deadline™ M-PS Mini-Pellets) and iron phosphate (Sluggo™) for different stages of growth for corn and soybeans.

Molluscicide	Corn growth stage	Maximum single application	Total applications per season	Re-application interval	PHI Pre-harvest interval	Type of application
metaldehyde	Up to V8 V8 to VT	25 lbs/Acre	3	7 days	0 d	Broadcast or ground directed
iron phosphate	Seedling or later stages	20 to 44 lbs/Acre	n/a	n/a	0 d	Broadcast or ground directed

higher slug densities. Two molluscicides (pesticides that specifically target slugs and snails) are available for control of mollusks in Kentucky. Rates of these two products are in Table 10.3. In many situations corn will outgrow injury by slugs when conditions promote rapid seedling growth.

Black Cutworm

*Agrostis ipsilo*n Hufnagel (Lepidoptera: Noctuidae)

Description and injury: The larval stage injures seedlings potentially killing plants and reducing stands. Small larvae climb small seedlings to chew small holes in leaves; large larvae chew into the base of seedlings, cut small plants, and may pull plant parts into their burrow. Symptoms are wilted or cut plants. Cutworm larvae 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. Although, chances of significant damage by this pest are low. Cutworms are potentially very destructive and unpredictable. Corn is vulnerable to cutworm attack 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 enough control. A rescue treatment may be necessary for moderate to heavy infestations 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 two weeks before planting.

When to monitor: Corn should be monitored for cutworms at least twice a week for the first three to four 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. Dig 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

Chaetocnema pulicaria (Coleoptera: Chrysomelidae)

Description and injury: Corn flea beetle is 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. These beetles are leaf feeders. They make small feeding scars on the surface giving leaves a gray, frosted appearance (Figure 10.1). Damage is generally serious on plants less than 6 inches tall. Flea beetles transmit Stewart's wilt, also known as bacterial leaf blight. There are several species of flea beetles that feed on corn; however, the corn flea beetle *C. pulicaria* is the species most frequently found in corn. This is a minute-sized black shiny beetle (2 mm or 1/12 inch in length) with thickened hind legs used to leap considerable distances when disturbed (Figure 10.2). 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

Image 10.1. Corn flea beetle and the damage it caused on a corn leaf. Photo: Raul Villanueva

Image 10.2. Ventral, dorsal, and lateral view of the corn flea beetle (space between lines under image are in measurements in millimeters). Notice the thickened hind leg (dorsal view image) showing the highly specialized thickened femur enabling it to make leaps when disturbed. Photo: Raul Villanueva

conditions are poor. Early feeding often occurs during cool weather when corn growth is retarded. Second, flea beetles are vectors of the pathogen that causes Stewart's wilt, also known as bacterial leaf blight. Selection of corn varieties resistant to this disease should be considered.

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.

Armyworm

Mythimna unipuncta (Lepidoptera: Noctuidae)

Description and injury: Armyworm is a sporadic early season pest species in corn. True armyworm is a noctuid, and in this group, there are many species of cutworms. It can cause occasional losses in corn and should be monitored in the spring. Infestations usually first develop in small grain fields, grass cover crops, or weedy fields. In a full-grown $1^1/_2$-inch armyworm the body has a greenish brown tone with a thin stripe down the center and two orange stripes along each side. The head is brown with honeycombed markings. In tilled fields, partially grown larvae can migrate into corn fields from grass waterways, weedy borders, or wheat fields. Damage is usually first noticeable around the field margins adjacent to these areas. Armyworm is nocturnal and feeds at night by chewing leave margins. 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 (Figure 10.3). During the day, armyworms are found in the soil, hidden in the whorl, or underneath groundcover.

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

How to scout: In fields with conventional tillage, check on plants in field borders adjacent to small grains or grassy strips. If armyworms are detected, determine how far the infestation extends into the field. 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 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.

Corn earworm

Helicoverpa zea (Lepidoptera: Noctuidae)

Description and injury: Adults emerge in the spring. They are approximately 3/4 to 1 inch in length, tan to buff-colored, sometimes with some olive shading, with a wavy darker band near the edge of the wings of younger specimens. The eyes have a distinctive serpentine green reflection when held up to sunlight in live specimens. A darker brown spot is located about midway along the outer edge of the front wings. They fly when evening temperatures exceed 55°F, with increasing activity at higher temperatures. They can be caught up in winds and storms and deposited with the weather patterns. Females are strongly attracted to fresh silks, where they lay the eggs individually directly on the silk. A female can lay from 500 to 3,000 eggs, and average about 1,000 eggs per female. Eggs will be laid on other plant tissue or hosts when corn silk is not available. Eggs hatch in two to 10 days, depending on temperature, and probably hatch within two to four days during the summer in Kentucky.

Image 10.3. Armyworm on seedling corn. Feeding occurs on leaf margins leaving the leaf midrib behind. Photo: Ric Bessin

Hatching larvae crawl away from light, and towards moist, shaded areas. When on silks, hatching larvae feed on the silk and burrow directly down into the ear (Figures 10.4 and 10.5). They can be cannibalistic as well, which tends to limit the number of larvae to one per ear. They feed on the corn kernels at the tip of the ear, this tip-feeding is often not important. Thus, the corn earworm is a pest to vegetable growers, but not to field corn growers. Corn earworm is a moth, in the insect family Noctuidae. As with all the noctuids (such as fall armyworm), it is a night-flying moth. It is a good flyer, and able to move long distances. However, it is migratory, and annually disperses from southern overwintering areas into northern states and Canada. Thus, areas have overwintering, both overwintering and immigrant, or immigrant populations, depending on location and weather. The number of generations is usually reported to be one in northern areas such as most of Canada, Minnesota, and western New York; two in northeastern states; two to three in Maryland; three in the central Great Plains; and northern California; four to five in Louisiana and southern California; and perhaps seven in southern Florida and southern Texas. The life cycle can be completed in about 30 days.

Monitoring and Scouting: The University of Kentucky monitors for corn earworm populations using pheromone traps at two locations, Princeton in western Kentucky and Lexington. Cone-shaped traps have been used for nearly 25 years and this information is available online during the corn growing season (March to September). These traps provide valuable information on the movement of migrating moths do not assess in-field population levels. Currently, estimates of corn injury to field corn based on captures of moths in traps are not possible.

Scouting is conducted for eggs oviposited on corn silks. Scouting for corn earworm eggs is done sampling five sites within a field and 20 ears per site. Clip silks from ears and place in a plastic bag. Silks for eggs are assessed separating silks and examining for eggs over a black or dark colored surface. In addition, ears can be evaluated for larval damage, pulling the husk open, and checking for earworm damage.

Economic threshold: A treatment may be necessary if 5% to 10% of the ears are infested with eggs or larvae. If infestation levels are below the threshold, then a second scouting should be conducted again two or three days later. After a second time, an insecticide application may be recommended if the cumulative infestation level (infestations from first plus second scoutings) exceeds the threshold level indicated above.

Management: The use of resistant hybrids is the key tool to manage this pest as they contribute to the reduction of injuries on leaf tissue and ears. Genetically modified hybrids or *Bt* hybrids suppress corn earworm populations and reduce injuries in ears. Early planted corn fields have high chance to escape injury as peak corn earworm females may arrive late to lay eggs on silk. Crop rotation or tillage practices may not have significant effects on corn earworm survival.

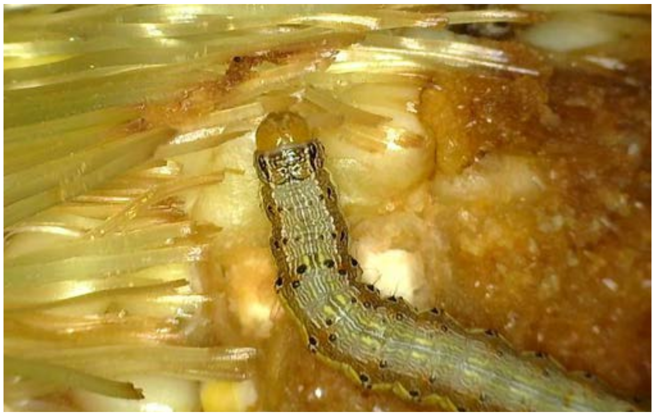


Image 10.4. Corn earworm larva and damage in corn kernels.
Photo: Raul Villanueva

Image 10.5. Corn earworm larva and exit hole on ear.
Photo: Raul Villanueva

Fall Armyworm

Spodoptera frugiperda (Lepidoptera: Noctuidae)

Description and injury: Spherical gray eggs are laid in clusters of 50 to 150, usually on the leaves or even walls or post near fields (Figure 10.6). 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 (Figure 10.7). Fall armyworm has four dark spots arranged in a square on top of the eighth abdominal segment.

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

Image 10.6. Egg batches of fall armyworm oviposited in a (A) wall, (B) trap, (C) sunflower bract and (D) plastic trap. Photos: Raul Villanueva

often recover from whorl damage without any reduction in yield. On later stages of corn, fall armyworm larvae often attack the developing ear directly. This pest may cause serious leaf feeding damage as well as direct injury to the corn ears. Producers should pay close attention to late-planted fields; problems are usually associated with fields planted after June 1.

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% of the plants or when 25% 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. For more information read *Fall Armyworm in Corn* (ENTFACT-110).

Image 10.7. Fall armyworms with distinctive Y shaped mark in the pronotum. Photos by

European Corn Borer

Ostrinia nubilalis (Lepidoptera: Crambidae)

Description and injury: European corn borer is an introduced pest that has spread across much of eastern and central North America. The number of generations of European corn borer ranges from one per year in the extreme north to four per year in the Southeastern U.S. Most of the range within the U.S. has two generations per year; sometimes these co-exist with a strain that has one generation per year. There are two different ECB populations or strains; the E-strain or New York strain and the Z-strain or Iowa strain that respond to different type of lure for trapping moths. The E-strain moths are attracted to corn and other host crops including vegetables, wheat, hemp etc. The Z-strain moths have high preference to corn. This is a pest is of European origin and may have introduced on several occasions.

In Kentucky, this pest is more of an issue in conventional (non-GMO corn) planted for specialty markets such as organic production or distillery industry. European corn borer larva tunnels into 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. There are two generations in Kentucky. The 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 (Figure 10.8). This is the primary cause of yield reduction. Second, borers produce cavities in the plant that weaken it. Stalk breakage an 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 egg laying 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.

When to monitor: Late May to early June for the first generation. Early planted corn has the greatest potential for damage. 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 feed leaves, tassels, leaf axils, or behind leaf sheaths.

