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Kentucky Wheat Guide

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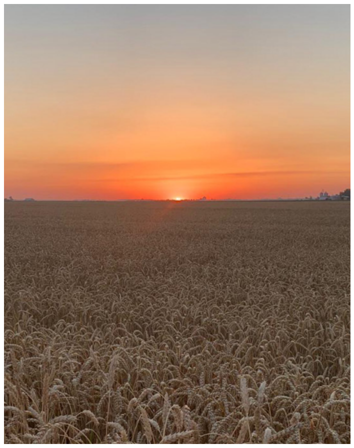

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Cover: *Wheat at sunset near Schochoh, Kentucky. Photo taken by Dr. David Van Sanford.*

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Photo 1-1. Soft red winter wheat (*Triticum aestivum* L.) grown in Kentucky is a valuable commodity and an important component to crop rotations. It also provides flour for cookies, cakes, pastries, and crackers and feed for livestock.

Chapter 1

Introduction

Chad Lee, Carrie Knott, and David Van Sanford

The soft red winter wheat (*Triticum aestivum* L.) grown in Kentucky provides flour for cookies, cakes, pastries, and crackers and is the fourth most valuable cash crop in the state. Winter wheat has been an integral part of crop rotation for Kentucky farmers. Wheat is normally harvested in June in Kentucky and provides an important source of cash flow during the summer months. Improvements in varieties and adoption of intensive wheat management practices have resulted in dramatically increased wheat yields. Prior to 1987, the highest average yield achieved in Kentucky was 42 bushels per acre; since 1987, averages have been at least 49 bushels per acre in all but two years (Figure 1-1). State average yields have averaged 76 bushels per acre since 2014, with the lowest of 76 and the highest of 87 bushels per acre (two years). Continued increases in yield help to keep wheat in the crop rotation.

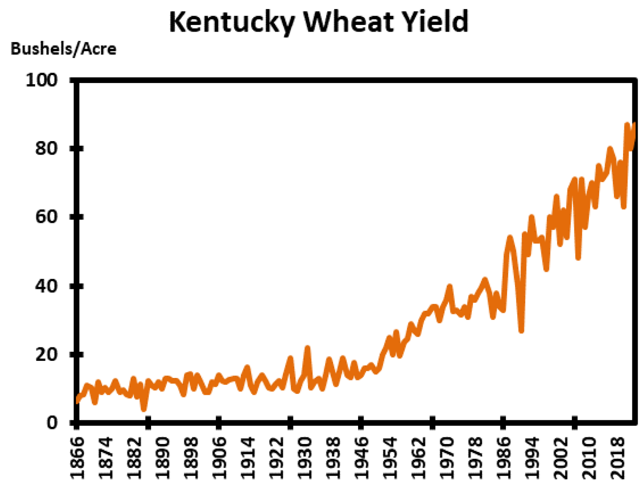

Figure 1-1. Kentucky average wheat yields each year according to the USDA National Agricultural Statistics Service.

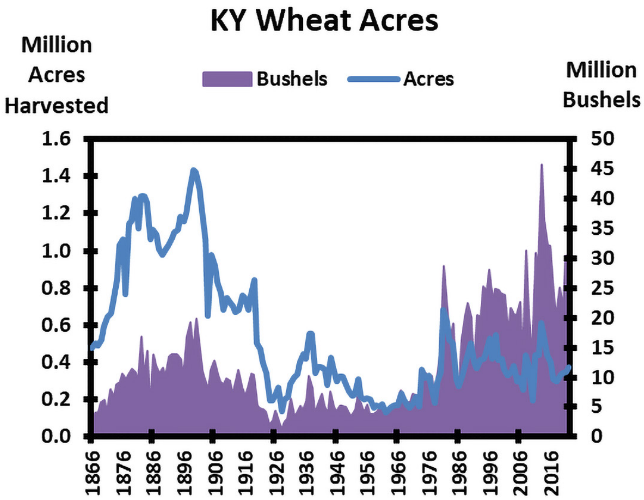

Figure 1-2. Kentucky wheat acres harvested, and total bushels produced each year according to the USDA National Agricultural Statistics Service.

The average yield of wheat trend has been upward, but the number of acres of wheat planted in the state has declined. Kentucky wheat acres reached a peak of just about 1.43 million in 1899 and since 2014 have averaged just under 400,000 (Figure 1-2). Fluctuation in wheat acres harvested is a function of wheat prices, fall corn harvest weather, government programs, and logistics. This publication will help you use wheat management practices to improve the competitiveness of wheat in your crop rotation. There is no single best wheat management prescription for all circumstances, but this comprehensive publication explains the principles of wheat growth and management so you can make decisions appropriate to your situation. This publication will also help troubleshoot problems encountered during the growing season. If you use and adopt the following principles and practices, you should see increased yields, higher profits, and improved environmental protection from your wheat fields.

Intensive wheat management can be summarized in 18 important steps. The application of these steps at the proper stage of growth and time of year is the basis for obtaining maximum and efficient wheat yields. See *ID-125 A: Kentucky Winter Wheat Calendar* for more information.

References

Simão, L.M., Cruppe, G., Michaud, J.P., Schillinger, W.F., Diaz, D.R., Dille, A.J., Rice, C.W. and Lollato, R.P., 2024. Beyond grain: Agronomic, ecological, and economic benefits of diversifying crop rotations with wheat. *Advances in Agronomy, 186*, p.51.

Table 1-1. 18 steps for maximum winter wheat yields.

1.	Test soil to determine fertility and pH of field.
2.	Apply P, K, and agricultural lime according to soil test and University of Kentucky recommendations.
3.	Select several high-yielding, disease-resistant, winter-hardy wheat varieties.
4.	Calibrate the drill or other seeding equipment.
5.	For conventional tillage, prepare a good seedbed.
6.	For no-tillage, use a broad spectrum herbicide.
7.	Use 30 lb/A nitrogen in fall as residual or applied.
8.	Plant from October 10 to 30.
9.	Plant in 4- to 8-inch row spacings. Tramlines may be established at this time for subsequent applications.
10.	Seed 35 (up to 40 for no-till) seeds/square foot of high quality, viable seed.
11.	Apply insecticide as needed for insect control (fall and spring).
12.	Check stand density near mid-February when winter survival can be rated.
	a) If stand is adequate (25 plants/square foot or more), apply 30 to 40 lb/A of nitrogen mid to late February.
	b) If stand is thin (less than 25 plants/square foot), apply 40 to 50 lb/A of nitrogen mid to late February
13.	Apply an additional 50 to 60 lb/A nitrogen at Feekes 5 (mid-March).
14.	Use proper weed control measures (fall and spring).
15.	Apply fungicides as needed for disease control during the growing season, paying special attention to Fusarium Head Blight risk.
16.	Harvest on time and store at optimum grain moisture (13 to 15%).
17.	Provide and prepare adequate, safe storage space.
18.	Market wisely for optimum profits.

Chapter 2

Growth and Development

Chad Lee, Carrie Knott, and Bill Bruening

Wheat responds best to inputs at specific stages of plant development. Therefore, it is important to understand wheat development and recognize wheat growth stages to properly time applications of nitrogen fertilizer, pest management options, and other practices.

Wheat plant growth and development can be broadly divided into the following progressive stages:

- Germination and seedling growth
- Tillering
- Stem elongation
- Boot
- Heading/anthesis
- Grain-fill and ripening

The Feekes scale and the Zadoks scale are two methods for identification of wheat growth stages. The Feekes scale has been used most frequently by Kentucky growers and crop scouts. Developmental stages are designated on a scale of 1 (seedling growth) through 11 (ripening). The Zadoks scale is much more descriptive of various stages of development. It uses a two-digit system for wheat plant development, divided into 10 primary stages, each of which is divided into 10 secondary stages, for a total of 100 stages. The Zadoks scale goes from primary stage 00 (dry seed) to 90-99 (ripening). Both the Zadoks and Feekes scales are shown for comparison (Table 2-1).

Photo 2-1. Understanding wheat stages can help with timing of key management practices.

Table 2-1. Wheat growth stages.

Stage	General Description	Scale Feekes	Scale Zadoks	Additional Comments
Germination	Dry seed		00	
	Start of imbibition		01	
	Imbibition complete		03	Seed typically at 35 to 40% moisture.
	Radicle emerged from seed (caryopsis)		05	
	Coleoptile emerged from seed (caryopsis)		07	
	Leaf just at coleoptile tip		09	
Seedling Growth	First leaf through coleoptile	1	10	
	First leaf unfolded		11	
	2 leaves unfolded		12	
	3 leaves unfolded		13	
	4 leaves unfolded		14	
	5 leaves unfolded		15	
	6 leaves unfolded		16	
	7 leaves unfolded		17	
	8 leaves unfolded		18	
	9 or more leaves unfolded		19	
Tillering	Main shoot only		20	
	Main shoot and 1 tiller	2	21	
	Main shoot and 2 tillers		22	
	Main shoot and 3 tillers		23	Many plants will only have 2 or 3 tillers per plant at recommended populations.
	Main shoot and 4 tillers		24	
	Main shoot and 5 tillers		25	
	Main shoot and 6 tillers	3	26	Leaves often twisting spirally.
	Main shoot and 7 tillers		27	
	Main shoot and 8 tillers		28	
	Main shoot and 9 tillers		29	
Stem Elongation	Pseudostem erection	4-5	30	
	1st detectable node	6	31	Jointing stage
	2nd detectable node	7	32	
	3rd detectable node		33	
	4th detectable node		34	Only 4 nodes may develop in modern varieties.
	5th detectable node		35	
	6th detectable node		36	
	Flag leaf visible	8	37	
	Flag leaf ligule and collar visible	9	39	
Booting	Flag leaf sheath extending		41	Early boot stage.
	Boot swollen	10	45	
	Flag leaf sheath opening		47	
	First visible awns		49	In awned varieties only.
Head (Inflorescence) Emergence	First spikelet of head visible	10.1	50	
	¼ of head visible	10.2	52	
	½ of head visible	10.3	54	
	¾ of head visible	10.4	56	
	Head completely emerged	10.5	58	
Pollination (Anthesis)	Beginning of flowering	10.51	60	Flowering usually begins in middle of head.
		10.52		Flowering completed at top of head.
		10.53		Flowering completed at bottom of head.
	½ of flowering complete		64	
	Flowering completed		68	
Milk Development	Kernel (caryopsis) watery ripe	10.54	71	
	Early milk		73	
	Medium milk	11.1	75	Milky ripe.
	Late milk		77	Noticeable increase in solids of liquid endosperm when crushing the kernel between fingers
Dough Development	Early dough		83	
	Soft dough	11.2	85	Mealy ripe: kernels soft but dry.
	Hard dough		87	
Ripening	Kernel hard (hard to split by thumbnail)	11.3	91	Physiological maturity. No more dry matter accumulation.
	Kernel hard (cannot split by thumbnail)	11.4	92	Ripe for harvest. Straw dead.
	Kernel loosening in daytime		93	
	Overripe		94	
	Seed dormant		95	
	Viable seed has 50% germination		96	
	Seed not dormant		97	
	Secondary dormancy		98	
	Secondary dormancy lost		99	

Sources: *Conley, et al. 2003. Management of Soft Red Winter Wheat. IPM1022. Univ. of Missouri. Alley, et al. 1993. Intensive Soft Red Winter Wheat Production: A Management Guide. Pub. 424-803. Virginia Coop. Extension. Johnson, Jr., et al. Arkansas Wheat Production and Management. MP404. Univ. of Arkansas. Coop. Ext. Serv.*

Germination and Seedling Growth

Adequate temperature and moisture are needed for wheat seeds to germinate. Wheat seeds germinate at temperatures of 39°F or higher but temperatures of 54° to 77°F are optimum for rapid germination and growth. Soil temperatures above 90°F can reduce germination of varieties with high-temperature germination sensitivity. Germination begins when the seed imbibes water from the soil and reaches 35% to 45% moisture on a dry weight basis. During germination, the seedling (seminal) roots, including the primary root (radicle), emerge from the seed along with the coleoptile (leaflike structure), which encloses the primary leaves and protects the first true leaf during emergence from the soil. The coleoptile extends to the soil surface, ceases growth when it emerges, and the first true leaf emerges from its tip. Under favorable conditions, seedling emergence occurs within seven days after planting. Until the first leaf becomes functional, the seedling depends on energy and nutrients stored in the seed.

Seedling growth begins with the emergence of the first leaf above the soil surface and continues until the next stage, tillering. Normally three or more leaves develop in the seedling stage before tillering is initiated. Each new leaf can be counted when it is over one-half the length of the older leaf below it. During this phase the fibrous root system develops more completely, helping plant establishment.

The crown (a region of lower nodes whose internodes do not elongate) is located between the seed and the soil surface. It tends to develop at the same level, about one-half to one inch below the soil surface, regardless of planting depth. Leaves, tillers, and roots (including the main root system) develop from the crown nodes. The growing point is located at the crown until it is elevated above the soil surface at the stem elongation stage.

Tillering

The tillering stage begins with the emergence of lateral shoots (tillers) from the axils of the true leaves at the base of the main stem of the plant. The tillers are formed from the auxiliary buds located at each crown node. Primary tillers form in the axils of the first four or more true leaves of the main stem. Secondary tillers may develop from the base of primary tillers if conditions favor tiller development. A tiller may also develop from the coleoptile node (coleoptile tiller), but this occurs sporadically and its appearance is dependent on genotype, planting practices, and environmental conditions. At the base of each tiller is a sheath (small leaflike structure) called the prophyll, from which the tiller leaves emerge. The prophyll acts like the coleoptile and protects the auxiliary bud before it elongates its first leaf to become a tiller. Identifying the prophyll, which encloses the base of the tiller, will help differentiate tiller leaves from the leaves on the main stem and from other tillers. Tillering usually begins when the seedling plant has three or more fully developed leaves. Tillers depend on the main stem for nutrition during their development. Once a tiller has developed three or more leaves, it becomes nutritionally independent of the main stem and forms its own root system.

Tillers are an important component of wheat yield because they have the potential to develop grain-bearing heads (Table 2-2). In Kentucky, each plant normally develops two or more tillers in the fall when planted at optimum dates. The total number of tillers eventually developed will not all produce grain-bearing heads. Under recommended plant populations, usually two or three tillers, in addition to the main shoot, will produce grain. Tiller development occurs in the fall until low temperatures stop plant growth. In Kentucky, during the tillering stage, winter wheat goes through the winter months in a dormant condition in which plant growth (including tiller production) essentially ceases due to cold temperature. Tiller production and development resumes in late winter/early spring with an increase in temperature as the plants "break" dormancy and resume growth. Due to cooler temperatures, late planted winter wheat may have little or no fall tillering because of limited seedling growth or because no wheat has emerged; late planted wheat will rely heavily on spring tiller development.

Fall tillers are necessary for maximum wheat yield in most years because spring tillers usually contribute less to yield. There are exceptions to this, but in most seasons, wheat should be managed to produce fall tillers. Tillers develop sequentially on a plant, resulting in a prioritization for development. The main stem and older (first-formed) tillers have priority to complete development and form a grain-bearing head. This same priority also exists regarding the size of the grain-bearing head on the main stem and subsequent tillers.

Photo 2-2. Wheat field at Feekes 4 or 5.