Image 10.8. Damages caused by second-generation European corn borer on ears and stalks. Photos: Ric Bessin

Scouting Procedures: Egg clusters (15 to 35 and overlap each other much like fish scales) are creamy white when first laid and develop a dark spot close to hatch. 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 mid-ribs and cause them to break. Larger larvae tunnel into the stalk. Second-generation damage includes feeding on the stalks, tassels, ear shanks, and developing kernels.

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* (ENT-49).

Southwestern Corn Borer

Diatraea grandiosella (Lepidoptera: Crambidae)

Description and Damage: 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 (Figure 10.9). The full-grown larva is $1^{1}/_{4}$ inch in length. For the first two 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

Image 10.9. Larva of south western corn borer. Photo: Ric Bessin

Table 10.4. Comparisons of symptoms of first and second generation of the European corn borer and the south western corn borer corn, eggs, larvae, and occurrences.

Characteristic	ECB	SWCB
1st Generation symptoms	Window pane: feeding to whorl	Window pane: feeding to whorl, dead heart
2nd Generation symptoms	Feeding in leaf axis; stalk boring concentrated in the middle 1/3 of plant, broken tassels	Feeding in leaf axis; stalk boring concentrated in the bottom 2/3 of girdling at base of stalk
Eggs	Laid in clusters of 15 to 35 eggs, without any markings	Eggs laid singly or groups of 2 to 5 each with transverse red bars
Larvae	Creamy with numerous black spots, faint gray stripes running length of body	Creamy-white with numerous black spots
Occurrences	Early June through harvest	Early June through harvest

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 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.

Corn leaf aphids

Rhopalosiphum maidis (Hemiptera: Aphididae)

Description and injury: Winged corn leaf aphids reinfest corn fields every year migrating from the south as this species may not overwinter in Kentucky or northern states. This annual migration occurs in the spring with aphids colonizing weedy plants (johnsongrass, crabgrass and barnyard grass, or small grain cereals). Upon arrival, winged aphids give birth to young aphids instead of eggs and populations can increase rapidly. Its color can vary from blue-green, green to gray and are approximately 1/8 inch long as adult. As many homopterans they have piercing-sucking mouthparts, with a stylet to suck sap from the plant.

Monitoring and scouting: Monitoring and scouting for corn leaf aphid should be conducted at least two times before tasseling. This should be done three weeks prior to tassel emergence and again one week later. Four consecutive plants should be randomly selected in each of five locations per field. Carefully pull the whorl leaves from these plants, unroll the leaves, and estimate the number of aphids. Do not include off-color aphids (those that are diseased or parasitized) in these estimates.

Economic threshold: Growers should consider treating for corn leaf aphids if an average of 15 or more aphids (10 with stressed plants) per whorl are found 3 weeks before tassel emergence or 30 or more aphids (15 with stressed plants) per whorl one week later. Closer to tassel emergence, greater numbers can be tolerated without loss of yield. There are few guidelines for making control decisions for tasseling corn. However, if less than 50 percent of pollination has occurred, aphids and honeydew are covering tassels, and plants are stressed, an insecticide may be necessary to ensure adequate pollination. If tasseled corn is to be treated for corn leaf aphids, treatments need to be made within 48 hours of tassel emergence.

Stink bugs

Description and Injury: In seedling corn, their feeding causes a characteristic oval holes with yellow margins. These holes run perpendicular to the length of the leaf and can be different sizes (Figure 10.10). Around the holes' edges, leaves have a yellowish shade; this is a sign of damage by stink bugs. While plants continue growing, these holes will expand.

Image 10.10. Elongated oval-shaped and transversal holes in (a) seedling corn leaves, and (b) more mature leaves. Photo: Raul Villanueva

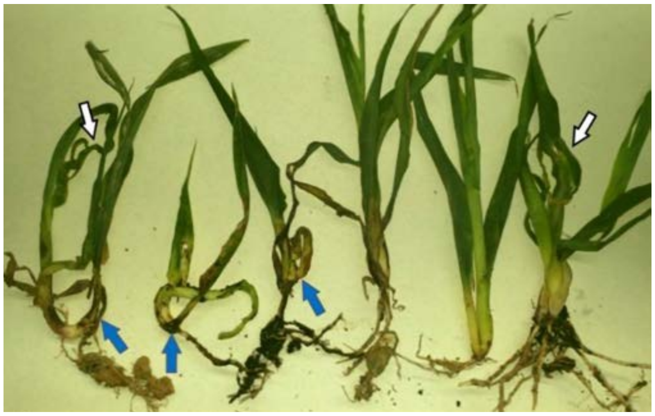


Image 10.11. Seedling corn with suckers (three plants in the right, blue arrows), and irregular growth of plants (white arrow) caused by feeding of stink bugs. Photo: Raul Villanueva

Also, corn plants damaged by stink bugs may produce suckers (tillering) and present irregular growth (Figure 10.11) or be stunted. All the morphological changes described above are caused by the insertion of stink bug piercing and sucking (needlelike) mouthparts into stems, leaves, or apical meristems of corn plants. During this process, stink bugs inject enzymes into plants to aid digestion and fluid removal. Laboratory and field studies conducted at the University of Kentucky by the end of the 1980's showed that the brown stink bug (*Euschistus servus*) and the onespotted stink bug (*E. variolarius*) can reduce plant densities, cause stunted

Table 10-5. Thresholds for stink bugs in corn field (Taken the Stink Bug Management in Corn)

Growth stage	Area to sample	Do not treat	Take more samples	Treat	If entire plant is sampled*
		Number of Stink Bugs			
V1 to V6	Base of plant on stalk below lowest green leaf	≤6	>7 to 12	≥13	1 per 10 plants
V14 to VT	Stalk from 1st leaf above and below primary ear	≤4	>5 to 9	≥10	1 per 8 plants
R1 to R2	Stalk at one leaf above and two leaves below primary ear	≤14	>15 to 27	≥28	1 per 4 plants

* Use the threshold of this column if entire plants are sampled, otherwise use thresholds shown in three previous columns. Note: Do not lower the threshold in response to better corn prices during 2021.

plants with reduced root systems, result in suckers, and cause these plants to yield small or no ears.

Attacks to corn were first reported around the mid-1980s, and their occurrence in corn has been increasing since that time. The brown stink bug is a complex of the *Euschistus* genus. The *Euschistus* complex are endemic to Kentucky and overwinter in non-tilled corn or wheat fields. In 2020, the brown marmorated stink bug (*Halyomorpha halys*) was started to be noticed in western Kentucky expanding from the eastern Kentucky or northern border states, however, little is known about the impact or management of this insect on corn field seedlings. Brown marmorated stink bugs are considered a new key pest on sweet corn (KPN).

When to monitor: This early occurrence of stink bugs in corn coincides with information from previous studies that suggested wheat could be an early spring host for these insects that move to corn fields when corn emerges. The abundances in corn may be related to the presence of stink bugs in soybeans near the harvest time in this field and many areas of central and western Kentucky in 2018. While conducting aphid tallies in research wheat plots, observations of nymphs and adults brown stink bug have been made from early May to June.

Scouting: Scouting for stink bugs in field corn should be conducted from V1 through R2. Emphasis should be done on checking field edges first, near wooded areas, weeds, and soybean fields. The growth stage and area to sample are provided in Table 10.5. The number of sites per field will depend on the number of stink bugs present and field size. At each sampling stop, check at least 10 corn plants.

Image 10.11. Brown stink bug. Photo: Raul Villanueva

Economic threshold: In North Carolina new data collected by Dr. Reisig in NC and VA resulted in lowering the economic threshold for stink bugs in 2020. Although these studies were done in a high-yield environment, Dr. Reisig believes that the thresholds set are very conservative. The information presented here is taken from the *Stink Bug Management in Corn*. Thresholds vary depending on growth stage and are based on a 100 plant-sample as described in Table 10.5. These thresholds are not percentages, but numbers. If a single plant has multiple stink bugs, this must be counted into the total. If the number of stink bugs exceeds the number in the "treat" category, treat the field even if 100 plants have not been sampled. If the number of stink bugs per plant falls between the "treat" and "do not treat" category, take more samples until a confident decision can be made.

Management: Management actions to control stink bugs at earlier stages of corn development have not completely studied. However, many pyrethroids can be effective reducing populations of stink bugs temporarily (one week). In North Carolina bifenthrin was effective controlling brown stink bugs.

Image 10.12. Southern corn rootworm (left) and Western corn rootworm adults (right). Photos: Ric Bessin

Corn Rootworms

Diabrotica spp. (Coleoptera*: Chrysomelidae)*

Description and injury: There are three species in the *Diabrotica* genus that feed on corn and are known as corn rootworms in Kentucky, the southern, western, and northern corn rootworms. Although adults feed on the foliage, the larval stages of these species cause serious injury to corn by feeding on the roots of developing plants. However, these species have some distinct differences in their biology and management. The adult beetles of all these species are approximately ¼-inch in size with a pale green body coloration. The adult southern corn rootworm also known as spotted cucumber beetle has 11 black spots (*D. undecincpunctata*) on the green wing covers and is the most common but only an occasional pest of corn (Figure 10.12). The western corn rootworm (*D. virgifera*) is the primary species attacking corn in Kentucky and has three distinct black stripes on its pale green body. The least common of the species in Kentucky is the northern corn rootworm (*Diabrotica barberi*) which is lacking in any black markings on the wings.

Table 10.6: Corn rootworm rating scale developed by the University of Iowa.

Root rating	Visual Injury to Root System
One	No injury or a few minor feeding scars
Two	Feeding, but no roots eaten off to within 1.5" of plant
Three	Several roots eaten to 1.5" but not an entire node (ring) eaten from the stalk
Four	One node (ring) of roots eaten from the stalk, or equivalent
Five	Two nodes (rings) of roots eaten form the stalk, or equivalent
Six	Three or more nodes (rings) of roots eaten from the stalk, or equivalent

Damage: Larvae feed on corn roots compromising plant support and 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 pollination. Adult rootworm feeding on leaves generally does not affect yield.

Monitoring: Iowa State University has developed as system for evaluating root injury where it has six root rating categories (Table 10.6). Category 1 indicates no damage. Ratings from 4 to 6 indicate that yield loss has occurred, and management efforts need to be implemented. Farmers can evaluate the impact of rootworms by digging and washing corn roots in late season (e.g. in late July).

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 injury 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 (l per plant), the farmer will be advised to use a rootworm insecticide if corn is grown in this field next year.

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Grain Bins in Nelson County, Kentucky. Image by Chad Lee.

Chapter 11

Corn Harvesting, Drying, and Storage

Sam McNeill, Mike Montross, and Tim Stombaugh

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 preserve the quality and market value of the crop. Successful post-harvest management of on-farm facilities requires a thorough understanding of the factors that influence grain quality.

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

The 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 collectively, and the best way to protect this investment is through prudent management throughout harvest and the post-harvest period until the grain is delivered to the buyer. 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 reduced significantly or lost entirely, depending on market conditions.

Preparing for Harvest

Ideal corn varieties have high yield potential, high test weight, strong stalks to avoid lodging problems, a rapid field dry-down rate and a broad range of disease resistance.

Genetics coupled with good crop management strategies can create a crop that is free from insect and mold damage prior to harvest. In reality though, less than ideal conditions require more management skills during and after harvest to create the highest quality product.

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 specialty 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.

Combines should be serviced and adjusted according to the owner's manual prior to harvest to assure reliable performance and minimal mechanical damage to corn kernels during harvest. Grain dryers should also have a routine maintenance check on the sensors and controls, be test-fired and cleaned out prior to the beginning of harvest to avoid equipment downtime and potential fires.

Thoroughly clean out storage bins prior to harvest and spray the vegetation around them with an approved herbicide to reduce 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. After mowing and cleaning, spray an approved residual insecticide inside the bin to the point of runoff for additional protection from insects. The UK Entomology Department publishes updates of approved products for stored corn (https://entomology.ca.uky.edu/files/ent16-field_corn.pdf). Be sure to read product labels carefully for any specific delays prior to filling the bin or other restrictions after application. It may be a good idea to fumigate the space under the bin floor well ahead of harvest to eradicate that area of insect populations. Unlike residual insecticides, fumigants have no carryover effect. Keep in mind that fumigants are highly toxic to humans and animals and therefore are Restricted Use pesticides. In addition to the risk to workers, application and monitoring equipment for fumigation is expensive. It is best to hire experienced, professional applicators when fumigation is needed.

Always, when working in and around grain bins or with chemicals, provide adequate personal protection equipment so workers can avoid potential breathing problems from exposure to dust and mold spores when cleaning bins and equipment.

Harvest Considerations

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. 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 high-capacity 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.

Image 11.1. Corn harvest often includes a combine transferring grain into a cart pulled by a tractor because they cause less soil compaction than semi trucks in the field.

Harvest losses generally increase as the time required to harvest the crop increases. Total harvest loss is a combination of pre-harvest losses and machine losses. Pre-harvest loss is grain that is lost before the crop is harvested, which can be caused by wildlife, high winds, hail, or similar weather event, plant disease(s), insect pressure, or (most likely) from a combination of these factors. Pre-harvest losses are minimized through proper crop pest management, optimum harvest timing, and increasing harvest capacity.

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 act when they reach economic thresholds (>3% of yield).

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

Where Do Combine Losses Occur?

Combine losses can occur in the gathering, threshing and cleaning areas of the machine (at the header, rotor or cylinder, and fan or shoe, respectively). Table 11.1 shows typical losses from each machine area for an average and expert operator. Recent research in Kentucky has confirmed the loss estimates for the expert operator. In that table, ear

Table 11.1. Typical combine losses for operators with different skills.

Type of loss	Combine losses (% of yield)		Combine losses (200 bu/acre corn)	
	Average	Expert	Average	Expert
Header (ear) loss	4	1	8	2
Threshing loss	0.7	0.3	1.4	0.6
Loose kernel loss	1.4	0.5	2.8	1
Total loss	6.1	1.8	12.2	3.6

losses are intact ears that are left on the stalk or dropped from the header after being snapped. Threshing losses are kernels that go through the combine but remain on the cob due to incomplete cylinder/rotary action. Cleaning losses are loose kernels that go out the back of the combine instead of going through the cleaning shoe into the clean grain elevator. Loose kernels on the ground behind the combine can be caused by header losses (shelling at the snapping rolls) or by an overloaded cleaning section in the combine. Differences between average and expert operators are largely due to combine adjustments and operation and can obviously impact profitability (4.3% in this case). Harvest losses are unavoidable but can often be controlled by taking a few minutes to measure them and then adjust machine settings and operation as 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, grain moisture level, time of day, etc.). Mark off a 1/100-acre area of the harvested crop and look through the residue for whole or broken ears that are loose on the ground and those still attached to stalks. See Table 11.2 for the row length needed to measure 1/100-acre for 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). Divide the total weight by 0.75 to determine the yield loss in bushels per acre. For example, if 5 pounds were found the ear loss would be 5/0.75 or 6.7 bushels per acre. The percentage loss is found by dividing the loss by the yield. In the example, a 6.7 bushel loss in corn yielding 200 bushels per acre would be 6.7/200=0.033, which is a 3.3% loss.

Table 11.2. Row length (feet) for 1/100-acre area at different row widths and header sizes.

Row width inches	Number or rows on header				
	4	6	8	12	16
	Row length (feet)				
20	65.3	43.6	32.7	21.8	16.3
30	43.6	29.0	21.8	14.5	10.9
36	36.3	24.2	18.2	12.1	9.1

Image 11.2. Many on-farm systems include driers, wet bins, load-out bins and several storage bins.

If ear losses are high (more than 2% of yield) and many intact ears are found on stalks, pre-harvest loss should be checked to determine if machine adjustments are merited. Measure an adjacent 1/100-acre area of unharvested corn and gather and weigh all ears found on the ground. Figure pre-harvest loss as above by dividing the weight by 0.75 to determine bushels lost per acre, then dividing by yield to determine percentage loss. Subtract pre-harvest loss from the total ear loss to determine the header loss. If header loss exceeds 2%, consider reducing ground speed, adjusting the header height, or snapping rolls to reduce ear losses.

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 11.3 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 the 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

Table 11.3. Dimensions of a 10 square-foot area for different row widths.

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

your losses are higher, combine adjustments are advised. If separation loss exceeds 0.3 bushels per acre, adjust cylinder or rotor speed for better shelling.

If loose kernel loss is above 1% of yield, one final measurement is needed to determine the problem area. Stop the combine near the middle of the row and back it up about 20 feet. Now place the frame over each row in front of the head and count loose kernels to determine header loss. The difference between loose kernels counted behind the combine and those associated with the header can be attributed to the cleaning system (walker, shoe and/or fan settings).

Adjustments to Improve Combine Performance

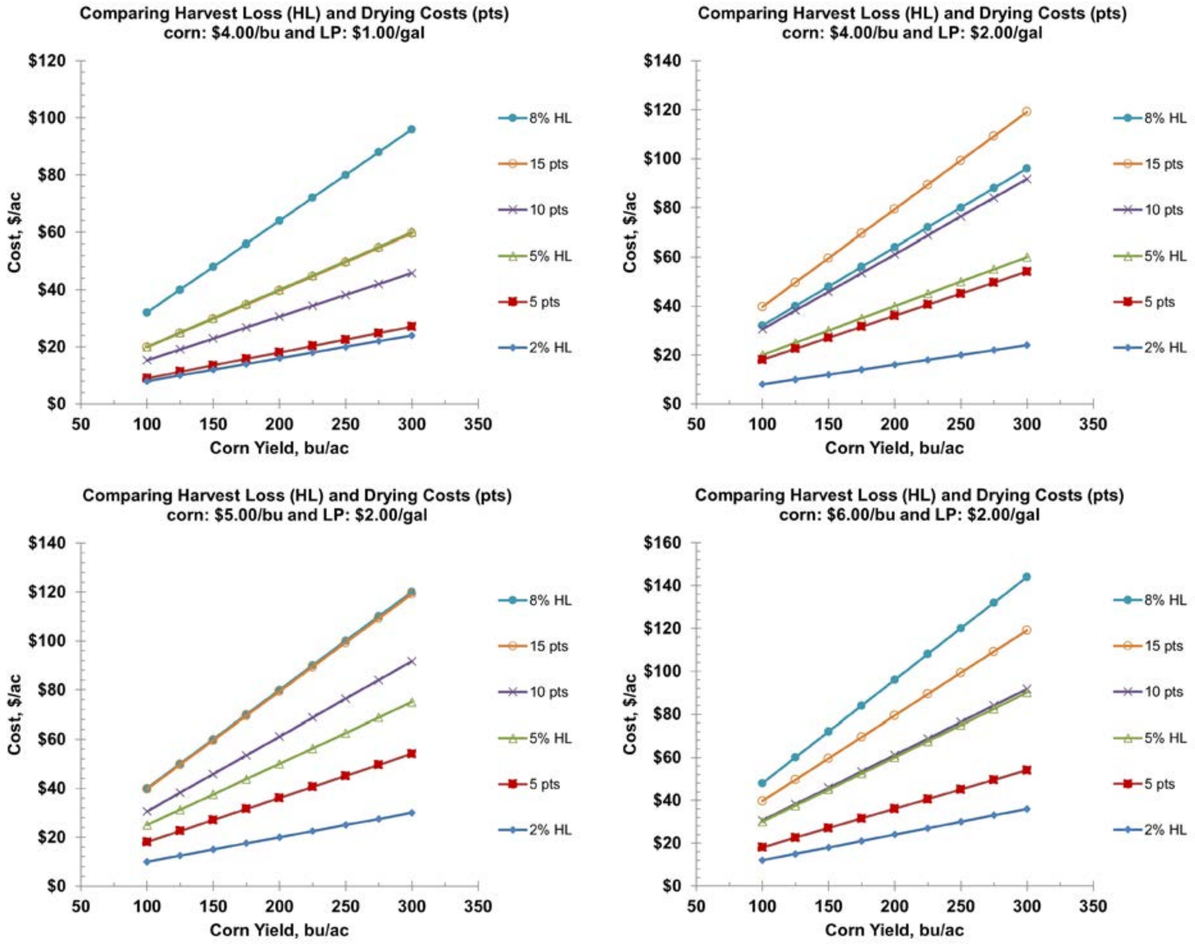
If excessive harvest losses are found, it is important to make the right machine adjustments quickly to minimize economic loss. Some problems require the adjustment of a single component, while others involve several different areas of the combine. It is usually best to make small individual changes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

Maintaining a ground speed of 2.5 to 3 miles per hour requires patience but usually produces good results to control machine losses. Position the header accurately over the rows to feed material smoothly into the gathering chains and snapping rolls. Set stripper planes and snapping rolls according to stalk width and match roll 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 stripper plates. Chain speed should be set to guide stalks into the rolls without uprooting them. Stripper plates should be spaced closer together in the front (about 1 ¼ inch) than at the rear (about 1 ⅜ 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. 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.