The number of tillers a plant develops is not a constant and will vary because of genetic potential, management, and environmental conditions. Some varieties have a greater potential to develop more tillers than others. Tillering is also a means for the plant to adapt to changing environmental conditions. Plants are likely to produce more tillers when environmental conditions such as temperature, moisture, and light are favorable, when plant populations are low, or when soil fertility levels are high. Under weather stress conditions such as high temperature, drought, high plant populations, low soil fertility, or pests, plants respond by producing fewer tillers or even aborting initiated tillers. Rarely do more than five auxiliary tillers form and complete development on a plant. Although the total number of tillers formed per plant can vary considerably and be quite high, not all the tillers remain productive. The later developing tillers usually contribute little to yield. Tillers that emerge after the fifth leaf on the main stem are likely to senesce (or die), abort, or not produce a grain head. Very few of the secondary tillers that form usually develop a head unless conditions dictate a need.

As temperatures decrease below the minimum for plant growth in late fall/winter, winter wheat will become dormant. Cooler temperatures and shorter days during the fall induce cold hardiness in wheat plants to protect against cold injury and to help them survive the winter. During this period, the low temperatures initiate in the plant a physiological response called vernalization. Once vernalization requirements have been met, the plant converts from vegetative to reproductive growth and the reproductive structures are developed. Because of this vernalization requirement, winter wheat produces only leaves for both the main stem and tillers aboveground in the fall in preparation for winter. The growing point and buds of both the main stem and tillers remain belowground, insulated against the cold winter temperatures. Once vernalization requirements are met, the growing point differentiates and develops an embryonic head. At this time, potential wheat head size or total number of spikelets per head is determined. Neither seedling growth nor tillering is required for vernalization to occur. This process can begin in seeds as soon as they absorb water and swell. Hence, late planted wheat that has not emerged prior to winter should be adequately vernalized. Following vernalization, exposure to progressively longer photoperiods (longer day length periods) is necessary to initiate and hasten reproductive development.

The vernalization requirement involves exposure to cooler temperatures for a required length of time. Temperatures below 50°F are needed to induce cold hardening and satisfy vernalization requirements; temperatures of 37° to 46°F are considered sufficient and most effective. The required length of low temperature exposure decreases with colder temperatures and advanced plant development. At sufficiently low temperatures, most varieties in Kentucky require three to six weeks of vernalization. This requirement differs in other states with different climates. Varieties also differ in their response to vernalizing temperature requirements. Generally, early maturing varieties require less time to vernalize than later-maturing varieties. In some varieties, vernalization is affected by photoperiod, in which exposure of the wheat plant to short days replaces the requirement for low temperatures. Exposure of wheat to temperatures above 86°F shortly following low temperatures can sometimes interrupt vernalization. Spring wheat varieties do not possess an absolute vernalization requirement. Reproductive development in most spring varieties is induced by light and accumulated heat units (growing degree days).

Stem Elongation/Jointing

Stem elongation is the next phase of growth (Feekes 4-9) after tillering. The overwintering, dormant wheat leaves are generally short and lie rather flat. As temperatures increase in the spring, the wheat plants break dormancy and resume growth. The leaf sheaths grow quickly and the succession of leaves are wrapped around each other, giving a strongly erect appearance known as a pseudostem (Table 2-3), which is not a real stem (Feekes 4-5). The actual stem has not elongated at this stage and the immature head (growing point) is still below ground level but has started to advance above the crown region. The growing point is only about one-eighth of an inch in length and has the appearance and shape of a very small pinecone.

As growth continues, stem elongation occurs because of internode elongation. The embryonic head (growing point) in the main stem and each tiller that has formed at the base of the plant begin to be pushed up the stem. The maximum possible number of kernels per head is determined at this time. The plant allocates nutrients to the main stem and tillers with at least three leaves. Once the plant has jointed, typically no more potential head-bearing tillers will form. However, if the growing point has been killed during stem elongation because of damage (physical, freeze, pests) to the immature head and/or supporting stem, that main stem or tiller will die. As a result, the wheat plant will tend to compensate for this loss by development of new shoots from the base of the plant.

During stem elongation, the stem nodes and internodes emerge above the soil surface and become visible. Nodes are areas of active plant cell division from which leaves, tillers and adventitious (crown) roots originate. Leaves originate from the stem nodes above the soil surface and emerge as the stem elongates. As jointing (stem elongation) occurs, the nodes swell, and they look and feel like bumps on the stem. This makes them easier to see or feel and easier to count. An internode is the region between two successive nodes. During stem elongation, the internodes above the soil surface elongate to form the stem. The elongated internode is hollow between the nodes. Wheat stems contain several internodes which can be described as "telescopic." Prior to stem elongation, the nodes and internodes are all formed but are sandwiched together at the growing point as alternating layers of cells destined to become the nodes

Photo 2-3. Many wheat varieties have awns and are called bearded wheat, while other varieties are awnless.

and the internodes of a mature stem. When jointing is initiated, these telescoped internodes begin to elongate, nodes appear one by one, and elongation continues until head emergence. When an internode has elongated to about half its final length, the internode above it begins elongating. This sequence continues until stem elongation is complete, usually at head emergence. Each succeeding stem internode (from the base to the top of the plant) becomes progressively longer. The last elongated internode is the peduncle, which supports the head. It accounts for a good proportion of the overall stem length. Plant height continues to increase during stem elongation until the heads emerge. Plant height is influenced by both genotype (variety) and growing conditions. Generally, variation in height is due more to differences in internode length than internode number.

When stem elongation begins, the first node of the stem is swollen, becomes visible as it appears above the soil surface, and is commonly called jointing (Feekes 6). Above this node is the immature head, which is being pushed upward as internodes elongate to eventually emerge (heading stage). Usually, a plant has about five to six leaves on the main shoot when jointing begins. The immature head continues to develop and enlarge during stem elongation until it becomes complete at the boot stage. As previously noted, the jointing stage will not occur prior to the onset of cold weather, as vernalization is required in winter wheat to initiate reproductive development. When the growing point moves above the soil surface and is no longer protected by the soil, the head becomes more susceptible to damage (mechanical , freeze, pests).

During stem elongation, the lower four nodes remain in the crown. The fifth node may remain in the crown or be elevated slightly. Nodes six, seven, and possible additional nodes are elevated above the soil. When stem elongation is complete, most wheat varieties usually have three nodes visible above the soil surface, but occasionally a fourth node can be found. The stem elongation stage is complete when the last leaf, commonly called the flag leaf, emerges from the whorl (Feekes 8-9). On most varieties, the flag leaf begins to emerge just after the third aboveground node is observed or can be felt. To confirm that the leaf emerging is the flag leaf, split the leaf sheath above the highest node. If the head and no additional leaves are found inside, the emerging leaf is the flag leaf. The flag leaf stage is significant because the flag leaf produces at least 75% of the photosynthate for filling grain. It must be protected from diseases, insects, and defoliation for the plant to develop its full yield potential. Flag leaf emergence is a visual indicator that the plant will soon be in the boot stage.

Boot

The boot stage (Feekes 10) occurs shortly after flag leaf emergence and indicates that the head is about to emerge. The flag leaf sheath is the tubular portion of the leaf that extends below the leaf blade and encloses the stem. The peduncle is the internode which supports the head. The flag leaf sheath and the peduncle elongate, and the developing head is pushed up through the flag leaf sheath. As the developing head beings to swell inside the leaf sheath, the leaf sheath visually obtains a swollen appearance to form a "boot." The boot stage is rather short and ends when the awns (or the heads in awnless varieties) are first visible at the flag leaf collar, which is the junction of the leaf blade and leaf sheath. Eventually, the leaf sheath is forced open by the head.

Heading and Flowering (Anthesis)

By the time heading occurs, the development of all shoots (main stem and tillers) on the same plant is in synchronization even though there were large differences tiller initiation. The tillers that initiated later developed faster allowing the main shoot and tillers to synchronize head emergence. Flowering occurs soon after the main stem has headed and flowered.

The heading stage begins when the tip of the spike (head) can be seen emerging from the flag leaf sheath (Feekes 10.1), and emergence continues until the head is completely emerged (Feekes 10.5). For most wheat varieties, the heading date is determined by temperature with the accumulation of heat units. In some varieties, a combination of heat accumulation and day length determines heading date.

Shortly after the wheat head has fully emerged, flowering (anthesis) occurs. Generally, flowering in wheat begins within three or four days after head emergence. Open flowering is characterized by extrusion of the anther, the reproductive portion of the flower which produces pollen, from each floret on the head. In contrast, closed-flowering types of varieties or cereals (such as barley) flower prior to head emergence and the anthers remain inside each floret. Flowering and pollination of wheat normally begins in the center of the head and progresses to the top and bottom of the head. Pollination normally lasts only about three to five days. Pollination occurs slightly later for tillers than on the main stem, but all heads on a plant pollinate within a few days of each other. Wheat is largely self-pollinated, and pollination and fertilization has already occurred before the pollen-bearing anthers are extruded from the florets. Kernels per head are determined by the number of flowers that are pollinated. Pollen formation and pollination are very sensitive to environmental conditions. High temperatures and drought stress during heading and flowering can reduce pollen viability and thus reduce kernel numbers. The period spanning 20 days before flowering (anthesis) to 10 days after flowering determines grain number and directly relates to final yield.

Flowering is the transition between two broadly categorized growth stages in wheat. In the first stage, vegetative growth, reproductive initiation, and reproductive development occur and determine the final yield potential of the crop. The vegetative stage also provides the photosynthetic factory necessary for maximum yield. The grain-filling period completes the yield process. The extent to which the potential yield is realized will depend on the environment and on management inputs prior to and after anthesis.

Photo 2-4. Flowering usually begins at the middle of the head and then progresses upward and downward simultaneously.

Grain Filling/Ripening

Grain filling follows anthesis and refers to the period during which the kernel matures or ripens. Within a few hours of pollination, the embryo and endosperm begin to form and photosynthates are transported to the developing grain from leaves, primarily the flag leaf. In addition, starches, proteins, and other compounds previously produced and stored in leaves, stems, and roots are also transferred to the developing grain. The grain filling period is critical for producing high yields because kernel size and weight are determined during this stage. Yields will be reduced by any stress occurring during grain fill. Examples of those stresses include: high temperatures, low soil moisture, nutrient deficiencies, and diseases. Environmental factors affect the rate and duration of the grain filling period. The longer this filling period lasts, the greater is the probability for higher yields. If this period is shortened, yields will usually be lower. In Kentucky, the average length of the grain filling period is one month. The grain fill period can be as few as 25 days or less in high stress environments and may exceed 35 days in high yield, low stress environments. The grain development stages are listed in Table 2-1 (Feekes 10.54 to 11.4). A brief description and comments of the grain filling and ripening stages follows below.

Watery ripe stage. Kernel length and width are established during this stage. The kernel rapidly increases in size but does not accumulate much dry matter. A clear fluid can be squeezed from the developing kernel.

Milk stage. During this stage there is a noticeable increase in solids of the liquid endosperm as nutrients in the plant are redistributed to the developing kernels. During the milk stage a white, milk-like fluid can be squeezed from the kernel when crushed between fingers. By the end of the milk stage, the embryo is fully formed.

Soft dough stage. The kernels are soft but dry. The water concentration of the kernel has decreased so that the material squeezed out of the kernel is no longer a liquid but has the consistency of meal or dough. The kernel rapidly accumulates starch and nutrients and by the end of this stage the green color begins to fade. Most of the kernel dry weight is accumulated in this stage.

Hard dough stage. The kernel has become firm and hard and is difficult to crush between fingers. It can be dented with a thumbnail. Kernel moisture content decreases from a level of 40% to 30%. At the end of the hard dough stage (Feekes 11.3), the kernel reaches its maximum dry weight, and the wheat is physiologically mature since no more weight is added to the grain. Kernel moisture content at physiological maturity often is between 30% and 40%. Previous research at the University of Kentucky indicated physiological maturity occurred at a kernel moisture content of 38% to 42% with no reduction in yield or test weight if swathed at this stage. Harvesting can occur any time after physiological maturity but often occurs when kernel moisture is drier.

Table 2-2. Key growth stages in wheat for yield determination.

Critical Yield Component	Determined by:
Tiller and head number	Jointing (Feekes 6)
Head Size	Mid to late tillering (Feekes 3)
Kernel number per head	Jointing (Feekes 6)
Kernel Size	Beginning at flag leaf (Feekes 8) and continuing through grain fill

Table 2-3. Wheat terms.

Term	Definition
anthesis	flowering
embryo	rudimentary, undeveloped plant in a seed
endosperm	area of starch and protein storage in the seed
flag leaf	uppermost leaf on a stem or tiller
head	structure holding the spikelets and eventually seeds of wheat
peduncle	elongated internode between the flag leaf and head
photosynthates	mostly carbohydrate products produced by photosynthesis
pseudostem	leaf sheaths grow quickly giving the plant an erect appearance that mimics a stem, but is not a real stem
spikelet	the basic inflorescence unit in the wheat
vernalization	requirement of a duration of temperatures below 50ºF to allow winter wheat to initiate reproductive development.

Ripening stage. Kernel weight is complete, but moisture content is still high, usually ranging from 25% to 35%, when wheat begins to ripen but decreases rapidly with warm weather. The plant turns to a straw color and the kernel becomes very hard. The kernel becomes difficult to divide with a thumbnail, cannot be crushed between fingernails, and can no longer be dented by a thumbnail. Harvest can begin when the grain has reached a suitable moisture level, which usually is less than 20% for many combine harvesters. For farms without drying facilities, wheat harvest begins when grain moisture content is closer to 15%. Once wheat reaches 15% moisture or less, harvest should begin immediately to maintain high grain quality. Test weight may be reduced during the ripening process. Decreased test weight results from the alternate wetting and drying of the grain after the wheat has physiologically matured . In this case, the seed imbibes water and expands. As the seed dries again, the does not shrink to the original size, which means each seed occupies more volume. Thus, fewer seeds fill a bushel and test weight drops. Rainfall events or heavy dews on wheat that is physiologically mature can result in poorer wheat grain quality. Wheat grain is marketed at 13.5% grain moisture. U.S. Grade no. 1 Soft Red Winter Wheat is 60 pounds per bushel, while U.S. Grade No. 2 Soft Red Winter Wheat is 58.0 pounds per bushel.

References

Fischer, R.A., 1985. Number of kernels in wheat crops and the influence of solar radiation and temperature. *The Journal of Agricultural Science*, *105*(2), pp.447-461.

Chapter 3

Cultural Practices

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Wheat grows best on well-drained soils and does not grow well on poorly drained soils. Wheat can be grown successfully on moderately and somewhat poorly drained soils, but long-term yields are usually reduced by five to ten bushels per acre due to stress placed on the wheat during wet springs, which may cause increased winterkill, higher nitrogen losses, inability to access fields with application equipment, and direct plant death due to waterlogging. During springs with normal or below normal rainfall, yields on poorly drained soils approach yields on well-drained soils.

Crop Rotation

Most of Kentucky's soft red winter wheat acreage is grown in a cropping system of three crops in two years (corn/wheat/double-crop soybeans). In this double-crop system, corn is planted in the spring, harvested in the fall and wheat is planted in October, harvested in June the following year with soybeans planted immediately after wheat harvest. Wheat following soybean generally yields more than wheat following corn (Figure 3-1). However, when wheat yields are high, the previous crop has less influence on wheat yield. Wheat is suited to the corn/wheat/double-crop soybean rotation system and offers both economic and agronomic advantages. Yields of all three crops in the rotation are increased over growing any crop without rotation.

Double-cropping is an important economic component of the wheat enterprise in Kentucky. More than 85% of the harvested wheat acreage is double-cropped, primarily with soybeans. Winter wheat also provides cover crop environmental benefits by reducing soil erosion, suppressing certain weeds, and improving soil tilth. Approximately 30% to 40% of the corn acres are planted to winter wheat for grain each year.

Photo 3-1. Wheat variety trials are conducted across the state to compare relative performances of varieties. Each variety is planted multiple times at each location to minimize field variability effects and to better predict performance potential.

Variety Selection

The best soft wheat varieties perform well across many environments and tillage systems. Choosing a wheat variety is one of the most important management decisions that Kentucky wheat producers make. Breeders and seed companies are continually releasing new varieties with higher yield potential and usually stronger tolerances to certain pests. The University of Kentucky Small Grain Variety Testing Program conducts unbiased, annual evaluation of varieties to help farmers select varieties with superior agronomic performance. Grain yield and test weight, as well as straw and forage yield potential are directly related to crop income, but secondary traits, such as plant height, lodging potential, maturity, winter cover crop biomass and disease resistance are also important management-related components of profitability and sustainability.

Heading date is an estimate of maturity and there is value in spreading out the harvest maturity so every variety is not ready to harvest at once. Selecting varieties with differences in maturity may also hedge against freeze damage and/or grain filling heat stress, given Kentucky's unpredictable weather patterns. Planting several varieties with good yield and test weight potential that complement one another in terms of disease resistance, maturity, and other characteristics will minimize risks.

State variety trials provide the most comprehensive source of information on varieties tested under a broad range of environments. These trials have demonstrated that good varieties perform well in tillage and no-tillage conditions. Results of the variety trials are published annually and are available at Cooperative Extension Service offices and online at https://varietytesting.ca.uky.edu/wheat. The best use of variety performance data for variety selection can be achieved by applying the following basic principles.

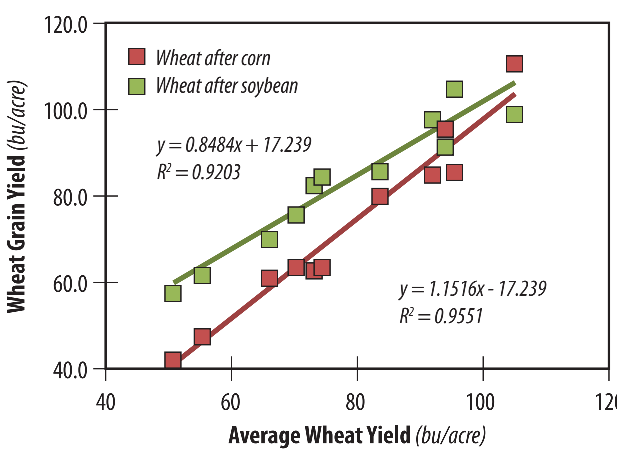


Figure 3-1. Wheat is commonly grown following corn in Kentucky. As overall wheat yield potential increases, the previous crop has less effect on wheat yield. (1998 through 2008 at Lexington, Kentucky, data provided by John Grove)

Multi-year/Multi-location Data

Growers should examine wheat performance from the statewide summary table first, and then examine which of the top-yielding varieties also performed well at the trial locations closest to their farms. The statewide average data combines results from all trial locations and provides the best estimate of the variety performance for the following year . Variety comparisons should only be made for varieties in each specific test. The 2-year variety performance data is preferred over single year performance data. After identifying a group of varieties with high grain yield potential, varietal selection can be based on secondary characteristics, such as test weight, disease resistance, lodging, height, maturity, cover crop potential, and straw yield potential.

Variety Differences in Forage Yield

The University of Kentucky Small Grain Variety Testing Program evaluates wheat varieties for differences in forage yield potential. Wheat is an important source of forage for many Kentucky growers. Approximately 20% of Kentucky's annual wheat acreage is not harvested for grain, and much of that acreage is used for forage production. Wheat for silage, green-chop, or hay production can be double-cropped with corn or full season soybeans. Additionally, wheat provides a reliable source of quality forage in late winter and early spring when other fall/summer sources are low in quantity and/or have deteriorated in quality. Wheat's potential for producing quality forage also allows growers some flexibility in crop choices. Many acres are planted specifically for forage or grain production, but factors such as grain prices, forage supply, forage prices, and crop condition (i.e., freeze damage) may affect end-use decisions based on potential profitability.

The time to harvest wheat forage is an important decision. A wheat silage crop for dairy forage should be cut at the boot stage. Wheat forage at the boot stage has high levels of energy, protein content, and high digestibility, similar to corn silage or alfalfa haylage. Double-cropping corn or full season soybeans are possible when wheat is cut at the boot stage.

Wheat forage harvest is more common in Kentucky at later stages of development such as the soft-dough stage. Biomass yields increase throughout the reproductive growth period, but the quality also declines throughout this period. Wheat cut at mid-dough stage produces what is considered average quality hay. Fiber content is higher and digestibility and protein are lower, but dry matter tonnage will be 30% to 60% greater than silage cut at the boot stage. It is highly recommended for palatability purposes, that awnless (smooth) head type varieties be used if harvesting at this latter stage. University of Kentucky wheat forage variety trials have shown dramatic differences in yield among varieties when harvested at the milk to soft-dough stage. The later cutting of wheat also leads to later planting of corn, which can reduce corn silage yields.

Variety Differences in Straw Yield

Straw is valued in many diverse industries and is an important secondary commodity for many small grain growers. Marketing both grain and straw provides additional income from a single crop. Harvesting straw reduces field residue and facilitates good double-crop soybean stand growth and development. The time and labor requirements of harvesting straw may however, delay double-crop soybean planting.

When making wheat variety selections, growers who are harvesting both grain and straw should select varieties with both high grain and straw yield potential. Growers producing grain exclusively may consider selecting varieties with high grain and low straw yield potential to minimize post-harvest field residue and aid soybean stand establishment. The UK Small Grain Variety Testing program annually evaluates wheat varieties for differences in straw yield. Results have shown that high straw yielding varieties can have more than twice the biomass yield potential of low straw yielding varieties.

When managing wheat for grain and straw production, a fungicide application is recommended along with the standard management practices for grain production. A fungicide application near bloom stage will improve the brightness and quality of straw produced. It is also important to note that wheat harvested for straw removes organic matter and nutrients, such as potassium from the soil (approx. 50 lb K_2O per acre). Growers need to factor soil nutrient loss into their economic decision to harvest straw.

Variety Differences in Cover Cropping Potential

Cover cropping is a primary component of sustainable agricultural practices. Winter cover crops reduce soil erosion, add organic matter to the soil, provide moisture-conserving residues and reduce ground water contamination by utilizing residual fertilizer from the previous crop. Wheat has lower cover crop growth potential than cereal rye but is more widely used due to seed availability and production familiarity. There are varietal differences in winter biomass accumulation among varieties. Wheat cover crop variety trial results are published annually with the UK forage variety trial results, as it also provides an estimate of winter grazing potential.

Economic Analysis of Varieties

Farmers are always interested in high yields, but the highest yielding variety may not always be the most profitable. One needs to consider other economic factors such as disease susceptibility (may require fungicides), lodging (costs more to harvest), maturity (affects harvest timing and double-crop soybean planting), potential straw yield as a secondary commodity, low test weight (discounts at the elevator), cover crop potential (sustainability) and seed cost. All of these factors require study and evaluation to determine the most profitable varieties for a particular operation . Maximum productivity and profitability begin with careful variety selection. Once varieties have been selected, it is best to use certified seed or seed of proven high quality from an established, reputable dealer.

Photo 3-2. While most wheat in Kentucky is grown for grain, some is grown for straw or forages. The University of Kentucky tests wheat varietal performance in forage, straw, and grain yields.

Table 3-1. Recommended number of wheat seeds to plant per square foot or per drill-row foot.[a]

Row Width (in)	Row Length Needed for 1 sq ft (in)	Seeds/sq ft 30	Seeds/sq ft 35
		Seeds/row ft Needed[a]	
4	36.0	10	12
6	24.0	15	18
7	20.6	17	20
7.5	19.2	19	22
8	18.0	20	23
10	14.4	25	29

[a] *If planting time is delayed, increase seeding rates by two to three seeds/sq ft (one to two seeds/row foot) for every two-week delay beyond the optimum planting date.*

Table 3-2. Number of pounds of wheat seed needed, depending on seed size and seeding rate.[a]

Seeds/lb	Seeds/sq ft[a] 30	Seeds/sq ft[a] 35
	lbs/acre	
10,000	131	152
12,000	109	127
14,000	93	109
16,000	82	95
18,000	73	85
20,000	65	76

[a] *Based on 90 percent or greater germination.*

Planting Practices

The target population for planting wheat is a uniform stand of 25 plants per square foot (Table 3-1). Usually planting 30 to 35 seeds per square foot (about 1.5 million seeds/A) will result in the desired plant population. Planting methods include seedbed preparation or no-tillage planting (see *Chapter 4—Planting Methods*), planting date, seed placement, seeding rate , row width, and use of tramlines.

Planting Date. The recommended planting date for most of Kentucky is October 10 through October 30. This window is a compromise between early planting to ensure adequate fall growth and winter survival, and later planting to decrease disease and insect infestations. Typically, these dates will fall within a period of one week before to one week after the expected date of the first fall frost. Soil temperatures are usually high enough during this window for the crop to emerge in seven to ten days or less. Also, the length of time between the first frost and winter dormancy for growth is critical for the development of an adequate number of tillers. Tillers developed in the fall are essential to producing high yields. A longer period of growth in the spring and more extensive root systems mean that fall tillers account for most of the grain produced in an intensively managed crop.

Late-planted wheat misses much of the critical fall growing period, generally suffers more winter damage and is more prone to heaving which is the uplifting of the plant and root system due to alternate freezing and thawing of soil. Late-planted wheat usually tillers less, has reduced yields, and matures later than wheat planted at the recommended time. Making up for late planting by management practices employed at later growth stages is difficult if not impossible.

Planting too early, on the other hand, can result in excessive fall growth and create the potential for more winter injury, greater risk of spring freeze injury, fall disease infection, and increased problems with aphids which vector barley yellow dwarf, and Hessian fly infestations. Delaying planting until October 10 in northern Kentucky and October 15 in southern Kentucky generally averts Hessian fly damage. These dates are known as the fly-free planting dates. The Hessian fly-free date is based partly on the first fall freeze date, so if air temperatures are warmer in the fall, the effective fly-free date would be delayed that season. If a freeze event occurs earlier, then planting can occur earlier.

Seed Placement. Plant seeds 1 to 1½ inches (2.54 to 3.81 cm) deep when soil moisture levels are adequate, slightly deeper if moisture is deficient. Do not plant wheat seed more than 2 inches (5 cm) deep. Rapid emergence and good root development start with good seed-soil contact.

Planting wheat seed deeper than 2 inches often delays emergence. Some semi-dwarf varieties with short coleoptiles might open the first leaf below ground and die. Deep seed placement delays emergence and reduces stand, resulting in plants with less vigor, less initial vegetative growth, and reduced tillering.

Shallow seed placement causes other problems. Planting seed less than ½-inch deep can result in uneven germination and emergence because of dry soil. Soil closer to the surface dries more quickly than soils even 1 inch below the surface. Shallow seed placement also can result in more winter injury and greater susceptibility to heaving. Shallow placement makes the influence of weather immediately after planting much more important. If timely rains accompany shallow planting, then adequate stands usually are achieved but the crop is still more susceptible to the issues above.

Seed placement is especially critical for no-till planting. Seed must be placed in the soil at the proper depth and below all the plant residue or mulch. The mulch should be distributed evenly on the soil surface to help drills successfully slice through the mulch and place the seed in the soil. Poor seed placement is a major problem in no-tillage planting. Fast, uniform seedling emergence provides quick ground cover and erosion protection.

Seeding Rate. Wheat seed size varies dramatically among varieties and can be influenced by production environment and degree of conditioning . For example, wheat seeds can vary from 8,000 to 15,000 seeds/lb. In some cases, seeds can be even smaller, approaching 20,000 seeds/lb. Using seeding rates expressed in terms of volume or weight (bushels or pounds) per acre—without consideration of seed size—can result in stands that are too low or too high. Proper stand establishment requires


Photo 3-3. Seeding wheat rows at a diagonal to the old corn rows is generally a good practice in no-till fields.

that the seeding rate be determined by the number of seeds per unit area (per square foot or linear row foot). Seeding rates below optimum may reduce yield potential, while excessive seeding rates increase lodging, create a greater potential for disease, and increase seed costs. The optimum planting rate is 35 (tilled) or 40 (no-till) seeds per square foot (1,524,600 or 1,742,400 seeds/A, respectively) with an objective of obtaining at least 25 plants per square foot (1,089,000 plants/A). The seed rate and seed size should be determined to calculate how many pounds of seed per acre are needed. Seed sizes and the pounds needed can vary widely (Table 3-2). For precise seeding, calibrate your planting equipment. Seeding rate charts on drills may not be precise and size and shape of seed can affect seed delivery. (See *Section 4—Planting Methods* for a five-step procedure for proper grain-drill calibration.)

Row Width. The most practical wheat row widths are normally 7 to 8 inches, combining the higher yield potential of narrow rows with the effective movement of planting equipment through the field. Research throughout the soft red winter wheat growing region has shown 5% to 10% higher yields when wheat is planted in 4-inch rows versus 8-inch rows. Likewise, research has shown significant yield decreases for wheat grown in row spacings greater than 10 inches. Wheat must be planted at a uniform rate and depth, and conservation requirements must be met. Drills with units 4 inches apart are likely to clog due to excessive surface residue or clods. Typically, drills with units about 7 to 8 inches apart have minimal clogging, but relatively high yield potential. Some farmers are choosing to use modified planters with units spaced 15 inches apart.


Photo 3-4 and 3-5. Corn residue that piles in the field can prevent the drill from placing the wheat seed under the soil surface. Seeds either fail to germinate or seedlings are killed during winter, leaving blank spaces in the field.

These 15-inch planters are often used for soybean. The cost of modifying the equipment is less than purchasing a drill, but the yield loss associated with the wider row spacings may not justify 15-inch rows.

Based on limited research in Kentucky, wheat in 15-inch rows will yield from 0% to 20% less than wheat planted in 7.5-inch rows. For wheat normally yielding 70 bushels per acre, that is a yield loss of 10.5 bushels per acre, or $63 per acre for wheat being sold at $6.00 per bushel. Based on these numbers, not very many acres are needed before a drill becomes more economical than a planter.

Tramlines and/or Satellite Guidance. Tramlines are roadways placed in the wheat field at planting and used by equipment for applying pesticides and fertilizers. Tramlines should match the width of the applicator tires and be spaced to match the width of the applicator boom. Tramlines allow timely application of input and more uniform applications of nutrients and pesticides with no skips or overlaps. Tramline establishment is achieved much easier with the highly accurate options for satellite guidance such as RTK (real-time kinematic positioning). Employing RTK allows a producer to maintain tramlines across wheat fields and across all crop rotations if desired.

Tramlines can be formed by blocking drill spouts and not planting wheat seed in specific rows. Tramlines can also be formed by planting wheat in all rows and then running over the same tracks each time an application is made. Tramlines formed by blocking seeding spouts will allow wheat plants in rows beside the tramlines to compensate some for the unplanted area. Devices that automatically close the selected drill spouts on the appropriate planting pass through the field are available for most grain drills.

When running over wheat to form tramlines, use the same track for each application and do the first track (application) prior to jointing (Feekes 6) to allow plants in adjacent rows to compensate for the tramlines. Neighboring plants will not compensate for the trampled wheat if tramlines are first created past jointing (Feekes 6). Fertilizer and spray booms should be at least 40 feet wide to be economical. Most sprayer tramlines are 80 ft or larger.

Winterkill and Freeze Injury

Soft red winter wheat is subjected to adverse weather conditions during much of its growth period. Autumn frosts and cool temperatures help by hardening plants for the months of cold winter weather ahead.