Figure 11.1. Harvest Losses v Drying Costs for a range of corn and LP gas prices. Note that the cost of average harvest losses (5%) can be nearly equal to 5 or 15 points of drying, depending on the situation.


Comparing Harvest Loss (HL) and Drying Costs (pts) corn: $4.00/bu and LP: $1.00/gal

Comparing Harvest Loss (HL) and Drying Costs (pts) corn: $4.00/bu and LP: $2.00/gal

Comparing Harvest Loss (HL) and Drying Costs (pts) corn: $5.00/bu and LP: $2.00/gal

Comparing Harvest Loss (HL) and Drying Costs (pts) corn: $6.00/bu and LP: $2.00/gal

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 with older machines 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 Figure 11.1 for various corn and energy prices, potential yield, and harvest loss levels. Even with low corn prices, producers 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 higher production costs.

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 while optimizing drying costs and 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, aerated high-moisture corn can be held safely without a loss in quality varies with grain temperature, as shown in Table 11.4. These times should be reduced by as much as one-half for corn with a high level of broken kernels, fines, trash, and foreign material.

Table 11.4. Allowable holding time for clean, aerated shelled corn at different temperature and moisture levels before a U.S. grade loss occurs.[1]

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

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

Image 11.3. Corn plants with nearly all green color gone should be harvested as soon as possible to reduce harvest losses.

The amount of water in shelled corn at various moisture levels is shown in Table 11.5. No. 2 yellow corn is usually marketed at 15.5% or 15.0% wet basis (% wb), whereas food-grade or distillers' corn is sold at 14.0%. Loads delivered above these levels usually receive a moisture discount, while those delivered below these levels do not. All corn that will be held into the summer should be dried to 13.0% moisture to avoid storage problems and maintain quality, so the storage costs for drying and moisture shrink should 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. This will reduce the chance of spoilage from mold and insect activity during the summer when average monthly temperatures are 80°F in Kentucky.

Table 11.5. Amount of water in shelled corn (test weight of 56 lb/bu) at different base moisture levels.

Base moisture	Corn moisture, % wb								
	13 %	15 %	17 %	19 %	21 %	23 %	25 %	27 %	29 %
% wb	Pounds of water per bushel								
14.0 %	7.07	8.50	9.86	11.30	12.80	14.39	16.05	17.81	19.67
15.0 %	7.11	8.40	9.75	11.17	12.65	14.22	15.87	17.61	19.44
15.5 %	7.20	8.35	9.69	11.10	12.58	14.13	15.77	17.50	19.33

Grain 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 11.6. More information for each drying system is available in other UK 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 warm and humid 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 11.6. 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.

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 per cycle. 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 temporary 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 kernel stress-cracks, 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 1,200 cfm of fan capacity. When cooling hot corn in a bin, the fan should run continuously to remove condensed moisture that can accumulate on the roof and inside wall.

Table 11.6. Comparison of corn drying systems for Kentucky conditions.

Dryer type	Relative drying capacity (bu/day)	Airflow rate (cfm/bu)	Air temp. °F	Harvest moisture limit %wb	Relative initial cost	Grain quality	Disadvantages	Archived 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 & controls	AEN-65
In-bin cooling away from dryer								
High temperature dryer	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

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 harvesting and handling equipment, dryers, and storage bins and the area surrounding them prior to harvest
- Controlling grain moisture throughout the drying step
- Cleaning dried corn prior to storage to remove broken kernels and trash
- Controlling temperature throughout storage
- Coring the bin to manage the depth of grain in the bin to permit uniform airflow
- Monitoring grain during storage for any moisture or temperature changes 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 are at the recommended 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 develop, mold and insect growth can flourish even in cool weather because their activity produces heat, which further accelerates grain deterioration. 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 11.7 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 11.8 and Figure 11.2). Clean corn that is dried to 15 percent moisture, cooled in September to 65°F, and cooled an additional 5°F to 10°F each month during the fall should store well for up to six months. Corn that will be stored up to nine months or 12 months should be dried to 14 percent or 13 percent, respectively. If the grain is in poor condition at harvest due to mold or insect damage or not cleaned prior to storage, reduce moisture levels by 0.5 to 1.0 percentage points to reduce the risk of further spoilage.

Table 11.7. Recommended grain moisture and temperature levels during storage in Kentucky.

Month	Average air temperature	Target moisture content	Target grain temperature
Sep	70° F	14.0%	60° – 70° F
Oct	60° F	15.0%	50° – 60° F
Nov	47° F	15.0%	40° – 50° F
Dec – Feb	36° F	15.0%	35° – 45° F
Mar	46° F	14.0%	35° – 45° F
Apr	55° F	13.0%	40° – 50° F
May	56° F	13.0%	40° – 50° F
Jun	75° F	13.0%	40° – 50° F
Jul-Aug	77° F	13.0%	40° – 50° F

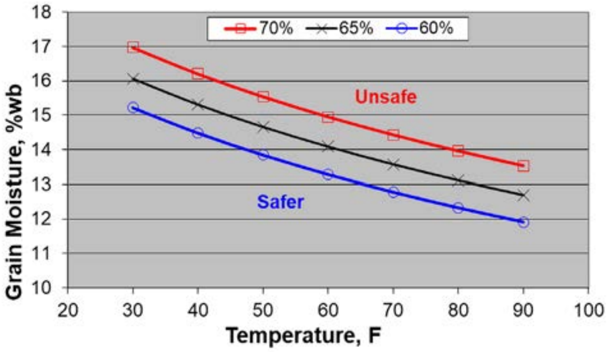


Figure 11.2. Equilibrium moisture content (%wb) for shelled yellow corn at 60%, 65%, and 70% relative humidity for the average monthly temperature range in Kentucky.

Table 11.8. Equilibrium moisture content (% wet basis) for shelled yellow corn.[1]

		Relative humidity (%)									
Temperature		10	20	30	40	50	60	65	70	80	90
°C	°F	Equilibrium moisture content, %wb									
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 D245.6 (average of two prediction equations).

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 (usually occurring in the top center of the bin), which can promote mold growth and insect activity. Aeration equalizes grain temperatures throughout the bin and removes moisture that condenses on the roof. 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 in Table 11.9. 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. With an electricity cost of 10 cents per kilowatt hour, three aeration cycles will only cost about 0.3 cents per bushel for airflow rates up to ¼ cfm/bu and 0.6 cents per bushel for higher airflow rates.

Table 11.9. Approximate operating times for different size fans (by horsepower).

Fan capacity hp/1,000 bu	Hours of fan operation	Operating mode when cooling hot corn[1]	Operating mode when aerating grain[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.

Another good management practice is to take out a few loads of grain soon after filling to remove the cone in the top of the bin. This is commonly referred to as 'coring' 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. This area receives little airflow since air follows the path of least resistance and bypasses the deepest grain. Also, trash and fines tend to accumulate in the center of the bin. Removing the core will remove a lot of undesirable material and reduce the depth in the center so air can move through the center of the bin 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. Coring the bin will also provide adequate room for workers to probe the bin, collect grain samples and check for possible problems during storage. Stored corn should be inspected every one to two weeks in the fall and spring and once every two to four weeks after conditions in the bin have stabilized during the winter. 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 11.10. 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 60°F. If conditions change to 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 11.9 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.

Table 11.10. Cost estimates for personal protection equipment, supplies, and tools needed to collect and inspect corn samples from on-farm bins.

Item	Recommended/ Optional	Cost
Respirator - N95 disposable	Recommended	$ 4 - 8
Respirator - 1/2 or full face mask	Recommended	$ 25 - 300
Respirator - forced air/full face	Optional	$ 300 - 1200
Full body climbing harness	Recommended	$ 100 - 200
Lock out / Tag Out Kit	Recommended	$ 100 - 200
Portable moisture meter	Recommended	$ 200 - 400
Dial thermometer	Recommended	$ 10 - 55
Grain probe/trier	Recommended	$ 80 - 600
Corn sieves	Recommended	$ 70
Insect probe traps	Recommended	$ 20
Temp/RH psychrometer	Recommended	$ 60 - 300
Grain Bin Rescue Tube (cofferdam)	Optional	$ 1200 - 4000
Carbon Dioxide meter	Optional	$ 300 - 800
Oxygen meter	Optional	$ 150 - 400
Temperature readout device	Optional	$ 300 - 500
Temperature cables (per bin)	Optional	$ 200 - 800
Aeration controller	Optional	$ 400 - 4,000

Image 11.4. Many lager grain bins have sensors on cables mounted on the roof to monitor grain temperature and moisture to help ensure the grain is storing properly.

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 the bin could not be unloaded because 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.

For information on sizing drying and aeration fans refer to the free program provided by the University of Minnesota (https://bbefans.cfans.umn.edu).

For more information on planning and layout, handling equipment, drying and storage systems, safety considerations and automation options for grain facilities, see Midwest Plans Service Handbook MWPS-13 (https://www-mwps.sws.iastate.edu/).

Image 11.5. Grain legs must be tall enough to provide proper angles to allow grain to fall into bins by gravity.