Expect winterkill on poorly drained soils, with extreme temperature fluctuations, where poor fall root development occurred, where the crown formed too close to the soil surface, and with sustained low temperatures, especially with no snow cover. Extremely cold winters tend to cause more winterkill in varieties developed in more southerly locations because they have less winter hardiness. Heaving is a major cause of late winter or early spring damage to small plants due to extreme temperature fluctuations, especially on poorly drained soils.

Generally, wheat in later stages of stem elongation, heading, and flowering are more susceptible to freezing temperatures than wheat that is at tillering. Usually, colder temperatures are needed to damage wheat at the tillering stages.

Wheat seeded close to the recommended dates typically allows the crop to avoid freeze injury event. Spring freeze injury can occur when low temperatures coincide with sensitive plant growth stages. The risk of spring freeze injury is greater when conditions cause wheat to break winter dormancy and begin growing (called greenup) and those conditions are followed by freezing temperatures. These scenarios occur with unusually warm temperatures in February or March or from unusually late freeze events in April or May. Injury can occur across large areas of the field but usually is most severe in low areas in the field where cold air settles. A late spring freeze can reduce yield because of damage to the head and stem. Usually, a week to ten days of good warm temperatures and adequate sunlight are required before head and stem damage from a freeze event becomes visible. If cool, cloudy days persist, then more time may be needed to assess the damage. If the plants are damaged from the freeze, then the wheat stems will likely be damaged close to the ground. Heavy rainfall will knock over the damaged wheat and severely reduce yields.

Photo 3-6. Using a hand lens or microscope to examine the growing point of wheat can help determine if the crop survived a freeze event.

Photo 3-7. A dowel road with specific lengths marked on it can be used to count plants and tillers on a square-foot-basis.

To check for damage to an unemerged wheat head, cut into the stem to find the developing head. An undamaged head normally appears light green, glossy, and turgid. A killed head is pale white or tan, limp, shrunken, and not developing in size. Spikelets within a single head can be damaged as well. Growing tissue of plants that have been frozen is dry, bleached, and shrunken.

A freeze event on winter wheat does not automatically result in poor yields. Over the past decade, soft red winter wheat in the state has experienced a potentially damaging freeze event several years. In most of those cases, the weather following the freeze events allowed for wheat to recover and yields to be better than expected.

Some wheat varieties may be avoid spring freezes based on the mechanisms that determine flowering in wheat. Flowering in some wheat varieties seems to be controlled more by day length while flowering in other varieties may be controlled more by temperature. Unusually warm temperatures could accelerate crop development in varieties more responsive to temperature more so than in varieties more responsive to day length. In these cases, varieties more sensitive to temperature would be at a greater risk for spring freeze. Assessing wheat damage from a freeze event can be difficult. Patience to examine the crop at least a week and up to a month after the freeze event is necessary to accurately assess damage and recovery.

For more detailed information on freeze damage in wheat, see *Identifying Damage and Estimating Yield Reductions following a Spring Freeze in Winter Wheat* (AGR-253).

Table 3-4. Wheat yield potential based on plants per area.

Final Stand (%)	Plants per:		Potential Yield[a] (%)
	sq ft	sq yd	
100	30 - 35	270 - 315	100
80	24 - 28	216 - 252	100
60	18 - 21	162 - 189	90 - 95
50	15 - 18	135 - 162	75 - 80
40	12 - 14	108 - 126	60 - 70
20	6 - 7	54 - 63	40 - 50

[a] *This provides an estimate of the relationship of wheat stand to yield potential and is only a guide. Many factors (plant vigor, weather, disease, fertility management, planting date, and variety) influence how a wheat stand ultimately responds to achieve its final yield potential.*

Table 3-5. Length of row needed for 1 sq ft.

Row Width (in)	Row Length for 1 sq ft	
	(ft)	(in)
6	2.0	24.0
7	1.7	20.6
7.5	1.6	19.2
8	1.5	18.0
10	1.2	14.4
15	0.8	9.6

Determining Plant Populations, Tiller, and Head Counts

Plant Populations. After the wheat has emerged, make a stand count to determine if your target population was achieved and if the final stand is acceptable for maximum yield potential. Make fall stand counts one to two weeks after emergence. Make spring stand counts before greenup of the plants occurs to determine if winter damage has reduced the initial plant population obtained in the fall. Count only whole plants, not tillers. Fields with stand counts below 15 plants per square foot have less than 75% yield potential (Table 3-4) and probably should not be kept but used instead for planting corn or soybeans. If stand counts are adequate to keep but somewhat reduced from optimum, consider an early nitrogen application.

To determine the number of plants per square foot:

- Use a yardstick or cut a dowel rod to a 3-foot length.
- Place the measuring stick next to an average-looking row and count all plants in the 3-foot length of the row. Record the number.
- Repeat the counting process in at least five other locations well-spaced around the field. Record all numbers.
- Average all the stand counts from the field.
- Calculate plants per square foot with the following equation:

plant number =
(average plant count × 4)/row width in inches

A second method to counting stands is to determine the length of row needed to equal one square foot (Table 3-5). Mark the needed length on a dowel rod or stick and then count the plants in a row.

A third method is to count the plants or tillers in 1, 2, or 3 feet of row and use Table 3-6 to determine stands.

Tiller and Head Counts. Taking a tiller count which includes main shoot and tillers at Feekes 3 is the first step in all fields for determining nitrogen needs in late winter or early spring. To determine tiller numbers, count all stems with three or more leaves. Tiller counts below 70 per square foot indicate the need for nitrogen at Feekes 3. At recommended populations, many plants will have only three to four stems (main shoot plus two to three tillers). Thus, 70 to 100-plus tillers (stems) per square foot at Feekes 3 are considered adequate. Head counts can be taken late in the season after heads have fully emerged (Feekes 10.5 or later) to help estimate yield potential. An ideal count for maximum yields is 60 to 70 heads per square foot with 35 kernels per head and 16 to 18 spikelets per head. For adequate yields, 55 heads per square foot are needed. If the number of heads per square foot is too high (90 to 100), severe lodging can occur and the seeding rates were probably too high. Use the same procedure to count tillers or heads as outlined above for plant populations.

Table 3-6. Wheat stand count table.

Row Width (in)	Row Length (ft)	Area (sq ft)	Plants (or tillers) per counted area											
			10	15	20	25	30	40	60	80	100	120	140	160
			Plants (or tillers) per sq ft											
7	1	0.58	17	26	34	43	51	69	103	137	.	.	.	.
	2	1.17	9	13	17	21	26	34	51	69	86	103	120	137
	3	1.75	6	9	11	14	17	23	34	46	57	69	80	91
7.5	1	0.63	16	24	32	40	48	64	96	128	.	.	.	.
	2	1.25	8	12	16	20	24	32	48	64	80	96	112	128
	3	1.88	5	8	11	13	16	21	32	43	53	64	75	85
8	1	0.67	15	23	30	38	45	60	90	120	.	.	.	.
	2	1.33	8	11	15	19	23	30	45	60	75	90	105	120
	3	2.00	5	8	10	13	15	20	30	40	50	60	70	80
10	1	0.83	12	18	24	30	36	48	72	96	120	.	.	.
	2	1.67	6	9	12	15	18	24	36	48	60	72	84	96
	3	2.50	4	6	8	10	12	16	24	32	40	48	56	64
15	1	1.25	8	12	16	20	24	32	48	64	80	96	112	128
	2	2.50	4	6	8	10	12	16	24	32	40	48	56	64
	3	3.75	3	4	5	7	8	11	16	21	27	32	37	43

Lodging Control and Plant Growth Regulators

Lodging can be a problem when too much nitrogen fertilizer is used, too much nitrogen carries over from the previous crop, too thick of a stand is established, stems sustain freeze damage and/or growing conditions favor excessive growth. Lodged wheat can result in decreased combine speed because of the amount of straw that must be processed through the combine, decreased grain recovery, delayed harvesting after rainfall and heavy dew, and more difficult planting conditions for double-crop soybeans that follow wheat. Risk of wheat lodging can be reduced by choosing varieties with good stem strength, establishing the correct plant population, and using the recommended amount of nitrogen fertilizer. Situations do occur, however, in which there is a large carryover of residual soil nitrogen or weather conditions produce very lush crops and the potential for lodging is high. When the potential for lodging is high, consider using a plant growth regulator. A plant growth regulator can prevent lodging by shortening the wheat plant and strengthening the straw. It does not increase yields if no lodging occurs. Correct application is critical and should be made between Feekes 8 and 10. Never apply a plant growth regulator to crops with exposed heads. Research at the University of Kentucky showed best results when the plant growth regulator was applied at Feekes 8 or 9. Carefully read the label and follow all directions.

Chapter 4

Planting and Drill Calibration

Chad Lee

The objective when planting wheat is to establish a uniform stand of at least 25 plants per square foot with adequate fall growth for tiller development and an established root system for winter survival. Planting methods include drilling, singulation seeding, broadcast seeding, and aerial seeding . Each has advantages and disadvantages. A planting method should be based on planting equipment, time, and labor availability, seeding costs, planting date opportunity, weather, crop usage, yield goals, and stand establishment risks associated with each method. In addition, calibration of planting equipment is critical to getting the correct number of seeds in the soil. Methods for drill calibration are included at the end of this section.

As machinery moves across a field, soil compaction is a concern. Compaction causes the soil to waterlog easily, reduces air movement through the soil, puts the wheat crop under stress, and can reduce grain yield. Fields should be tested for compaction by using a penetrometer or similar device when there is ample water in the soil. If soil compaction exists in the field, it should be alleviated before wheat is seeded, when the field is relatively dry. Subsoiling equipment can alleviate deep compaction while a field cultivator can alleviate shallow compaction. These tillage operations should only be conducted when the field is dry. If the field is wet, then these operations could worsen compaction. Some types of subsoilers leave most of the residue on the surface and other types cause considerable soil disturbance which would require additional tillage. Once the compaction is remedied and the field is managed in a complete no-tillage system, the field usually will remain free of compaction.

Drilling

The best results in wheat stand establishment and yield are obtained by seeding with a grain drill. A drill ensures good seed-to-soil contact, promotes rapid germination, results in more uniform and optimum stands, reduces winter injury, and increases yields over broadcast seeding and aerial seeding. (For calibration of a drill, see the end of this section.)

Photo 4-1. Proper seeding techniques are critical for an excellent stand of wheat.

Photo 4-2. Wheat can be seeded into heavy corn residue with modern no-tillage drills.

Drills can be used for conventional tillage, reduced tillage, and no-tillage field conditions. Conventional or full tillage provides a level, smooth seedbed for drilling and can result in a more uniform planting depth. No-till drills with additional coulters and more down pressure on the planter units can establish a good stand of wheat in reduced tillage and no-tillage fields. Leaving crop residue on the soil surface protects the soil from erosion until the wheat crop becomes established. The majority of wheat fields in Kentucky are either no-tillage or minimum tillage. In the minimum tillage fields, often a single, shallow disking is used.

No-tillage conditions provide several advantages over tillage conditions, including reduced soil erosion, reduced equipment requirements, reduced labor costs and reduced fuel costs. Soils under longer term no-tillage management will remain firmer during adverse weather conditions over the winter and spring. Thus, no-tillage conditions also allow more timely management, such as spring applications of nitrogen (N) fertilizer . On the other hand, no-till wheat can result in variable planting depths and uneven stands, especially if equipment is not properly adjusted for no-tillage fields. In the early stages of no-tillage adoption by a producer, yields can be reduced in a high-yield environment. However, management experience seems to eliminate most of these disadvantages. Yield comparisons from research and on-farm trials over the last 25 years show little or no difference in yield between no-tillage and tillage. The small increase in yields of soybean and corn in a true no-tillage system for wheat, double-cropped soybean and corn is attractive to producers, also.

Residue management varies with the previous crop. Planting into no-tillage conditions after soybeans is ideal but may not be the most economical crop rotation. Planting into corn residue requires proper management of that residue to get uniform seed depth and uniform emergence. Combine harvesters should have residue choppers and spreaders to distribute the corn residue evenly. In many fields, wheat seeding occurs very soon after corn harvest. Normally, stalk shredding or mowing prior to seeding is not necessary if cornstalks are moist and firmly in the soil. However, if two or three weeks will elapse between stalk shredding and wheat seeding, then shredding the corn residue can improve drill coulter penetration. A flail mower is a better tool to mow stalks because it distributes the residue more evenly for a more uniform seeding depth. A rotary mower may tend to "windrow" the residue, creating uneven residue depths and hindering drill performance. Drilling wheat at an angle to the corn stalk row is also helpful because a drill unit is not continually in a row of corn stalks. Usually, drilling at about 10 degrees helps the drill handle residue the best.

Winterkill is a problem about every four or five years in Kentucky. It can be more pronounced in no-till plantings if the planting depth is ½ inch or less or when heavy residue precludes good seed-to-soil contact. To remove this increased risk, use the proper planting methods and adjustments to plant 1 to 1½ inches deep.

Drills should be adjusted to target 30 to 35 live seeds per square foot for conventional tillage systems and 35 to 40 live seeds per square foot for no-tillage systems.

Broadcasting

Wheat seed can be broadcast as either a planned or emergency seeding method. The wheat seed is broadcast on the soil surface with a fertilizer spreader and incorporated into the soil with light tillage, usually disk or field cultivator. Broadcasting is a fast method of seeding wheat and is an acceptable option if corn or soybean harvest is delayed or weather delays push planting dates to the end of or beyond the optimum planting period. Timely rainfall events shortly after broadcasting are vital for excellent stand establishment.

When broadcast seeding into corn stubble, tillage is often conducted before broadcasting. Once broadcasting occurs, then a light tillage operation incorporates the seed into the soil. When broadcasting wheat into a field of soybean stubble, generally a single, light tillage operation after broadcasting is necessary.

Broadcast seeding often results in uneven seed placement in the soil, which results in uneven emergence and stands. Seeds may be placed as deep as 3 to 4 inches, where many seeds will germinate but will not emerge through the soil surface. Other seeds may be placed very shallow or on the soil surface. These seeds often do not survive due to dry soil or winter damage. The uneven stands from broadcasting often result in lower yields compared with drilling.

One method of improving stand uniformity is to broadcast seed in two passes across the field, with a half seeding rate for each pass. The second pass is made perpendicular to the first pass. While this method should improve stand uniformity, it also increases time required and fuel cost to seed the field.

Because plant establishment potential is reduced and seed placement is not uniform, seeding rates should be increased for broadcast seeding. Increase broadcast seeding rates by 30% to 35% over drilled seeding rates. This equates to seeding rates of 45 to 47 seeds per square foot or approximately 2½ bushels per acre at average seed size. Soil moisture, crop residue, and accuracy of seed incorporation into the soil are crucial to stand establishment.

Broadcasting wheat with fertilizer is a fast way to seed after harvest. Take precautions to ensure that the seed is uniformly blended with the fertilizer and that the fertilizer-seed mixture is uniformly applied. Seed should be mixed with fertilizer as close to the time of application as possible and applied immediately after blending. Allowing the fertilizer-seed mixture to sit after blending for longer than eight hours results in seed damage and a poor stand. Triple super phosphate (0-46-0) or diammonium phosphate (18-46-0) are especially damaging to wheat seeds after eight hours of contact.

In summary, broadcast seeding is a faster method of seeding and can save time during corn or soybean harvest. The time saved may offset some of the greater costs and potential yield loss associated with broadcast wheat. Disadvantages include inconsistent seed depth and emergence, nonuniform stands, potential for reduced stands, usually lower yields, increased chances of winter injury and higher seed costs.

Aerial Seeding

Aerial seeding is a risky method for establishing wheat and is not very common. It may be considered as an option when harvest of the summer crop is delayed well into the optimum time for planting wheat. An airplane, helicopter, or unmanned aerial vehicle (UAV) drops a high rate of wheat seed onto the soil surface through the canopy of corn or soybean. The wheat seed is not incorporated into the soil, making successful germination and stand establishment heavily dependent on adequate and timely rainfall. Depending on the weather during stand establishments, yields from aerial seeding can be as high as other methods but also are much more likely to be a complete failure.

Aerial seeding normally works best when the summer crop of corn or soybean is turning yellow and leaves are dropping to the ground. This leaf drop can provide a mulch cover and improve the environment for germination. Even in the best conditions, aerial seeding will result in wheat plants with crowns at or above the soil surface, making the wheat crop extremely vulnerable to winterkill.

Historically, aerial seeding was conducting in September prior to the Hessian fly free date. This practice is not recommended, because rainfall is usually low during this period, and there is a greater risk of damage from Hessian fly, aphids, take-all and wheat spindle streak mosaic virus. Aerial seeding is not recommended for late October or November plantings, either. Normally, wheat growth from late aerial seedings will be inadequate for winter survival.

Seeding rates should be 50 to 55 seeds per square foot for aerial seeding, nearly 40% to 50% greater than those used for drill seeding. Expected stand establishment will be about 50% to 75% of the seeding rate.

In summary, aerial seeding is a high-risk venture and should only be considered for the early window of wheat seeding dates when harvest of the summer crop is delayed. Even in these cases, seeding wheat late with a drill may have better odds of surviving than aerial-seeded wheat.

Grain Drill Calibration

Several methods for calibrating drills are presented below. For any of these methods, ensure that all units are properly delivering seed before conducting any calibration. Look for any loose hoses or chains, gears, etc. that might affect seed delivery.

For all target recommendations, we are expecting a germination rate of 90%. For example, when 30 to 35 seeds/sq ft is recommended, we are expecting 27 to 32 plants to emerge. Seeding rates for no-tillage are slightly higher than conventional tillage because we anticipate slightly lower emergence rates.

Photo 4-3. Drill calibration takes time, but the results are worth the effort.

Table 4-1. Adjusted seeding rate needed based on standard germination and desired live seeding rate.

Live Seeding Rate (seeds/sq ft)	Standard Germination Rate				
	95%	90%	85%	80%	75%
	Adjusted Seeding Rate (seeds/sq ft)				
25	26	28	29	31	33
30	32	33	35	38	40
35	37	39	41	44	47

Table 4-2. Recommended number of wheat seeds to plant per 50 drill-row feet.[a]

Row Width (in)	Row Length Needed for 1 sq ft (in)	Seeds/sq ft	
		30	35
		Seeds/50 drill-row ft needed[a]	
4	36.0	500	600
6	24.0	750	900
7	20.6	850	1000
7.5	19.2	950	1100
8	18.0	1000	1150
10	14.4	1250	1450

[a] *Assumes 90 percent germination rate.*

Table 4-3. Number of pounds of wheat seed needed, depending on seed size and seeding rate.[a]

Seeds/lb	Seeds/sq ft[a]	
	30	35
	lb/acre	
10,000	131	152
12,000	109	127
14,000	93	109
16,000	82	95
18,000	73	85
20,000	65	76

[a] *Based on 90 percent or greater germination.*

When calibrating a drill, make note of the standard germination of seed as marked on the bag tag. That number can be used with the desired live seeding rate to calculate how many total seeds to drop. For example, if the targeted seeding rate is 35 live seeds per sq ft and the standard germination is 80 percent, then the total seeds needed are 38 seeds per sq ft (30 ÷ 0.8 = 38). Table 4-1 can help with calculations of standard germination and adjusted seeding rate.

Once desired seeding rate has been determined, based on field conditions and standard germination of the seed, then the following methods can be used.

Method 1 (most accurate). A five-step process for proper grain-drill calibration follows:

Step 1. Use Table 4-2 as a guide for seeding rates at various row widths when the seed germination test is 90 percent or higher. Table 4-3 gives estimates of the pounds of seed needed per acre at seeding rates of 30 and 35 seeds per square foot for a known seed size.

Step 2. Calculate the number of seeds required in 50 drill-row feet. For example, with 7-inch wide rows and on-time planting, an appropriate seeding rate would be 20 seeds per drill-row foot multiplied by 50 feet, which equals 1,000 seeds planted every 50 feet of row. Count 1,000 seeds of each variety and put them in a graduated tube, such as a rain gauge, or other clear tube or cylinder. Mark the level of the 1,000 seeds on the tube. Or, if you have scales, weigh the 1,000 seeds of each variety.

Step 3. Hook a tractor to the grain drill so that the drive wheels of the drill can be raised off the ground and the drive gears can be engaged. Jack up the drive wheel so it clears the ground and turn the wheel several revolutions to be certain all working parts are turning freely. Check all drill spouts for blockages.

Step 4. Determine the number of revolutions the drive wheel must make to travel 50 feet. Measure the distance around the drive wheel. This distance can be measured directly with a tape measure or calculated by measuring the diameter or distance across the tire and multiplying that distance by a factor of 3.2. For example, if the drive wheel measures 30 inches from tread to tread (diameter), the distance around the tire should measure 96 inches (30 x 3.2). The number of tire revolutions per 50 feet (50 x 12 inches) equals 600 inches. Divide 600 inches by 96 inches to get 6.25 revolutions of the tire per 50 feet of travel. Make a mark on the wheel so the number of revolutions can be conveniently determined when the wheel is turned.

Step 5. Calibrate the drill.

- Put at least a quart of seed of the variety to be calibrated over at least two drill spouts. (You get better accuracy if you use more than one drill spout.)
- Set the drill on a rate setting expected to be close to that desired, and turn the wheel the number of revolutions needed for 50 feet (as determined in step 4) while catching the seed from each spout in a separate container. Pour the seed caught into the precalibrated tube (as determined in Step 2), and check the level. Repeat for each of the drill spouts.

- Change settings as needed and repeat until you get the appropriate number of seeds (level marked on the tube). Repeat the above steps for each variety.

Option: The above procedure also can be used under actual field conditions by catching seed while the drill is traveling a distance of 50 feet. Use Table 4-4 to determine how much seed should be collected from each row unit.

Method 2 (less accurate). Put enough wheat seed in the hopper of the drill to cover two or three drill spouts. Keep the bag tag for reference.

- Pull one or more hoses off the planter units and attach bags to the bottom of the hoses using either zip ties or duct tape.
- With the drill engaged, drive the drill for 50 feet.
- Pull the bags off the row units and weigh the seed.
- Use Table 4-4 to determine how much seed should be collected from each row unit. Use the bag tag to identify how many wheat seeds are in a pound. Each variety and possibly each seed lot of wheat will be a different seed size.
- Adjust the settings on the drill if necessary.

Method 3 (least accurate). Calculate out how many pounds of seed should be planted for each acre. For example, a target of 35 seeds per square foot is 1,524,600 seeds per acre. If the seed size is 10,000 seeds per pound, the total pounds per acre needed is 152 pounds per acre (Table 4-3).

- Put a specific amount of wheat seed into the drill hopper: Either fill to a certain line inside the hopper or fill the hopper to the top.
- Plant a specified area, either one acre or one-half acre in size.
- Weigh out 200 pounds of seed. Put seed into the hopper until you have filled the hopper back to the specified height.
- Weigh the remaining seed to determine how many pounds were added back to the hopper.

Table 4-4. Weight of seed needed for one row unit and 50 feet of row, depending on seed size, target seeding rate and spacing between row units (assuming 90% seed germination).

Seed Size (seeds/lb)	Row Width (in)					
	7	7.5	8	7	7.5	8
	Seed collected from one unit in 50 ft of row					
	ounces			grams		
30 seeds/sq ft (target seeding rate)						
10,000	1.55	1.67	1.78	44.1	47.2	50.3
12,000	1.30	1.39	1.48	36.7	39.4	42.0
14,000	1.11	1.19	1.27	31.5	33.7	36.0
16,000	0.97	1.04	1.11	27.5	29.5	31.5
18,000	0.86	0.93	0.99	24.5	26.2	28.0
20,000	0.78	0.83	0.89	22.0	23.6	25.2
35 seeds/sq ft (target seeding rate)						
10,000	1.81	1.94	2.07	51.4	55.1	58.7
12,000	1.51	1.62	1.73	42.8	45.9	49.0
14,000	1.30	1.39	1.48	36.7	39.4	42.0
16,000	1.13	1.22	1.30	32.1	34.5	36.7
18,000	1.01	1.08	1.15	28.6	30.6	32.6
20,000	0.91	0.97	1.04	25.7	27.6	29.4
40 seeds/sq ft (target seeding rate)						
10,000	2.07	2.22	2.37	58.8	63.0	67.1
12,000	1.73	1.85	1.97	49.0	52.5	55.9
14,000	1.48	1.59	1.69	42.0	45.0	48.0
16,000	1.30	1.39	1.48	36.7	39.4	42.0
18,000	1.15	1.23	1.32	32.6	35.0	37.3
20,000	1.04	1.11	1.18	29.4	31.5	33.6

Calculation to determine seeds needed:

Ounces of seed needed = [seeds per sq ft x (50 ft x row width in ft) ÷ seeds per pound) x 16 ounces per pound]/0.9

Where seeding rate is seeds per sq ft, row width is in feet, and 0.9 is 90% germination.

Chapter 5

Fertilizer Management

John Grove and Edwin Ritchey

The most important first step in your fertilizer management program is to take a soil sample. Except for nitrogen (N), your fertilizer and lime decisions will be based on the soil test results. It is advantageous to take the sample as soon as possible after harvest of the previous crop to supply necessary phosphorus (P) and potassium (K) throughout wheat growth, from seedling to grain maturity. However, in drought years, soil testing at this time can sometimes result in K soil test values that are artificially low due to reduced K leaching from the previous crop's residues. Extension publication *Managing Seasonal Fluctuations of Soil Tests* (AGR-189) gives recommendations on taking soil samples under such conditions. Refer to Extension publication *Lime and Fertilizer Recommendations* (AGR-1), for specific recommendations based on soil tests.

Nitrogen

Nitrogen is the nutrient requiring the most management. Proper N rate and timing are important for high tiller numbers and yield (Figure 5-1). Nitrogen deficiency symptoms consist of pale green (chlorotic) plants that are poorly tillered (Photos 5-2, 5-3, and 5-5). Excessive N can cause lodging, increased disease incidence and severity, and lower yield. Additionally, excessive N may result in increased levels of N in ground and surface waters, with negative economic and environmental consequences.

Photo 5-1. The wheat is at about Feekes 2.
Stand counts at this stage can help determine how much N to apply for the first application.

N Rates and Timing

Wheat requires a small but important amount of N in the fall, but the fall N rate generally should not exceed 40 lb N/acre. Sufficient fall N stimulates early tillering, which is important for high yields, but does not cause excessive fall growth, which can contribute to lodging and wheat damage during late winter/early spring freeze events. Fall N fertilization also becomes more important with late planting (after November 1) in a wet fall season and with poor initial emergence (less than 25 plants per square foot). The fall N need can usually be met by residual soil N remaining after the preceding corn or soybean crop. Producers needing additional P may select P fertilizer sources containing N (either monoammonium phosphate, MAP, 11-52-0 or diammonium phosphate, DAP, 18-46-0). Summer weather conditions can cause prior corn yields to be either lower or higher than expected. With lower than expected corn yields, higher residual fall soil N levels mean no fall N fertilizer is needed. In fact, this situation often causes greater fall wheat growth and reduces the need for spring N by 30 to 40 lb N/acre. With higher than expected corn yields, low residual fall soil N levels cause a need for 30 to 40 lb N/acre at or near wheat planting.

Nitrogen applied in late winter-early spring is most important to wheat grain yield. Nitrogen can be applied in one (single) or two (split) applications, depending on the crop management strategy, seasonal weather, and time. Research indicates that a split spring N application can increase yield and reduce lodging potential. Split spring N applications are recommended, when possible, but early crop development (adequate tillering), available equipment and logistics cause growers to make a single spring N application.

With the split spring N strategy, the first application should be made in late winter (mid-February to early March, Feekes 2-3) at a rate between 30 and 50 lb N/ acre. Nitrogen applied at this time maintains current tiller numbers and encourages further tillering. Fields with thin stands or little fall tillering should receive higher late winter N rates, while those with high tiller counts (above 70 tillers per square foot) should receive little or no late winter N (Figure 5-2). Excessive late winter N can increase the potential for lodging, disease, and late spring freeze damage.

The second N application should be made in mid to late March (Feekes 5-6). The second N rate for no-till wheat should be sufficient to bring the total spring N rate to 80 to 110 lb N/acre. In no-till fields with yield potential greater than 70 bu/acre, spring N should total 100 to 120 lb N/acre. For tilled plantings the total spring N rate should be decreased by 20 lb N/acre because N fertilizers supply N more efficiently with tillage and N loss potential is lower. If there is some freeze damage or excessively high rainfall in February or March, then the higher N rates should be used. Recent research indicates that applying N at rates higher than those recommended here increases lodging potential and does not increase yield potential enough to pay for the cost of the additional N fertilizer unless specific conditions that require more N nutrition are identified (Photo 5-4 and 5-6a).

The best time to make a single N fertilizer application is when the crop growth stage is Feekes 4-5 (usually mid-March), just before the first joint appears on the main stem and when wheat starts growing rapidly. Rapid growth causes a large demand for N. The rate of N fertilizer for a single application should be between 60 and 90 lb N/acre for fields with a yield potential less than 70 bu/acre and 90 to 100 lb N/acre for fields with greater yield potential. An early (late February) single N application is recommended only when the field's stand or tiller density is low. Earlier N applications are at increased risk of denitrification loss (N loss during extended wet periods). Early single applications increase the risk of spring freeze damage because they encourage earlier heading. Single applications made too early generally result in lower yields and encourage the growth of succulent plants with lush canopies susceptible to diseases like powdery mildew.

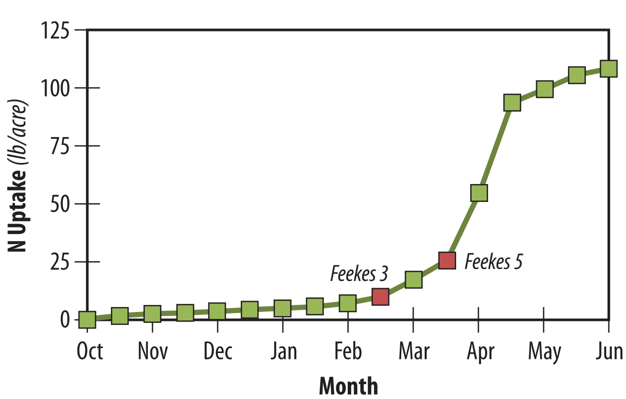


Figure 5-1. Nitrogen uptake during the growth of winter wheat.

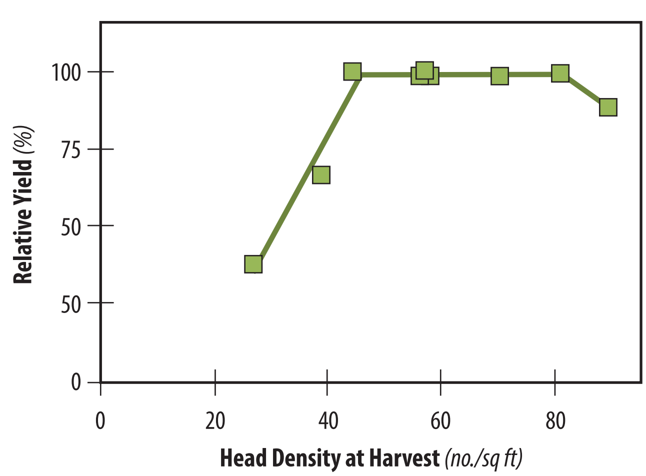


Figure 5-2. Head density influence on relative yield of wheat (average of three varieties in two tillage systems over three years).