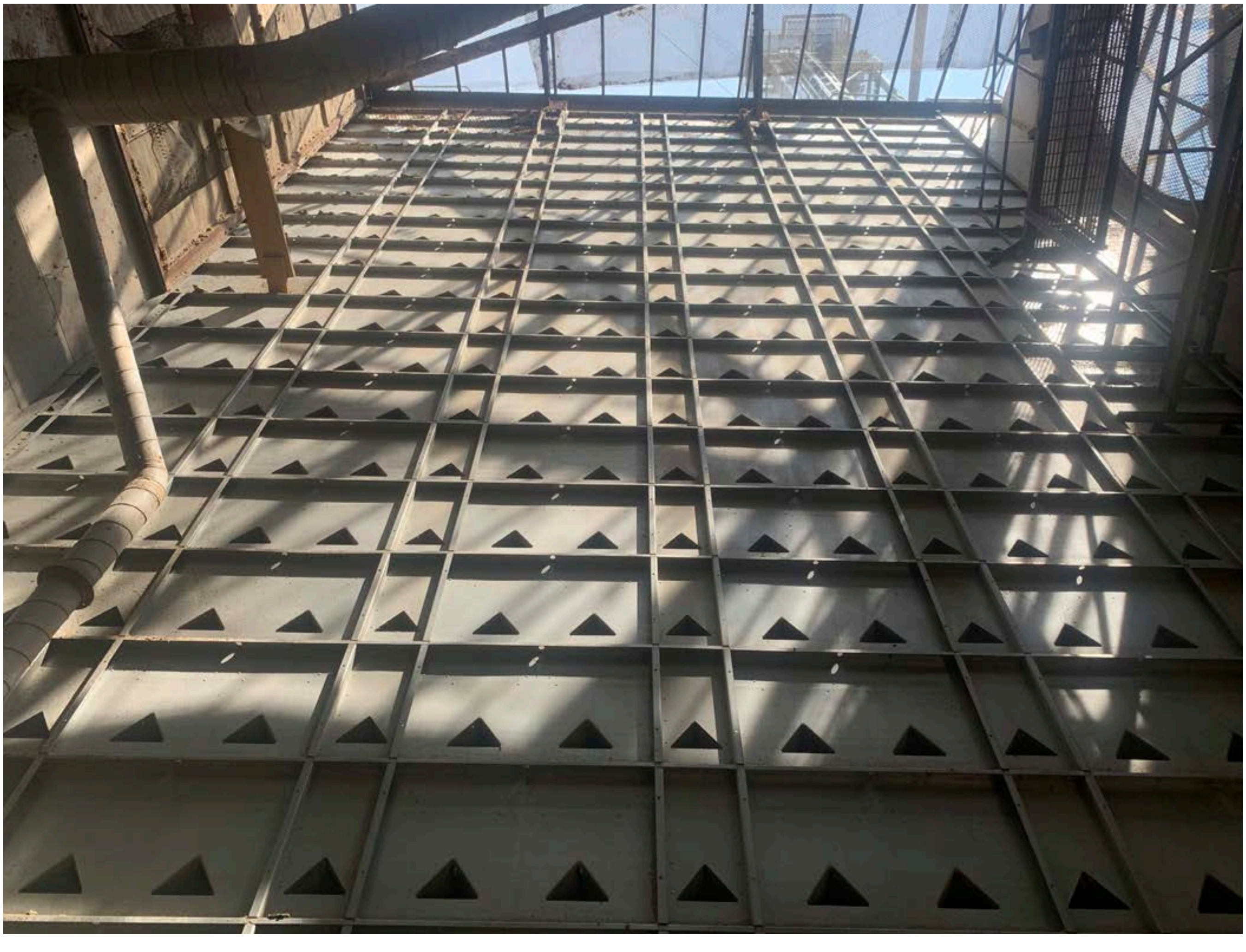


Image 11.6. A cross directional/mixed flow drier is one type of drying system.

Unloading corn into the semi truck. Image by Chad Lee

Chapter 12

Economics of Corn Production in Kentucky

Greg Halich and Jordan Shockley

Estimating the profitability of any commodity, including corn production, begins with understanding the costs and returns. Enterprise budgeting allows a producer to outline projected input costs of production and anticipated returns from corn sales based on a production plan for the upcoming cropping season. Given the projected costs and returns for the upcoming year, an enterprise budget estimates the profitability of the existing production plan. In addition to estimating profitability, enterprise budgeting can determine what commodity price or yield is required to cover the estimated production costs. This technique is referred to as a breakeven analysis. By outlining costs, a producer can determine which inputs are the costliest and manage those accordingly. For example, on rented ground, the largest cost is typically land rent. Enterprise budgeting allows a producer to decide what they can afford to pay for rented ground and still be profitable.

Corn Enterprise Budget

Enterprise budgets for corn are easily accessible online at the University of Kentucky, Department of Agricultural Economics Extension website under Budgets and Decision Tools. The link to the website is below. Corn enterprise budgets are available for both Central and Western Kentucky production areas and reflect no-till or conventional tillage operations. Both are Microsoft Excel-based budgets that outline the costs and revenues on a per acre basis for corn production and are updated annually. These budgets represent a typical operation in Kentucky and should be adjusted to represent a particular farm more accurately. To change the inputs, adjust the highlighted blue cells to accurately depict the user's corn operation and production plan. The information that can be modified includes both costs of production and anticipated revenues. An example of 2020 corn costs and returns is illustrated in Table 12.1.

Corn Enterprise Budgets: https://agecon.ca.uky.edu/budgets

Variable Costs of Production

Variable costs of corn production include operating expenses that typically last one production season. The above UK Enterprise Budgets allow the user to customize the spreadsheet to reflect the variable cost of their operation by changing the quantity of the input or the unit price of the input (items are blue in the budget). The first variable cost in the corn enterprise budget is seed. Seed costs are reflected in the number of bags used to plant one acre and the price for each bag of seed.

Next is the fertilizer cost, specifically nitrogen, phosphorus, and potassium required for corn production. All fertilizer quantities are actual (100%) fertilizer required (regardless of fertilizer source) and unit price for one pound of fertilizer. To help determine the unit price given a particular source, the Fertilizer Price Calculator can be used and is available online https://agecon.ca.uky.edu/budgets. If other fertilizers are applied (e.g., micronutrients), they should be reflected in the budget under the "other fertilizer" category. In addition to fertilizer, lime is also typically applied to fields in Kentucky. Lime is reflected in the enterprise budget as the amount (tons) applied per acre and with a unit cost per ton.

Pest management costs should also be reflected in the budget. Those include any costs for herbicide, insecticide, and fungicides applied during the cropping season to control weeds, insects, or any corn diseases that might occur. The per acre cost of pest management products should be reflected in this portion of the budget. The application cost of either fertilizer or pest control is on the machinery side of the budget.

Machinery costs include fuel, repairs and maintenance, and labor required for corn production. If the user has accurate estimates of their machinery costs, their per acre costs can be entered into the budgets. However, if the user wants the tool to estimate machinery costs, they can do this by entering a "Y" in the machinery section. Field operations include the application of fertilizer and lime, a burn-down herbicide application, nitrogen application, planting, post-emergence herbicide application, and harvesting costs. For conventional tillage corn, burn-down herbicide machinery costs are replaced with tillage costs. The user can customize the machinery portion of the budget by entering the $/gallon for diesel fuel, labor cost ($/hour), and trucking distance to the grain elevator or other delivery point. Once the machinery inputs are entered, the calculations are automatically completed in the budget. If the user deems these costs too high or too low, they can be adjusted in the machinery calculations tab on the spreadsheet by increasing or decreasing the costs by any desired percentage. These estimated costs are based on custom machinery rates, most producers should increase these costs by 10-25% to reflect a higher cost structure. If you rent machinery or if an operation was custom hired, there is a section on the budget below the machinery cost for those items.

Other variable costs included in the corn budget include drying, crop insurance, cash rent, and operating interest. Crop insurance will vary substantially by policy type and contract level and should be reflected appropriately in the budget. Furthermore, cash rent can vary by productivity, accessibility, and competition. Therefore, use the average of all rented land in the budget, or use specific farm rents if evaluating at the farm level.

Fixed Costs of Production

Fixed costs (a.k.a. ownership cost, overhead, indirect cost, or sunk cost) of corn production are sometimes considered "non-cash" costs and are not immediately seen or paid. An example of fixed costs in corn production is machinery depreciation, meaning it is slowly losing value over time. To help determine deprecation of a farm asset, refer to the extension publication below for assistance. Fixed costs do not affect the decision-making in the short-term (within a season); however, in the long-term, all costs are variable (e.g., machinery can be sold). Fixed costs are sometimes difficult to estimate across various crops, for instance, the same tractor may be used for corn and soybean production. Therefore, like the variable cost of machinery, the budget will estimate the fixed cost for the user for operator labor, machinery depreciation, and overhead. In addition to fixed machinery costs, taxes, insurance, and other fixed costs are reflected in the budget and can be customized by the user.

Machinery depreciation and overhead are the largest portion of fixed costs in the production of corn. For example, during the 2007-2013 period when we saw record profits for grain production, it was easier for a producer to invest in new equipment, even if it was larger than what they needed for their given operation. To determine the appropriate size of machinery, both farm size and the number of days typical for conducting an operation must be considered. Weather risk in the corn production area for completing an operation should be considered, especially for critical operations like planting. Controlling fixed costs through appropriate machinery sizing is vital for long-term profitability.

Estimating the Economic Depreciation of Farm Assets: https://agecon.ca.uky.edu/ext-publications

Sensitivity Analysis using Enterprise Budgets

Enterprise budgets also determine what yields and prices are required to cover the cost of production. This technique is called a breakeven analysis. At the bottom of the enterprise budgets online, the breakeven yield and breakeven price to cover production costs are calculated. As seen in Table 12.1, the breakeven corn yield to cover variable costs is 149 bushels (at a $3.75/bu corn price). The breakeven corn price required to cover variable costs would be $3.38/bu if 165 bu/ac were produced.

Additional Tools for Corn Management

In addition to enterprise budgets, there are other economic tools available that aid in cost management. One key element discussed above is machinery costs and high depreciation and overhead. There are alternatives to acquiring machinery for Kentucky corn producers that could reduce or eliminate the fixed costs incurred from machinery ownership. Kentucky corn producers can lease or custom hire machinery to complete operations on the farm. Custom hiring activities will avoid the fixed cost of machinery ownership but increase the variable costs of production. Although the cash cost is typically higher than the cost to complete the task yourself, ownership costs are avoided when custom work is hired. Custom hire rates applicable to Kentucky can be found at the link below. These rates are based on reported surveys from surrounding states and adjusted to account for changes in fuel price, machinery costs, and wages from the time of the surveys. Each grain crop operation, including corn, is listed along with the three rates. The average final rate highlighted in blue, and then 15% below the average and 30% above the average is reported. These rates are updated annually and estimate the variable costs for hiring custom work in corn production.

Custom Hire Rates: https://agecon.ca.uky.edu/ext-publications

Land Rental Tools

There are two ways to acquire land for corn production. One way is to own the land, and the other is to lease the land. For Kentucky producers leasing land for corn production, rental rates could be the highest variable cost of production. Also, the productivity of the land and quality will influence what a producer can afford to pay for the rental arrangement. However, various leasing arrangements can be used. The most common for Kentucky producers is a cash rental arrangement. For a guide, an annual cash rent survey is conducted with Kentucky Agricultural and Natural Resource county agents to estimate the land rents for their area. These results are then summarized by regions, eight in total, and reported based on good or fair cropland. See the link below to access the most recent cash rent survey conducted for Kentucky.