Single applications made too late are equally problematic. Nitrogen must be applied in a timely manner to maximize yield potential. Delaying N application after Feekes 6 (appearance of the first joint on the main stem) to an N deficient crop will result in lower yield potential most years. As plant development advances, yield response to added N progressively declines. After Feekes 9 (flag leaf fully developed), there is usually little yield return to added N. However, N applied after Feekes 9 will increase the grain protein concentration.

Fertilizer N Sources

Fertilizer N sources for wheat include urea (45-46% N), urea-ammonium nitrate (UAN) solutions (28-32% N), ammonium nitrate (34%N), and ammonium sulfate (21% N, 24% S). All are equally good sources of wheat N nutrition, when properly managed, in all tillage systems and regardless of previous crop residue. Ammonium sulfate provides plant available S, if needed.

Slow-release N is now available for use on wheat. It consists of polyurethane (plastic polymer) coated urea prills. The trade name is ESN®. This product should be used at the same rate of N as recommended for other N sources. Since ESN releases N slowly, there is no advantage to split N applications with this source. Research results show that ESN applications between January 15 and February 15 produce wheat yields equal to those observed with uncoated urea applied at Feekes 5. Applying ESN after March 1 increases the risk that too little N will be made available for plant uptake during the critical early growth period.

Other N loss inhibitors (e.g. urease and nitrification inhibitors) have shown little benefit in wheat production. Urease (enzyme causing ammonia volatilization from urea-containing fertilizers) activity is slowed by the cooler fall-winter-spring temperatures when wheat fertilizer N is applied. Most Kentucky wheat is produced on well or moderately well-drained soils where saturated soil conditions are relatively rare.. This means that denitrification N loss (biological conversion of nitrate-N to nitrogen and nitrous oxide gases) is usually low. A nitrification inhibitor, which slows the biological conversion of ammonium-N to nitrate-N, is less likely to be needed. Further, wheat competes aggressively for ammonium-N as the crop grows, reducing the amount of ammonium-N available for nitrification. That said, as seasonal weather changes (warmer temperatures and heavier rainfall events) the need for N loss inhibitors as a wheat N management tool could become more important.

Distribution of Fertilizer N and Leaf Burn

Since the difference between enough and too much N is small, field fertilizer N distribution is important. The best distribution is most usually achieved using a sprayer/streamer for liquid sources or an airflow delivery truck for solid materials. Spinner equipped trailer or truck spreaders delivering solid materials are typically less uniform. Distribution of a solid N material that contains a lot of fines (small particle size material) is improved by double spreading (reducing the distance between passes by half and spreading half the desired rate in each pass). If evenly distributed, N from liquid and solid sources perform equally well.

Leaf burn can be a concern with liquid N sources, but this concern can be minimized by using stream or flood nozzles, mixing liquid N with additional water, applying less than 60 lb N/acre per application, and avoiding applications on cold, windy days. Although wheat fertilizer burn is visually disturbing, research indicates no yield reduction occurs when N is applied in late winter-early spring (February and March). Leaf burn after flag leaf emergence (Feekes 9) can cause yield reduction (Photo 5-7).

Photo 5-2. Streaks in this field were caused from anhydrous ammonia applications made before corn where some knife slits were closed, and others were not. Where the knife slits were closed, more N was in the soil (for the corn and then for the wheat), resulting in greener wheat.

Photo 5-3. Streaks in a field are common at field entrances where sprayers overlap and skips in N application are more likely to occur.

Photo 5-4. Wheat varieties at Feekes 5 ready for a second application of fertilizer N.

Photo 5-5. Variations in green color within a field can be due to weather and field conditions as well as N application methods.

Methods to Fine-Tune Wheat Fertilizer N Application Rates

When the amount of fertilizer N to apply in March is in question, a plant sample collected at Feekes 5 and analyzed for N concentration can help. Cut a handful of wheat about ½ inch above the ground at 20 to 30 places in the field, put altogether, mix well, and then place a subsample of the collected plant material in a paper bag. Send the sample to a laboratory with a quick turnaround time so that fertilizer N application will not be delayed. Table 5-1 shows guidelines for fertilizer N rates recommended at various tissue N concentrations.

A chlorophyll meter is a hand-held, non-destructive field diagnostic tool that measures plant leaf greenness. Chlorophyll measurements can provide additional information to help predict the amount of N fertilizer that needs to be added at Feekes 5 or 6 (usually in March). To help calibrate the chlorophyll meter, large amounts of fertilizer N (150 pounds per acre) are added to two or three small field areas or strips in early to mid-February. At Feekes 5, chlorophyll readings are taken on 10 to 20 plants in the high N areas and then on 20 to 30 plants in the rest of the field. The measurements are made on the first fully expanded leaf (leaf with a leaf collar) at the top of the plant. Measurements are made about halfway between the tip and base of the leaf. The following formula is used to make the March fertilizer N rate recommendation:

Table 5-1. Guidelines for fertilizer N application using wheat tissue N concentrations at Feekes 5.

Plant N Concentration *(%)*	Recommended Fertilizer N Rate *(lb N/acre)*
2.3	100
2.7	80
3.2	60
3.6	40
4.0	20

Murdock (unpublished data)

$$N = 6 + (7 \times D)$$

Where N = fertilizer N rate (lb N/acre) needed for optimum growth at Feekes 5 (March) and D = difference between the average chlorophyll reading for the bulk of the field and that found for the high N rate small areas/strips.

Example: Small areas or strips with high N (150 lb N/acre) added earlier give an average chlorophyll meter reading of 52 at Feekes 5 (Zadoks 30). The bulk of the wheat field gives an average chlorophyll meter reading of 45.

52 – 45 = 7
6 + (7 x 7) = 55 lb N/acre =
the recommended fertilizer N rate.

A soil nitrate-N (NO_3) test may be helpful if high N carryover occurs from a very poor corn crop or a heavy manure application. But, in most situations, the soil-nitrate test may not be very helpful. Take soil samples to a depth of 3 feet in February and place them on brown kraft paper to dry. Hand crush the samples, mix well, and then send to a soil test laboratory. The nitrate-N measured in the sample will be reported in parts per million (ppm N), which should be multiplied by 12 to get lb nitrate-N/acre. The test result simply tells you whether more fertilizer N is needed and does not tell you, if needed, the fertilizer N rate to apply. In other words, if the test result is 10 ppm nitrate-N, or higher, no fertilizer N should be added. If the soil test result is lower than 10 ppm nitrate-N, then fertilizer N is likely needed.

Phosphorus and Potassium

Phosphorus is essential for root development, tillering, early heading, grain fill, timely maturity, and winterkill resistance. Wheat takes up about 0.6 pounds of P_2O_5 for each bushel produced, and 80 percent of this ends up in the grain. A soil test is necessary to determine the proper P fertilization rate. Apply P fertilizer as a broadcast application in the fall, prior to seeding, for best results . See Table 5-2 for P_2O_5 concentrations of wheat grain and straw.

Potassium helps to lower the incidence of some diseases and increases straw strength, which helps reduce lodging. Wheat takes up about 2 pounds of K_2O for each bushel produced, but only about 15 percent of this is removed with the grain. A soil test is required to determine the proper rate of K fertilization. Potassium fertilizer should be applied in the fall but can be applied in the spring if needed. See Table 5-2 for K_2O concentrations of wheat grain and straw.

Secondary Macronutrients (Ca, Mg, S)

Calcium (Ca) and magnesium (Mg) deficiencies have not been observed on wheat in Kentucky. Calcium and Mg will generally be adequate if the proper soil pH is maintained using agricultural lime. Additional Mg should be added only if soil test Mg is below 60 pounds per acre .

Historically, wheat sulfur (S) deficiencies have not been widely observed in Kentucky. Lately, S deficiencies have been confirmed. Most all of these are rather "spotty", observed in eroded field areas. Sulfur deficiencies are more likely now due to reduced atmospheric deposition of S, fewer S impurities in fertilizer materials, and greater yield/S removal. The need for S addition to wheat is best determined by a combination of plant tissue analysis of the previous crop and soil testing. If the previous crop's tissue S concentration is deficient/marginal, then the next wheat crop is more likely to experience S deficiency.

Organic matter S and adsorbed sulfate-S are the most important soil S sources. Wheat, as a winter annual, depends more heavily on sulfate-S as organic matter mineralization is lower during late winter and early spring. Recent research shows that Mehlich III extractable S can help indicate the likelihood of wheat S deficiency, depending upon the soil sampling depth. Figure 5-3 illustrates the relationship between the wheat yield increment to S addition and Mehlich III extractable S. When soil test S in the topsoil (0 to 4 inch depth) exceeded 20 lb S/acre, the probability of a positive wheat yield response to S addition was essentially nil and there were several locations where the response was decidedly negative (Figure 5-3a). When deeper depths (either 0 to 8 or 0 to 12 inches) were considered (Figure 5-3b), the average soil test S value generally shifted to the left (subsoil soil test S was lower than topsoil soil test S). But there were several sites where the average soil test S value shifted to the right because subsoil S levels were higher than those found in the topsoil. Those sites usually exhibited a significant negative wheat yield response to S addition. Again, considering deeper sampling depths, no fertilizer S would be recommended when Mehlich III soil test S exceeds 20 lb S/acre.

Table 5-2. Nutrients in wheat grain and straw.

Crop Part	Yield Unit	Nutrient Concentration (lb)		
		N	P_2O_5	K_2O
Grain	Bu	1.2	0.5	0.3
Straw	Ton	12	4	20

Photos 5-6a and 5-6b. Scientists are constantly working with equipment to improve N application, N timing and N use by the wheat crop.

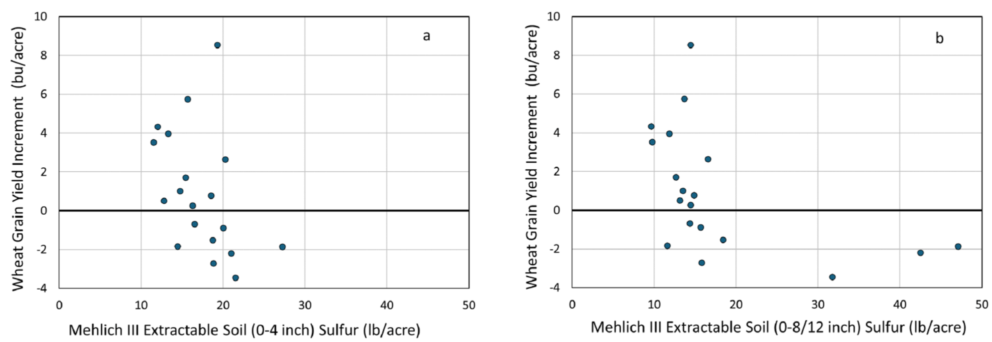


Figure 5-3. Relationship between wheat grain yield increment (bu/acre) to fertilizer S addition and Mehlich III soil test S (lb S/acre) for the: a) 0 to 4 inch depth increment; and b) the 0 to 8/0 to 12 inch depth increment.

When the soil test S value indicates that an S addition is needed, 10 to 20 lb sulfate-S/acre will meet the needs of the crop. For wheat, ammonium thiosulfate (ATS, 12-0-0-26S) is commonly used because it is soluble in UAN solutions. Other sulfate sources include ammonium sulfate (AMS, 21-0-0-24S), potassium sulfate (SOP, 0-0-50-17S), potassium magnesium sulfate (K-Mag, sul-po-mag, 0-0-21-22S) and calcium sulfate (gypsum, 14 to 19% S). If an elemental S material is used, biological conversion of elemental S to sulfate-S is required and is then dependent on the size of the elemental S fertilizer particle (smaller is better/faster), soil conditions (temperature, moisture) and time. Elemental S should be added a year prior to wheat planting to allow for the conversion of S to plant available forms. Figure 5-3b suggests that over application of S can reduce wheat grain yield, so soil S levels need to be monitored.

Micronutrients (B, Cl, Cu, Fe, Mn, Mo, Zn)

Boron (B) has recently been found to limit wheat yield in field research. Soil testing for B will help wheat producers decide when to apply B. Hot water extractable B levels lower than 0.8 lb B/acre indicate a need for B addition. Mehlich III extractable B was also evaluated and was not usable as an indicator of wheat B need. When a need for B fertilization is indicated, the recommended rate is 1 lb B/acre. Uniform application of such a low rate is difficult. There are B sources (e.g. disodium octaborate tetrahydrate) that are soluble in UAN solutions. Others are co-granulated/co-prilled with a dry fertilizer material (e.g. muriate of potash plus sodium and calcium borates/Aspire 0.5% B). Over application of B can result in B toxicity, so B soil testing should be done regularly to prevent this problem from occurring.

The other micronutrients, chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) were not deficient on wheat grown in Kentucky. The best way to determine the potential need for one of these micronutrients is plant tissue analysis. See AGR 92, Sampling Plant Tissue for Nutrient Analysis (https://publications.ca.uky.edu/sites/publications.ca.uky.edu/files/agr92.pdf) for additional sampling instructions and interpretation. Micronutrient deficiencies often occur when the soil pH is too high or too low. A soil pH between 6.0 and 7.0, with a target pH of 6.4, should provide excellent conditions for micronutrient availability and wheat growth. Lime should be applied prior to planting.

Burning Wheat Straw

Burning wheat straw in the field will cause loss of some of the nutrients. Research indicates that losses of carbon (C), N, P and K are as follows:

C - 90 to 100%
N - 90 to 100%
P - 20 to 40%
K - 20 to 40%

Photo 5-7. Most nitrogen fertilizer is applied as a liquid urea ammonium nitrate (UAN) and 28% or 32% N. By using stream bars or stream jet style nozzles, leaf burn from UAN is minimized.

Photo 5-8. Nitrogen test strips in a field with tram lines.

Chapter 6

Weed Management

Travis Legleiter and J.D. Green

The crop rotation system that includes wheat used in Kentucky can contribute to the increased control of certain weed species. The establishment of no-till corn and early planted soybean often break the life cycle of cool-season weeds such as common chickweed, purple deadnettle, or henbit before plants mature and produce seeds. While a competitive wheat stand can help weed control in double-cropped soybeans by preventing or delaying emergence of warm-season weeds.

The crop rotation in Kentucky also has a drawback in that it may perpetuate certain weed species problems. For example, Italian ryegrass often begins in wheat where its seeds are easily spread during wheat harvest with combines. Ryegrass seedlings that emerge in the fall following wheat harvest are able to overwinter and compete the following spring during the establishment of no-till corn. Heavy ryegrass infestations limit no-till corn stands by direct competition as well as harbor voles that feed on corn seed. Studies have shown that if ryegrass is not completely controlled in corn, escaped plants will produce seed and perpetuate the problem in within the entire corn, wheat, doublecrop soybean rotation.

Another unique feature about growing wheat in a rotation with corn and double-crop soybeans is associated with the risk of crop injury caused by carryover of herbicide residues. Growers must use caution in selecting herbicides that do not persist in soil for long periods and cause injury to rotational crops.

The spectrum of weeds in conventional and no-tillage plantings of wheat is similar; however, there are some species that tend to be more troublesome where no-tillage practices are used. Wild garlic populations tend to be greater in no tillage programs compared with programs that use tillage for seedbed preparation. The infestation level of common chickweed, purple deadnettle, and henbit tend to be greater in no-till plantings than in conventional till plantings.

Photo 6-1. Italian or annual ryegrass (*Lolium rigidum*) is a problematic weed in wheat and must be aggressively managed.

Why Control Weeds in Small Grains?

The ability of weeds to compete and limit wheat yield will vary depending on the weed species. Italian ryegrass is the most competitive weed in wheat in Kentucky. One ryegrass plant per square foot can reduce wheat yield by approximately 4%. As much as 90 bu/A of yield loss of wheat has been measured in research trials on ryegrass. Common chickweed has a prostrate growth habit that forms dense mats and tends to be more competitive than purple deadnettle or henbit. In no-till plantings infestations of common chickweed can reduce potential wheat yield by 14%. However, the impact of these weeds is less where preplant tillage is used for preparing the seedbed.

Weeds can also affect the quality of harvested grain and harvesting efficiency. The aerial bulblets of wild garlic contaminate the grain during the harvesting process. Dockage due to bulblet contamination can vary due to a number of factors determined at the grain elevator. In some cases, aerial bulblet contamination may be severe enough to render the grain unfit for sale at the elevator. Giant ragweed, common ragweed, johnsongrass, and marestail are examples of warm-season weeds that produce sufficient amounts of green vegetation in the spring that can reduce harvesting efficiency. The green vegetation may also lead to dockage due to increased moisture and foreign matter. Once wheat has been harvested, the clipped stubble of these weeds may survive and be more difficult to control with burndown applications in double-cropped soybeans.

Weed Scouting

Periodically monitoring fields helps detect problems before weedy plants become too large to control effectively. Critical periods for monitoring weeds are:

Early October. Near the time of planting, especially in no-tillage fields, watch for emerging cool-season weed species that cause problems in wheat .

Mid- to late November (about one month after planting). Once wheat has emerged, watch for cool-season annuals, such as common chickweed, henbit, purple deadnettle, or Italian ryegrass. These weeds initiate growth during early fall and sometimes grow too large to control effectively with spring applications of herbicides.

Early March to early April. Begin monitoring soon after wheat recovers from winter dormancy, but before plants are jointing, because some herbicides need to be applied after tillering but before the jointing stage.

Late May to early June. After wheat has headed, watch for emerging warm-season weeds. A preharvest treatment after the hard-dough stage may be needed to control summer annual weeds and improve harvesting efficiency of wheat, especially where wheat stands are poor and weed infestations are heavy.

Photo 6-2. Common chickweed is a cool-season annual with white flowers that grows prostrate and is sparsely hairy.

Photo 6-3. Shepard's purse is a cool-season annual that grows 12 to 18 inches tall when mature. Rosette leaves are deeply lobed, and stem leaves are arrow-shaped with clasping leaf bases. Its flowers are white with four petals, and its triangular- or heart-shaped fruit is about ¼ inch long.

Photo 6-4. Field pennycress is a cool-season annual with four-petal white flowers. Its basal leaves are egg-shaped and have petioles, while middle and upper leaves are without petioles and have clasping leaf bases. Seed capsules are oval and notched at the tip. Mature plant grows 4 to 20 inches tall.

Photo 6-5. Marestail is an annual that grows 1 to 6 feet tall when mature. Seedlings normally grow as rosettes in fall or late winter and bolt (develop elongated stems) in early to late spring. Stems are hairy and are erect unless damaged from herbicides or mowing. Leaves are hairy with entire or slightly toothed margins. Seed are small achenes that are attached to a pappus or group of hairs.

Scouting Procedures for Weeds in Wheat

Scouting of fields and recording weed infestations can be essential for both short and long term weed management. Scouting of wheat fields will help producers determine what weed control practices are needed for the given season, as well as detect early infestations of problematic weeds.

Step 1. Randomly select survey sites so they are representative of the entire field. Do not survey within 100 feet of a fence or roadway. As Table 6-1 indicates, the minimum number of sites varies according to field size. At each survey site, walk forward 60 feet (approximately 20 steps) and observe for weeds occurring within 5 feet on either side (see Figure 6-1). Each site should be approximately 600 square feet.

Step 2. Infestation levels of weeds can be recorded as estimates of the percentage of ground cover occupied by each species or plant counts within a given area.

For broadleaf weeds and weedy grasses, estimate the percent ground cover at each survey site. A general guideline for categorizing ground cover is light (<5%), moderate (5% to 30%), and severe (>30%). It might help to visualize the total percentage occupied by all weeds, then estimate the percentage occupied by each weed species so that the sum of all species equals the total. For example, at the first site you visit, you estimate that the total ground cover occupied by all weeds is approximately 20%. You then determine that common chickweed occupies about half of the weed cover, with henbit and Italian ryegrass accounting for the remaining space in equal proportions. Based on these observations, common chickweed accounts for 10% of the ground cover (i.e., moderate infestation) and henbit and ryegrass each account for 5% of the ground cover (i.e., light infestation).

Photo 6-6. Purple deadnettle and henbit are cool-season annuals with square stems and reddish to purple flowers. Mature plants grow about 4 to 16 inches tall. Purple deadnettle has uppermost leaves that tend to be reflexed (turned downward) and all leaves occur on petioles. Henbit leaves are not reflexed and its lower leaves have petioles while mid- to upper leaves have no petioles.

Table 6-1. Minimum number of survey sites based on field size.	
Field Size (ac)	**Number of Survey Sites**
1-20	3
20-30	4
30-40	5
40-50[a]	6

a For fields larger than 50 acres, increase number of sites by 1 for each additional 10 acres.

Figure 6-1. Survey diagram.

Use plant counts for describing infestation levels for wild garlic. Estimate the infestation of wild garlic at each site as light (one plant per 600 square feet), moderate (two to five plants per 600 square feet), or severe (more than five plants per 600 square feet). It is not necessary to count all wild garlic that occurs in clusters of small plants because only a few, if any, of the small plants occurring in groups develop aerial bulblets. Focus primarily on single plants, and count each cluster of small plants as a single plant.

Step 3. Record the average size or growth stage of each weed species present in the field. The size of cool-season broadleaf weeds that have a low or spreading growth habit is often based on diameter instead of height of plant. Cool-season grasses are defined by growth stage (number of leaves on main stem of seedlings or number of tillers on established plants). This information can help you select herbicide options and determine when to treat.

Step 4. A field map can be used to show general locations of survey sites and problem areas not included in the survey sites. A weed map helps chart special weed problems and may isolate areas of the field that need treatments. The map can also be a useful reference for planning future weed control programs. Figure 6-2 is a sample weed map of a wheat field.

Economic Thresholds

Economic thresholds for weeds in wheat are not well defined; consequently, growers need to rely on their personal experience to determine if an herbicide treatment is warranted. General treatment guidelines are in Table 6-2 and vary depending on several factors including weed species, cost of treatment, and price of wheat.

Photo 6-7. Yellow rocket is a cool-season annual or biennial that grows 1 to 2 feet tall when mature. Rosette leaves have large terminal lobes and one to four lateral lobes. Upper leaves become progressively smaller and are less deeply lobbed. Flowers are yellow with four petals. Seed pods are cylindrical, about 1 inch long and nearly square in cross section.

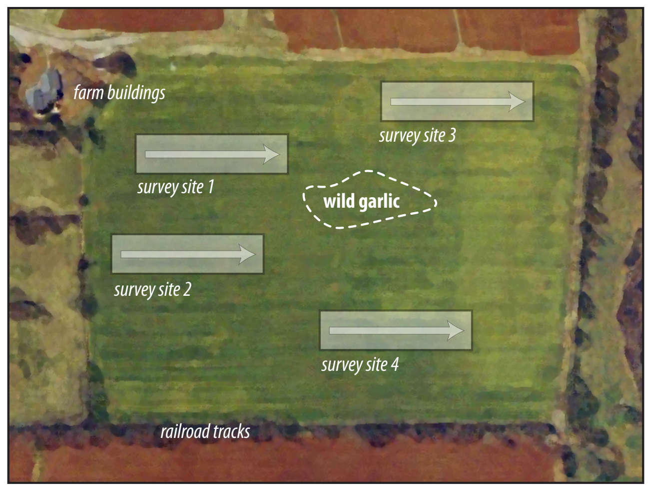


Figure 6-2. Sample weed map.

Table 6-2. Treatment guidelines for wheat.			
	Infestation level[a]		
	Weed Cover	**Wild garlic counts/600 sq ft**	**Treatment Guideline[b]**
Light	<5%	1	Probably no economic benefit to treat
Moderate	5 to 30%	2 to 5 plants	Treatment may or may not be justified
Severe	>30%	>5 plants	Treatment may be justified if implemented in a timely manner.

a The infestation level is the total weed cover (in the fall) or wild garlic counts (in the spring) averaged across survey sites. In some instances the average infestation level may suggest no need for treating, yet a few sites may be heavily infested and warrant control. It may be feasible to spot-treat portions of a field where severe infestations occur based on a weed map.

b Light infestations of problem weeds such as Italian ryegrass may still warrant treatment in order to limit spread of weed seed.

Winter Wheat Calendar

Wheat Growth Stages			One Shoot	Tillering	Tillering

Dormancy

Month	August	September	October	Nov/Dec/Jan	February

Production Practices

- Purchase seed
- Clean, treat seed
- Soil test
- Prepare drill for planting
- Calibrate drill
- Soil probe for compaction
- Fertilize (lime, P, K)
- Tillage (if any)
- Plant seed
- Assess stands
- Early nitrogen applica
- Single
- Take s
- As

Insect and Disease Management

- Scout for aphids and fall armyworms
- Scout for aphids ar

Weed Management

- No-till weed control
- Scout for weeds
- Spray for grasses or broadleaf weeds
- Spray for wild ga chickweed, and c

Stored Grain Management and Marketing

- Inspect grain bins
- Aerate to cool grain
- Aerate to maintain grain temperature

Completed | Jointing | Boot | Heading | Ripening

March | April | May | June | July

- Apply PGR
- Prepare combine for harvest
- tion
- Start harvest
- e nitrogen application
- Start variety selection
- tand counts
- Plant double-crop soybeans
- ssess winter injury
- Plan for next crop
- Finish harvest
- nd armyworms
- Scout for aphids, armyworms, cereal leaf beetle
- Scout for diseases: spray if needed
- rlic, henbit,
  other weeds
- Clean and spray storage bins, prepare dryer
- Aerate to warm grain
- Prepare a marketing plan
- Treat grain for long-term storage
- Summarize and analyze
  Enterprise Costs and Returns (past and present)

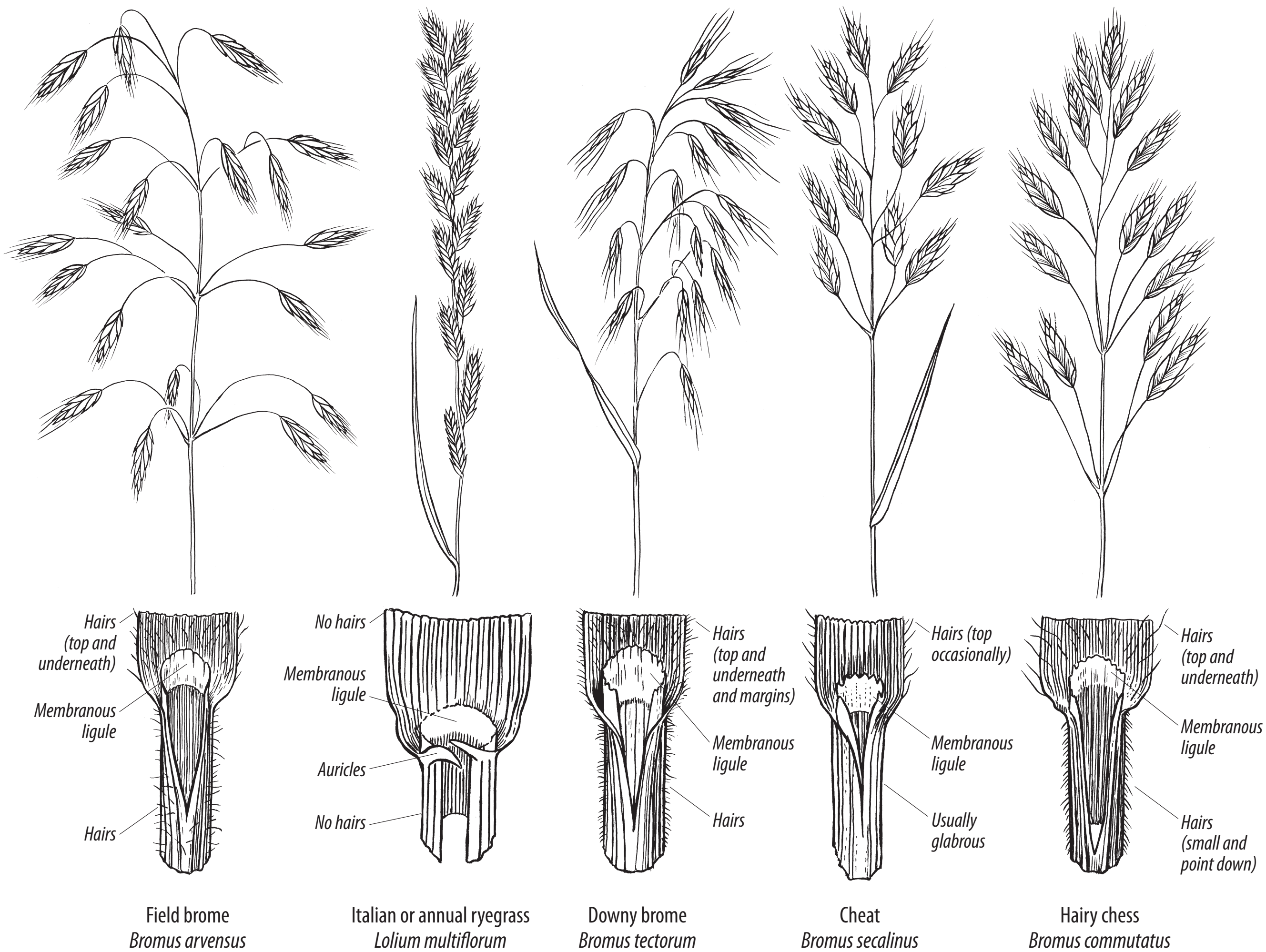
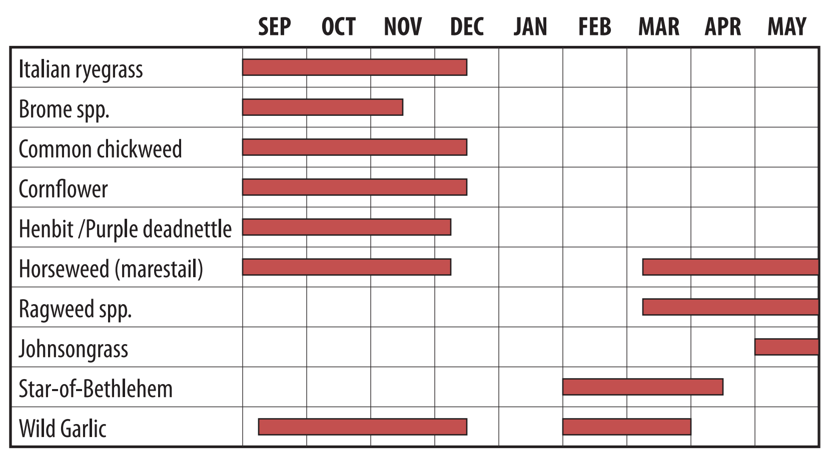


Figure 6-3. Drawings of grass species that occur as weeds in wheat in Kentucky.

Weed Identification

Correctly identifying weeds during their early stages of development is important to help select and initiate successful control strategies. Many weed species look similar during early stages of development. Vegetative characteristics such as shape, color, arrangement of leaves, and location of pubescence (hairs) can aid in identification; providing these characteristics remain consistent under a wide variety of conditions. However, it is not unusual for these vegetative characteristics to vary for some weed species, so they are not always reliable for identification. See the illustrations in this section for descriptions and visual aids to be used in identifying weed species.