Cash Rent Survey: https://agecon.ca.uky.edu/ext-publications

In addition to cash rental arrangements, Kentucky corn producers also use traditional crop share arrangements. However, a hybrid arrangement, or a flexible cash lease (a.k.a. flex lease), is becoming increasingly more popular. Flex leases provide a base rent or a floor that is lower than what the equivalent cash rent would be. The landowner also receives a bonus or revenue percent based on the production and market prices for that season. There are many variations to a flex lease and may not work for every landowner and producer. If considering a flex lease, a decision-aid is available online that is designed to assist the landowner and producer regarding terms of the rental arrangement.

Flexible Cash Lease Decision-Aid: https://agecon.ca.uky.edu/budgets

Grain Transportation

Determining the optimal market for a load of corn is a complex decision. Most producers only consider one key factor when choosing a market (e.g., highest price). Other factors such as distance to market, fuel price, wait time, quality discounts, labor, and truck capacity must all be considered simultaneously to minimize transportation costs and maximize net price per bushel. Most producers, particularly in western Kentucky, have multiple markets to sell their corn. This decision process begins with identifying all markets in the area. A map of Kentucky grain markets is available online, which displays over eighty grain markets across Kentucky and bordering states.

Kentucky Grain Market Map: https://drive.google.com/open?id=1nUoO2dd8NCFtNLAlz4QXZoh_mnQ&usp=sharing

Once the market(s) are identified, the user needs to determine the cost to transport a load of corn, each market's cash price (with basis), and quality discounts. Cash prices and quality discounts are available by contacting each potential market and acquiring the information. Determining the cost of transportation can be more difficult. Two tools are available online, which will aid in determining these costs. One is a document that walks through the expenses of transporting grain and how to calculate both operating costs and fixed costs. The other is a spreadsheet tool that will determine the most profitable market based on all the key factors outlined above. The spreadsheet tool can compare up to six different markets and estimated both transportation costs and net price received for each market. Also, corn discounts for each market are calculated based on moisture content and each market's discount schedule. The grain transportation tool is online at the link below.

Grain Hauling Decision Guide: https://agecon.ca.uky.edu/budgets

Summary and Conclusions

Managing corn profitability begins with understanding the costs and returns to production. Enterprise budgeting is a vital tool to outline the costs and returns for a plan given production plan. Specifying these costs also allows a producer to determine which inputs are the costliest and manage those accordingly. The UK Corn Enterprise Budgets and other decision aids and tools are available online. The budgets and decision aids allow user input on key variables so that users can customize the tool to match their specific conditions. All these tools are designed to help producers manage corn production and enhance profitability.

Image 12.1. Corn field in Simpson County, Kentucky. Image by Chad Lee.

Table 12.1: 2022 enterprise budget for no-till corn, per acre costs and returns in Western Kentucky. The budgets can be edited for each field. The values here are representative at the time this version was created. This budget and others can be found on the University of Kentucky Agricultural Economics Budgets and Decisions Tools page.

No-Till Corn, Per Acre Costs and Returns						
	Quant.	**Unit**	**Price**			**Total**
Gross Returns Per Acre						
Corn	170	bu	$5.15			$875.50
Crop Insurance Payment	1	acre	$0.00			$0.00
Gov't Program Payment	1	acre	$0.00			$0.00
Total Revenue						$875.50
Variable Costs Per Acre						
Seed	0.38	bags	$225.00			$85.50
Nitrogen [1]	170	units	$0.87			$147.90
Phosphorous (P_2O_5)	60	units	$0.55			$33.00
Potassium (K_2O)	55	units	$0.65			$35.75
Other Fertilizer	0	units	$0.00			$0.00
Lime - Delivered and Spread	0.7	ton	$20.00			$14.00
Herbicides	1	acre	$65.00			$65.00
Insecticides (Planting and Foliar)[2]	1	acre	$0.00			$0.00
Fungicides (Foliar)[2]	1	acre	$0.00			$0.00
Fuel and Lube	1	acre	$0.00	**Calculate Machinery Related Costs?**	Y	$23.09
Repairs	1	acre	$0.00			$33.74
Hired Labor	1	acre	$0.00			$0.00
Operator Labor (Variable Only)	1	acre	$0.00			$33.13
Machinery Rental	1	acre	$0.00			$0.00
Custom Work	1	acre	$0.00			$0.00
Drying: LP, Electric, Maint & Labor	1	gallon LP	$2.00	**Pts Remove**	3.0	$21.27
Crop Insurance[3]	1	acre	$20.00			$20.00
Cash Rent[4]	1	acre	$165.00			$165.00
Other Variable Costs	1	acre	$10.00			$10.00
Operating Interest	$619	dollars	6.0%	**# Months**	6	$18.58
Total Variable Costs Per Acre						$705.95
Return Above Variable Costs Per Acre						**$170**
Budgeted Fixed Costs Per Acre						
Operator Labor (Fixed Only)	1	acre	$0.00	See Question Above		$0.00
Machinery Depreciation and Overhead	1	acre	$0.00			$55.37
Taxes and Insurance	1	acre	$5.00			$5.00
Other Fixed Costs	1	acre	$10.00			$5.00
Return Above All Specified Costs						**$104**
Breakeven Yield: Var. Costs at $5.15 /bushel	**137**	**bu per acre to cover variable costs**				
Breakeven Price: Var. Costs at 170 bu/acre	**$4.15**	**per bu to cover variable costs**				
Breakeven Price: All Costs at 170 bu/acre	**$4.54**	**per bu to cover all specified costs**				

University of Kentucky Corn Economic Resources

Corn Enterprise Budget: https://agecon.ca.uky.edu/budgets

Economic Depreciation Publication: https://agecon.ca.uky.edu/ext-publications

Custom Hire Rates: https://agecon.ca.uky.edu/ext-publications

Cash Rent Survey: https://agecon.ca.uky.edu/ext-publications

Flexible Cash Lease Decision Aid: https://agecon.ca.uky.edu/budgets

Grain Hauling Decision Guide: https://agecon.ca.uky.edu/budgets

Kentucky Grain Market Map: https://drive.google.com/open?id=1nUoO2dd8NCFtNLAlz4QXZoh_mnQ&usp=sharing

Chapter 13

Effective Use of Cover Crops in Corn

Erin Haramoto, Hanna Poffenbarger, John Grove, and Dan Quinn

Cover crops offer many benefits, such as reducing soil erosion, adding organic matter to soil, improving water infiltration, and suppressing weeds. Their inclusion in cropping systems, however, can also increase risk and management complexity. For example, corn following cereal rye cover crops may be more susceptible to seedling diseases and may require additional nitrogen (N) fertilizer. In dry springs, cover crops can lower soil moisture, reducing plant available water needed for developing corn seedlings. Conversely, cover crop residue can reduce evaporation, increasing soil moisture and creating conditions favorable for disease in wet springs. Attentive and flexible management can mitigate many of these risks. A recent compilation of multiple studies across the Corn Belt showed that corn yield is maintained or slightly increased following cover crops provided that proper management is used. University of Kentucky research studies show that corn yield can also be maintained with adjustments to N applications and planting equipment. To maximize corn yield, all these studies emphasize the importance of flexibility and adapting cover crop and corn management to suit conditions.

New cover crop users are encouraged to start small with a reasonable plan. Before deciding how to start, consider cover cropping goals and desired benefits. Selecting and ranking these goals will help with deciding which species to plant and desired biomass levels, and how to modify other practices, including cover crop planting and termination date. Some in-season goals include reducing soil erosion, capturing excess nutrients, and suppressing weeds. Some long-term goals include further reducing soil erosion, maintaining or increasing soil organic matter, and improving soil structure. Reducing erosion is often a top priority on Kentucky's sloping fields that are susceptible to soil loss. Balancing this with other goals and with high corn performance is the challenge addressed in this chapter.

Information on cover crops can be found through the Southern Cover Crops Council (southerncovercrops.org), the Midwest Cover Crops Council (mccc.msu.edu), or by contacting your local extension agent. Consult AGR-18: Grain, Forage, and Cover Crop Guide for Kentucky and AGR-240: Cover Crop Benefits and Challenges for additional information.

While cover crops can provide multiple benefits, many of these benefits may take multiple seasons to accrue. Soil organic matter, for example, increases at a very slow rate. On the other hand, poorly adjusted planters that result in

Corn emerging in cereal rye residue. Image by Hanna Poffenbarger.

corn establishment problems are immediately apparent. It is important to have a "long view" on cover crops while also paying close attention to problems and immediately working to resolve them.

General Considerations

Planting Cover Crops

Two important considerations include the planting method and the available window for cover crop planting. As outlined below in the section titled "Cover Crop Options Before Corn," some cover crop species must be planted relatively early, often before typical corn and soybean harvest dates. Such species may be good options following early harvested soybean. Drilling seed into the soil works best when establishing cover crops during dry fall weather, but drilling can only occur after crop harvest. Interseeding into a standing cash crop can be effective in some situations but requires specialized equipment and potential modifications to your herbicide plan. Moreover, University of Kentucky research has yet to identify species that consistently will work in interseeded systems. Broadcasting seed onto the soil surface may be the most feasible planting method in most systems but can result in poor establishment in dry soil conditions and requires higher seeding rates.

Weed management prior to cover crop planting is generally not necessary, particularly when a competitive cover crop such as a winter annual small grain is planted with a grain drill. In fact, fall-planted small grain cover crops can be effective in suppressing weeds. For example, a cereal rye cover crop will suppress marestail (horseweed) that emerges either in the fall or early spring. Depending on planting conditions, chemical or mechanical weed management may be necessary prior to sowing pure stands of small-seeded cover crops such as crimson clover. This will help ensure good cover crop establishment and early growth in the absence of weed competition.

Because small grain cover crops can tiller, higher seeding rates do not typically produce more spring cover crop biomass. Higher seeding rates can provide earlier ground cover in the fall that will suppress weed germination and growth. Small grain cover crops may benefit from a small amount of N fertilizer (around 30 lb N/acre) after establishment, particularly following high-yielding summer cereal crops such as corn. In these conditions, soil stocks of inorganic N and easily mineralizable organic N are likely depleted. The added fertilizer N can improve the winter cereal cover crop's competitive ability against weeds and increase spring biomass.

Cover Crop Termination

The desired goals for using a cover crop and the agronomic considerations can help inform when to terminate a cover crop. Regardless of the termination time and method used, complete cover crop termination is crucial to preventing the cover crop from interfering with the subsequent corn crop. Earlier termination relative to corn planting can be advantageous for many reasons but can limit some of the resulting cover crop benefits.

Image 13.1. Corn planted into recently terminated wheat. Photo by Dan Quinn.

Corn is a warm season crop, and cool and wet conditions during the seedling stage can add stress to developing plants and make them more susceptible to disease. Heavy cover crop mulches can exacerbate these cool and wet conditions, increasing disease incidence. Terminating cover crops at least three to four weeks prior to corn planting reduces cover crop biomass/residue and provides a longer window for residue decomposition. This termination timing can effectively reduce residue interference with the planting process and result in more uniform corn stands.

However, when early termination limits cover crop biomass production, it also reduces the amount of residue that provides weed suppression early in the corn season, protects soil from erosion, and reduces evaporative soil moisture loss. Further, legume cover crops accumulate most of their biomass and biologically fixed N in the spring months (April and May), so early termination also limits their N contribution to subsequent corn. See the section titled "Fertility Adjustments" for more information on anticipated nitrogen contribution from legumes.

A special cover crop termination case is the "planting green" method. With this method, corn is planted directly into a standing, living cover crop which is then terminated after corn planting. This is most common with a cereal cover crop, typically wheat or cereal rye (Figure 13.1). Planting green can result in some benefits. Delayed termination provides a thicker mulch layer that is more weed suppressive. In wet springs, the living cover crop can draw moisture from the soil, improving planting conditions. Planting may also be easier into a standing small grain compared to planting through a residue mulch. However, this method is more challenging and riskier, and is only recommended for experienced cover crop practitioners. Cover crop lodging can complicate and slow down corn planting. Adequate cover crop termination after planting is crucial to avoid early season competition with corn. Across six site-years in Kentucky, terminating a cereal rye cover crop one day after corn planting resulted in approximately 15% lower corn yield than terminating a cereal rye cover crop three weeks before planting or leaving the land fallow for the winter. The yield loss was largely due to reduced corn stand with the planting green approach. If an ideal corn stand is achieved, then the late termination of the cover crop can result in excellent corn yields. However, the challenge is getting this practice to work well.

Cover crops are typically terminated by herbicides, tillage, or roller-crimping. Herbicide selection depends on the species planted—growth regulator herbicides such as dicamba or 2,4-D, for example, may be necessary to kill some legumes but will not effectively kill small grain cover crops. Some cover crop species can be harder to kill with herbicides as they develop in late-flowering stages. If tillage is used, multiple passes likely will be necessary to terminate and completely break down cover crop plants, including the roots. Be sure that any tillage equipment is adequate for the biomass produced, and carefully consider all the belowground biomass, too. Mowing prior to tillage can break up cover crop plants and help reduce the number of tillage passes needed. Roller-crimping can be used to terminate cover crops, but the roller-crimper must be operated when plants are fully flowering or regrowth can be expected. Because of this, herbicides are often applied in conjunction with roller-crimpers to ensure adequate termination. Depending on the equipment setup, roller-crimping may result in an additional pass through the field, but can result in an even, unidirectional residue laydown that facilitates planting.

Cover Crop Options Before Corn

Choosing a cover crop species requires careful consideration of the desired goals as well as how the cover crop will fit within the overall production system. An outline of some benefits of common cover crop types is below, along with some potential negative aspects to consider. This information is also summarized in Table 13.1 for some specific cover crops. Subsequent sections give details on fertility and other adjustments. Seeding rates and planting dates vary widely depending on the species and goals selected, so consult resources including AGR-18 or fact sheets from the Southern Cover Crops Council for up-to-date information. Lastly, be sure to verify specific seeding rate, planting date, and termination requirements with any local, state, or federal cost-share programs.

Legumes (Includes Clovers, Vetches, Peas)

Benefits:

- Legumes fix N in their root nodules and may increase available N in the soil after termination. See the "Fertility Adjustments" section below for more details.
- When mixed with small grains, legumes can increase biomass production relative to small grain monocultures, especially when planted relatively early and with a high seeding rate.
- Because legumes are in a different plant family than corn

Image 13.2. Cereal rye (left), crimson clover (middle), and a cereal rye/crimson clover mixture (right) on November 27, 2020. The cover crops was planted September 18, 2020. Photos by Hanna Poffenbarger.

(a grass), they provide rotational benefits relative to winter annual small grain or grass covers.

Negatives:

- Legumes require an earlier planting date for the best success. Crimson clover (Figure 13.2) can be sown later than other legumes (including hairy vetch or winter pea) but should still be planted in early to mid-October (in Eastern/Central Kentucky and Western Kentucky, respectively).
- Most biomass and N content are accumulated in late spring, so late termination and corn planting are needed for maximum N benefit.
- Seed is more expensive relative to other cover crop options, and some legumes have hard seed that will not germinate in the year it is planted.

Small Grains (Includes Oat, Barley, Wheat, Cereal Rye, Triticale)

Benefits:

- Small grains can be planted later than legumes and still establish and survive the winter. Cereal rye (Figure 13.2) and triticale are the most winter-hardy and can continue to grow at lower temperatures than wheat. Winter oat is the least winter-hardy and regularly winter-kills in Central Kentucky.
- Small grains produce the most biomass and ground cover—good for slowing soil erosion and suppressing weeds.
- They are deeply rooted and can capture and recycle residual soil nitrate.

Negatives:

- Small grains can grow rapidly in the spring and accumulate a lot of biomass if not terminated early. This is less of a concern for wheat than for cereal rye.
- Small grain residues decompose slowly, with slower N release and, in some cases, N immobilization. This is exacerbated by late termination when the carbon to nitrogen ratio (C:N; the amount of C relative to the amount of N) is higher.
- Large amounts of residue can make planting more difficult and increase potential for disease infection in subsequent corn.

Brassicas (Includes Radishes, Canola/Rapeseed, Turnips)

Benefits:

- An additional plant family that increases rotational diversity in continuous corn and corn/soybean production.
- Deep taproots can effectively capture and recycle residual soil nitrate and possibly loosen mildly compacted soil (winter-killed brassicas release most of their captured N prior to corn planting).
- Some will winter-kill (including radishes), so spring termination is not always necessary.
- Some larger-seeded species (including radishes) are good for fall weed suppression, while other smaller-seeded species (including canola/rapeseed) are less competitive after establishment.

Negatives:

- Brassicas require early planting, even earlier than legumes.
- Over-wintering brassicas can be hard to chemically terminate, especially once flowering commences.
- Chemical termination is recommended before plants reach 12" tall, limiting benefits received from residue.

Mixtures

Cover crop mixtures have generated considerable interest in recent years. There is some evidence that mixtures can provide some benefits of all component species, particularly from simple two-species mixtures (Figure 13.2). For example, crimson clover can contribute N to cereal rye, resulting in greater biomass relative to cereal rye alone. The cereal rye acts as a nurse crop and suppresses weeds for the clover. Cereal rye alone may immobilize N as it decomposes but adding crimson clover can help to overcome the N tie-up by the rye. Other legumes that have been successfully grown with cereal rye include both hairy and big flower vetch. Another common mixture includes winter oats and radishes, with oats again serving as a nurse crop. Both species are expected to winter-kill in most regions of Kentucky, so spring termination is not necessary.

The small grain component can dominate mixtures, especially cereal rye because it is competitive. The competitive potential of legume and brassica components can be improved by increasing their seeding rates and planting earlier. If more legume or brassica biomass is desired, wheat can be used instead of cereal rye in mixtures as wheat is less competitive. Trials from around Kentucky highlight the importance of these factors. In more than four site-years of research trials with crimson clover (20 lb/acre seeding rate) and cereal rye (45 lb/acre seeding rate) mixtures in Kentucky, when the cover crops were planted in mid-October and terminated in mid-April, crimson clover made up 10% to 35% of the cover crop mixture biomass. Two years of experiments in Lexington used a 30-lb/acre seeding rate for crimson clover and higher small grain seeding rates and were terminated in mid-April. Crimson clover represented a wide range (2-45%) of total mixture biomass. Site-years with late planting dates, cereal rye, and cold winter weather had lower percentages of crimson clover in the biomass; treatments with early planting, wheat, and mild winter weather had proportionally more crimson clover.

Careful planning is necessary for mixture termination as herbicide selection may be more complex than for single species cover crops. Very few single herbicides will effectively kill small grains, legumes, and brassicas, so tank mixes of glyphosate plus dicamba may be necessary. Growth stage of the different species will vary at any given time. Mixtures can be terminated early so no components are flowering (and harder to kill chemically), but this decreases benefits received from the residue. If a roller crimper is used, species may not reach the desired growth stage for crimping at the same time.

Necessary Adjustments

Equipment Adjustments

Corn is responsive to an optimal plant population and is less forgiving than soybean of missing plants and gaps in the stand. Without proper equipment adjustment, a higher corn seeding rate may be needed to overcome stand loss and maximize yield following a later terminated cereal rye cover crop. One of the most common forms of cereal rye residue interference is "hair pinning," when residue is folded into the furrow by the coulter/disc opener, underlying some of the corn seed and reducing seed to soil contact. Planter adjustment to plant through residue and achieve good seed to soil contact is critical. Depending on the type of residue and residue orientation, residue slicers and/or row cleaners should be considered. In all these cases, cutting blades should be sharp. When planting into heavy residue, expect that a cover crop will interfere with a planter at some point in the planting process. Paying close attention to planting is critical anytime for corn planting, but especially so when planting into cover crops.

Fertility Adjustments

The C:N ratio (the amount of C relative to the amount of N) of cover crop residue plays a large role in determining whether that residue will release/mineralize or tie up/immobilize N and over what timeframe. Residues with relatively more N (lower C:N ratios) include legumes and small grains killed before they enter reproductive growth stages (heading). These may decompose relatively quickly and release N that will then be available to corn. However, if these cover crops are terminated too far in advance of corn planting, that N may be released without benefit to corn, be taken up by weeds, and/or lost to the environment. Residues with relatively high C:N ratios (more C relative to N), including late-terminated small grains and brassicas, will decompose slower and immobilize N from soil or fertilizer sources. Weather conditions also play a large role in how cover crop residues affect N availability in the soil. Cool or dry conditions will also slow the release of N from cover crop residues. Warm, moist conditions increase decomposition rates.

Corn following late-terminated cereal rye (particularly after it has headed out) generally needs additional N. The N deficit caused by cereal rye is estimated to be about 10-20 lb N/acre in Kentucky. Research in Kentucky has shown that split N fertilizer application involving 30-50 lb N/acre at-planting, with the rest after V4, helps to reduce the negative effect of a cereal rye cover crop on N supply to corn, relative to a single pre-plant N application. Some N credits can result from legume cover crops, particularly if they are terminated late enough to accumulate sufficient biomass. As noted above, adding crimson clover to cereal rye can help to alleviate the N deficit from cereal rye, and provide modest amounts of newly fixed nitrogen (5-20 lb N/acre) to the cropping system that may be available in current and future years.

Legume cover crops can also provide rotational benefits in continuous corn production fields and are preferred over small grain cover crops in this situation. Unless legumes are allowed to grow well into mid-May in Central Kentucky, they are unlikely to provide a *substantial* N benefit to the subsequent corn. A late-terminated, high-biomass legume cover crop may release 30-80 lb N/acre during the following corn growing season, though excessively delayed corn planting may cause yield reductions. Refer to Chapter 7 for details about the pre-sidedress nitrogen test (PSNT), which may provide information about actual credit received from your legume cover crop and additional N needs for corn.

Weed Management Adjustments

Cover crops can outcompete winter weeds, potentially eliminating the need for fall herbicides or tillage used to control fall-emerged marestail. Small grain cover crops are generally the most competitive and effective in reducing the density and size of weeds, including marestail and dandelion, that persist through the winter and spring periods. Lower weed growth rates are a result of competition by the cover crop plants for light, water, and nutrients—this competition results in smaller weeds and improved control when burndown herbicides are applied. Research at the University of Kentucky and many other locations shows that winter weed biomass decreases as the amount of cover crop biomass increases. Observations also show adequate control of these winter weeds by burndown herbicides applied to terminate cover crops.

Cover crop residue mulches can also contribute to reducing weed density around the time of corn planting. ***These residue mulches rarely (if ever) result in adequate weed control without herbicide use and should be viewed as an important part of an integrated weed management program.*** Mulches are generally more effective in suppressing emergence of small-seeded broadleaf weeds like smooth pigweed, waterhemp, Palmer amaranth, and common lambsquarters. Seeds of these species require light for germination and mulches decrease light penetration to the soil surface; mulch layers also offer a formidable physical impediment to these small seedlings. Mulches are generally

Image 13.3. Corn following cereal rye terminated three weeks prior to planting, Lexington, KY, June 2019. No soil residual herbicides were applied, and weeds can be seen emerging through the residue. Photo by Erin Haramoto.

Image 13.4. Incidence of root rot on V2 corn planted following a cereal rye cover crop. Princeton, KY, 2020. Photo by Dan Quinn.

less effective in preventing emergence of large-seeded species (including giant ragweed and morningglories), annual grasses (crabgrasses and foxtails), and perennials emerging from vegetative structures. These species tend to have fewer light requirements for germination and are better able to emerge through mulch layers. Weeds that do successfully emerge through residues still face challenges—increased moisture near the soil surface can create more potential for seedling-borne disease and decomposing small grain residues can immobilize N needed for weed growth.

The cover crop mulch layer must 4 inches or more, generally resulting from 8,000 to 10,000 lb cover crop biomass/acre, and evenly distributed to result in acceptable early season weed suppression. Good early-season suppression will diminish as the mulch layer degrades and, without additional control measures, weeds will emerge. *The presence of a cover crop itself rarely results in fewer herbicide applications*. However, there are generally fewer and smaller weeds in corn systems with cover crop mulches, resulting in improved efficacy of herbicide applications and slower evolution of herbicide resistant populations. Soil residual herbicides that prevent weed emergence can be used in conjunction with cover crops and will provide additional protection against weeds in areas with thin mulch layers and in years with low cover crop biomass. The timing of these applications will depend on the amount of residue present, as well as residue uniformity (Figure 13.3). Application close to planting is recommended if little suppression is expected from the cover crop residue, or later in the season if the residue is expected to provide early-season weed suppression. Continued scouting, combined with timely post-emergence herbicide applications, are also necessary for good weed control. See the weed management chapter for more information on how crop and cover crop residues affect penetration of these herbicides into the soil.

Disease and Insect Management Adjustments

Cover crops can serve as a "green bridge" to corn—hosting diseases and insects that can be detrimental to corn plants (Figure 13.4). Lengthening the time between cover crop termination and corn planting is effective in reducing problems associated with this green bridge. Considering the balance between benefits resulting from earlier and later cover crop termination in relation to cover cropping goals is important, but also requires a plan for potential disease, insect, and slug issues. *A minimum of three weeks between cover crop termination and corn planting is recommended to reduce potential damage from diseases, insects, and slugs.*

When planting corn soon after cover crop termination, there is good evidence that cereal rye cover crops increase corn seedling disease. In the northern Great Plains, seedling disease incidence was lower following a camelina cover crop relative to cereal rye, but incidence following camelina was still higher than following no cover crop. Camelina is a brassica cover crop being investigated across the northern Great Plains. Fungicide seed treatments may be effective in mitigating some damage but are rarely effective against all the disease organisms that may be present in a field. University of Kentucky research has shown no additional benefit to in-furrow pyraclostrobin fungicide to corn stand or yield following a cereal rye cover crop in conditions of low disease pressure. Studies in conditions with high disease pressure are needed to clarify the role of these in-furrow applications. In addition to terminating cover crops at least three weeks prior to planting, disease pressure can be reduced by not planting into soils that are too wet and cold.

Cutworms, wireworms, and other insect larvae can move from small grain cover crops and begin feeding on corn seedlings. Insecticide seed treatments may manage some of this feeding damage, but reduced corn stands can result in some years. Prophylactic insecticide applications at cover crop termination are not recommended, as problems with these insects can be sporadic. These applications can also reduce populations of beneficial insects.

Slugs can also be more problematic in systems with cover crop residue (Figure 13.5). Slug feeding on corn seedlings is worse when cool, wet weather occurs soon after corn emergence. Insecticide treatments are not effective against slugs, which are mollusks. In fact, insecticide seed treatments may kill beneficial beetles that feed on slugs and worsen the problem. University of Kentucky has ongoing research on the relationship between cover crops and slugs, and best management practices.

Image 13.5. Slug damage on a corn seedling planted into cereal rye residue. Lexington, KY, June 2019. Photo by Dan Quinn.

Summary

Cover crops provide multiple benefits and can be a major component of a soil conservation program, particularly with the sloping terrain of much of Kentucky's row crop acreage. Their potential to reduce erosion is particularly key when crop residues, especially full-season soybean residues, are insufficient. Some benefits, such as cover crop contributions to soil organic matter, nitrate-N recovery, nutrient cycling, and general soil health accrue over a long period of time. Other benefits, such as marestail management, may be visible immediately. Cover crops can be successfully integrated into corn production systems in Kentucky, both before and after the corn growing season. This integration will be more successful with careful planning and management practice adjustments. Interested growers are urged to start small, with simpler cover crop plans, noting what does and does not work in their fields. Consult resources and rely heavily on the advice of more experienced, nearby, cover crop users. University of Kentucky research and Extension faculty and county agents are always available to assist.

Resources

AGR-1: 2020-2021 Lime and Fertilizer Recommendations
AGR-18: Grain, Forage, and Cover Crop Guide for Kentucky
AGR-240: Cover Crop Benefits and Challenges in Kentucky
Southern Cover Crops Council (southerncovercrops.org)
Midwest Cover Crops Council (midwestcovercrops.org)

Table 13.1. Advantages and disadvantages of select cover crops used prior to corn. (Additional details can be found in AGR-240 and AGR-18; AGR-18 includes recommended planting date ranges and seeding rates. All cover crop plantings should use seed that is free of contaminants and weed seed.)

Cover Crop	Family	Advantages	Disadvantages
Cereal rye *(Secale cereale)*	Grass	• Ground cover and fibrous roots lead to excellent soil erosion management • Excellent weed suppression while growing and after termination • Winter hardy, and can be planted later than many other species	• Residue can increase soil moisture in wet springs; actively growing plants can reduce soil moisture in dry springs • Rapid spring growth can lead to large increases in biomass over short periods • Heavy residue can be difficult to plant through • Additional N at planting is recommended • Can harbor diseases and maybe other pests
Winter Wheat *(Triticum aestivum)*	Grass	• Many attributes of cereal rye, but less biomass produced and easier to manage, especially in the spring • Excellent soil erosion control, generally somewhat less than cereal rye • Good weed suppression while growing and after termination	• Not as much residue produced as cereal rye • Not as strong on weed suppression as rye • Use not advised with grain wheat in the rotation
Crimson clover *(Trifoloium incarnatum)*	Legume	• Will fix and contribute some N to subsequent cash crop • Different plant family from corn and may add rotational benefits	• Requires relatively early planting date • N contribution and biomass are limited with early termination • Higher seed cost • Minimal soil erosion protection in fall and winter • Minimal weed suppression while establishing
Hairy vetch *(Vicia villosa)*	Legume	• Will fix and contribute some N to subsequent corn • Different plant family from corn, adds rotational benefit • Potential for more biomass than crimson clover, especially with later termination	• Requires earlier planting date than crimson clover • N contribution and biomass are limited with early termination • Higher seed cost • Minimal soil erosion protection in fall and winter • Minimal weed suppression while establishing • Vining growth form may cause planting difficulties • Not recommended in systems producing grain wheat
Radishes *(Raphanus sativus)*	Brassica	• Additional plant family adds rotational benefit • With early planting, can produce lots of fall biomass and ground cover • Extensive roots can take up soil N remaining after corn harvest • Good erosion control and weed suppression in fall • Typically winter kills; spring termination not necessary	• Requires early planting date (earlier than legumes) • N taken up in the fall can be lost as biomass decomposes after winter-kill (depending on the release timing, N may be available to other species if used in a mixture) • Biomass decomposes rapidly after winter-kill, so weed suppression is limited • Higher seed cost (though low seeding rates used)
Canola/ Rapeseed *(Brassica napus)*	Brassica	• Additional plant family adds rotational benefit • With early planting, can produce lots of fall biomass and ground cover • Extensive roots can take up soil N remaining after corn harvest	• Requires early planting date (earlier than legumes) • Higher seed cost (though low seeding rates used) • Chemical termination is more challenging, and special attention to herbicide selection is required • Termination is especially difficult after plants start to reproduce
Simple small grain + legume mixtures (crimson clover plus either winter wheat or cereal rye)	Grass + legume	• Crimson clover addition can reduce or eliminate the need for extra N normally necessary with cereal rye alone • Mixture biomass may exceed that of small grain alone • Small grain serves as a nurse crop and improves crimson clover establishment • Wheat is less likely to outcompete crimson clover than cereal rye	• Multiple herbicides needed for effective termination • Growth stages are hard to match for optimal termination with non-chemical methods • Small grain can outcompete the crimson clover in some winters, reducing or eliminating the benefits of the mix

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