*Some cool-season species, particularly ryegrass, may continue to emerge sporadically throughout winter and early spring when conditions are favorable for emergence.

Figure 6-4. Approximate time of significant emergence of weeds in wheat in Kentucky.*

Photo 6-8. Corn Speedwell, *Veronica arvensis*. Corn speedwell is a cool-season annual that grows prostrate. Its lower leaves are opposite, have petioles and are rounded at the base. Upper leaves may be alternate and do not have petioles. Leaves and stems have fine hairs. Ivyleaf speedwell (*Veronica hederifolia*) looks similar, but its leaves have larger toothed margins and more flat or truncated leaf bases.

Photo 6-9. Wild Garlic, *Allium vineale*. Wild garlic is a perennial that grows 1 to 3 feet tall when mature. It has hollow round stem-like leaves and underground bulbs. Aerial bulblets occur in cluster(s) at the top of the plant. Wild onion (*Allium canadense*) looks similar, but its stem-like leaves are flat and are not hollow. Star-of-Bethlehem (*Ornithogalum umbellatum*) also looks similar, but it does not have the garlic odor and its leaves are somewhat flat with a pale midrib.

Weed Control—An Ongoing Process

The timeline for emergence of various weed species in wheat (Figure 6-4) illustrates why weed management can be an ongoing process beginning prior to planting up through wheat maturity.

An effective overall weed management program for Kentucky wheat involves a combination of cultural and chemical practices.

Cultural Practices

Establishing and maintaining a competitive wheat stand contributes to weed control. A seeding rate that results in a minimum of 25 wheat seedlings per square foot is ideal for achieving optimum wheat yields and often limits the amount of weedy vegetation. Planting wheat in narrow rows increases the likelihood for achieving early-season shading and competition to weeds compared with wheat planted in wide rows. Applying nitrogen at recommended rates and times can promote tillering of wheat and limit the presence of warm-season weeds that affect harvest.

Crop rotation often reduces weed populations. For example, infestation levels of wild garlic, common chickweed, and henbit tend to be lower following corn than soybeans. A rotation of corn/wheat/double-crop soybeans is common in Kentucky and is often more favorable for managing weeds in wheat than a soybean/wheat/soybean rotation.

Preplant tillage was once the only option for managing such weeds as wild garlic and certain cool-season weedy grasses in wheat. There are several drawbacks with tillage including added fuel, time, and soil erosion. Unless wheat is organically grown, herbicides have often replaced the need for using tillage for weed control.

Growing wheat in rotation with corn and soybeans can be beneficial in controlling broadleaf weeds, such as common chickweed or henbit. The timely use of burndown herbicides or preplant tillage in corn or soybeans limits production of weed seed by destroying cool-season weeds before they mature.

Sanitation is an effective preventative option for limiting the spread of Italian ryegrass. Clipping infested field borders and waterways ahead of wheat harvest can limit the spread of ryegrass seed; however, it is critical to clean equipment after mowing infested areas. Harvest infested fields last. Cleaning combines after harvesting infested areas is especially important. In instances where a portion of wheat seed is being saved for next season's crop, care should be taken to avoid using crop seed harvested from ryegrass-infested areas. Also, cleaning the harvested wheat seed is important in limiting the spread of seed in future crops.

Chemical Control

Herbicides play a major role in managing weeds in wheat. Herbicide recommendations for wheat production are discussed in the University of Kentucky extension publication: *Weed Control Recommendations for Kentucky Grain Crops* (AGR-6). Always read and follow the restrictions and precautions stated on the label of herbicide products.

Photo 6-10. Hairy Chess *(Bromus commutatus)*, left, and Italian Ryegrass/ Annual Ryegrass *(Lolium multiflorum)*.

Hairy chess is a cool-season annual that grows 1 to 3 feet tall. The leaf blade has hairs, and the leaf sheath has hairs pointed downward. There are no auricles. Cheat, downy brome, and field brome are similar in appearance to hairy chess.

Ryegrass is a cool-season annual that grows 1 to 3 feet tall. The leaf blade is glabrous (no hairs), and the leaf sheath is glabrous and shiny. Clasping auricles are present at the leaf collar.

Examples of issues that need to be considered when using herbicides for weed control in wheat are: 1) application timing, 2) compatibility with other chemicals, 3) varietal sensitivity, 4) herbicide-resistant weeds, 5) herbicide carryover, 6) harvesting restrictions for grain or forage, and 7) cleaning spray equipment.

Application timing. The four periods of time when wheat herbicides are applied are: 1) before wheat emergence, 2) postemergence in the fall, 3) postemergence in late winter or early spring, and 4) preharvest. Important issues associated with each timing and some of the factors that determine when treatments should be applied are discussed below.

Before wheat emergence. Fields planted to no-till wheat often require a foliar-applied burndown herbicide such as glyphosate or paraquat. These herbicides will control grasses and broadleaf weeds and can be applied before or after wheat planting but before wheat emerges. Paraquat is a contact herbicide that is labeled to control annual weeds up to six inches in height. It is usually applied in 20 to 40 gallons of clean water or clear liquid fertilizers per acre. Glyphosate is a translocated herbicide used to control annual and perennial weeds. It is often applied in 10 to 20 gallons of water per acre.

The adoption of soil-residual herbicides ahead of wheat emergence is increasing in Kentucky. The use of soil residual herbicide applied at wheat planting or shortly after wheat planting can reduce emergence of problematic weeds such as Italian ryegrass and annual bluegrass that may have limited postemergence herbicide options. Wheat crop injury is possible with soil residual herbicides. Planting at least 1 inch in depth in a quality seed bed and ensuring furrow closure can minimize this risk. Cool, wet weather or applying soil residuals to extremely dry soils that are then saturated with heavy rainfall are two weather conditions that can also increase crop injury risk. Despite the risk of crop injury, wheat typically recovers from early season injury, in the seldom occasion it occurs, and reductions in yield are rare.

Fall postemergence applications. The likelihood of achieving optimum wheat yield tends to be greater when cool-season broadleaf weeds such as common chickweed, henbit, or purple deadnettle are controlled in the fall rather than in the spring. This is particularly true for no-till plantings. The level of control of these broadleaf weeds is essentially the same regardless of whether treatments are applied in the fall or spring; however, fall tends to be a more favorable timing for optimum control of such weeds as cornflower, annual bluegrass, Italian ryegrass, and certain Brome species.

Fall postemergence sprays can be made soon after wheat emergence and continue through late fall, providing weather conditions are favorable for plant growth. Most postemergence herbicides used in wheat rely on foliar absorption to control weeds; consequently, plants should be actively growing in order to achieve optimum weed control and crop safety. Cold and dry conditions may also delay herbicide activity and in some cases, limit weed control. Heavy rainfall, prolonged cold temperatures, or widely fluctuating day/night temperatures before, during, and shortly after application may lead to crop injury.

There are a few soil-residual herbicides that can also be applied after wheat emergence. These products are often similar to those applied at or around wheat planting, but have a reduced risk of crop injury. These products often only have soil activity alone and need to be tank mixed with a foliar herbicide to control emerged weeds. Premixed formulations of foliar and soil residual herbicides are also available.

Photo 6-11. 2,4-D or Banvel (*dicamba*) injury. Wheat treatment during boot stage of growth with auxin-type herbicides result in trapped heads, missing florets, or twisted awns.

Photo 6-12. Atrazine or Princep (*simazine*) carryover. Wheat plants emerge, then dieback from leaf tips of oldest leaves.

Photo 6-13. Command (*clomazone*) carryover. Wheat plants emerge and often have chlorotic or bleached appearance. Plants may recover from early-season injury.

Late winter—early spring postemergence applications. Wild garlic emerges during the fall and early spring months. Achieving optimum control of this weed is important; therefore, growers tend to delay herbicide applications until late winter or early spring to ensure that most of the population of wild garlic plants has emerged. It is not unusual for growers to apply postemergence herbicides during this time for managing cool-season broadleaf weeds and grasses, especially if conditions in the fall were not favorable for weed emergence and growth.

Several postemergence herbicides can be applied when wheat is coming out of dormancy and in Feekes growth stage 5. This timing usually occurs in March and will vary depending on environmental conditions. Some postemergence herbicides may also be applied up to boot stage, although this practice is seldomly used.

Preharvest treatments. Preharvest treatments are not a part of a planned weed control program but are often used as salvage treatments to help prevent such weeds as Pennsylvania smartweed, ragweeds (common and giant), and johnsongrass from impeding wheat harvest and competing for soil moisture in double-crop soybeans. However, research has shown preharvest treatments are not effective in preventing production of viable seed of winter annual weeds such as Italian ryegrass.

Most glyphosate formulations are registered for preharvest weed control in wheat. Preharvest treatments of glyphosate must be made after the hard dough stage of grain and at least seven days prior to wheat harvest. Different products have different pre harvest intervals. The response of weeds to preharvest treatments can be slow and does not occur as rapidly as with certain harvest-aid applications used in other crops. Preharvest treatments can injure wheat or reduce seed germination or seedling vigor and are not recommended for wheat grown for seed production.

Photo 6-14. Wheat with no injury symptoms (left). Wheat injured by Opsrey herbicide (mesosulfuron-methyl) (right). Leaf burn is more likely to occur when fertilzer N is applied within 14 days of the Opsrey application.

Herbicide compatibility with other chemicals. Herbicides can interact with other chemicals when tank mixed with one another or applied near the same time. These interactions can occur between herbicides or other pesticides (especially organophosphate insecticides) as well as fertilizers or additives. Consult the label(s) for potential problems with physical compatibility of the mixtures as well as the potential for crop injury or poor weed control. Also, be certain the application timing is within the recommended period for all chemicals and fertilizers involved. **Varietal Sensitivity.** Wheat varieties vary in their susceptibility to certain herbicides. Metribuzin is an example of a wheat herbicide that can vary in its ability to cause crop injury based on variety. While the labels of products containing metribuzin may list varieties that are sensitive or tolerant to metribuzin, these lists are typically not a complete list of varieties. The University of Kentucky Small Grain Variety Testing Program is an additional source of information about wheat variety sensitivity. The program evaluates wheat varietal sensitivity to metribuzin approximately every 3 years and results are available online at varietytesting.ca.uky.edu/wheat. When information on varietal sensitivity is not known, treat only a small area until sensitivity is established before treating large acreages.

Herbicide-resistant weeds. Herbicide resistance is the ability of certain biotypes within a weed species to survive a herbicide that would normally control it. A biotype is a naturally occurring individual of a species that often looks the same but has a different genetic makeup than other individuals of the species. The difference in genetics among biotypes within a species accounts for the presence of herbicide resistant weeds.

There are increasing populations of Italian ryegrass in Kentucky that are resistant to the ACCase inhibitor herbicides pinoxaden and fenoxaprop (Axial Bold). Additionally, resistance to ALS-inhibiting herbicides such as pyroxsulam (Powerflex HL) and mesosulfuron (Osprey) is considered to moderate to widespread in Kentucky wheat growing regions. Additionally, Italian ryegrass resistant to glyphosate has been identified in isolated populations. Common chickweed resistant to ALS inhibitor herbicides has been reported at low levels in Kentucky. Although these cases have remained isolated and problematic outbreaks have not been reported. The fact that sulfonylurea herbicides, which are ALS inhibitors, are widely used in Kentucky makes it important that growers be on the lookout for increased problems with ALS resistance.

The potential for weed resistance to develop increases with repeated use of herbicides that have the same site or mode of action. Therefore, monitor herbicides used in all rotational crops and use production practices that prevent or reduce the potential for the development of herbicide resistant weedy biotypes.

Herbicide carryover. Injury due to carryover of herbicide residues is a concern when growing wheat in rotation with corn and double-crop soybeans. Growers must use caution in selecting herbicides that do not persist in soil for long periods and cause injury to rotational crops. While wheat injury due to carryover of atrazine residues has not been a widespread problem in Kentucky, the atrazine label warns that the risk of injury may occur. Simazine is chemically similar to atrazine, but may pose a greater threat to carryover injury to wheat than atrazine. There is a significant risk of injuring wheat where clomazone (Command) was used the previous spring in other crops. See Photos 6-11, 6-12, and 6-13 for injury symptoms due to herbicide carryover.

Certain ALS inhibitor wheat herbicides persist in soil and can cause injury to double-crop soybean. Dry weather and high soil pH are conditions that prolong the persistence of many ALS inhibitor herbicides. Products that contain active ingredients such as chlorsulfuron, metsulfuron, mesosulfuron, or pyroxsulam, have potential to injure double-cropped soybean. It is important that growers consult labels for the required rotational interval and any recommendation on planting a sulfonylurea tolerant variety.

Harvesting restrictions. Most herbicides used in wheat have label restrictions regarding use of the crop as grain or for forage purposes. The EPA has established these restrictions to prevent illegal residues in the harvested grain or forage for livestock feed. When more than one product is included in the spray tank mixture, follow the label that is most restrictive.

Cleaning spray equipment. If spray equipment is not rinsed properly, herbicide residues can accumulate in the spraying system and dislodge in subsequent applications, causing injury to susceptible crops. Check the herbicide label for recommended procedures for cleaning equipment. The procedures may appear cumbersome but are often necessary to remove small amounts of herbicide that could injure other crops.

Chapter 7

Disease Management

Carl A. Bradley

Diseases cause yield and quality losses in wheat grown in Kentucky every year. In Kentucky alone, approximately 1.4% of the potential wheat yield is reduced due to diseases annually, which totals approximately 379,000 bushels worth approximately $2.3 million (Crop Protection Network, https://cropprotectionnetwork.org/). Disease occurrence is driven by the three factors of the plant disease triangle, which are the presence of a susceptible host, the presence of the pathogen, and the presence of environmental conditions that favor pathogen infection. All three factors of the plant disease triangle must be present for a disease to occur. The spectrum of diseases observed can differ from year to year, also due to the factors in the plant disease triangle. Some pathogens may overwinter in Kentucky (i.e. Fusarium head blight pathogen), while others rely on weather systems to bring them into the state (i.e. stripe rust pathogen). Because of the potential yield and quality losses that can occur due to wheat diseases, it is important to understand how to evaluate disease risk, how to identify diseases, and the best management practices available for each disease.

General Disease Management Strategies

Disease management often works best when multiple strategies are deployed together. Understanding factors that affect the risk of disease and utilizing scouting observations to help make disease management decisions are important. Below are the primary disease management strategies available in wheat production.

Cultural Practices

Cultural practices include the following:

Crop rotation. Rotating to a non-host crop can help reduce the amount of inoculum of certain pathogens of wheat. This helps reduce the risk of disease the next time wheat is grown in that field.

Planting date. Altering planting date may allow for wheat to escape infections by certain pathogens depending on the growth stage of wheat, environment, and presence of pathogens.

Photo 7-1. Fusarium head blight (head scab) is caused by *Fusarium graminearum* and must be managed in Kentucky.

Tillage. Tilling the soil may allow for quicker decomposition of pathogen-harboring plant debris. This can help reduce the risk of disease the next time wheat is planted in that field; however, no-till and reduced tillage production systems help reduce erosion, keeping soil as a precious resource. The benefits provided with no-till and reduced tillage systems often outweigh any potential disease control benefits that might be gained from tilling the soil.

Pathogen-free seed. Planting seed that is free of pathogens can help reduce the introduction of new pathogens to a field and can help ensure quick germination, emergence, and a reduced risk of seedborne diseases. Purchasing new seed every year and avoiding planting "bin-run" seed is the best way to help ensure that pathogen-free seed is being planted.

Seeding rate. Utilizing proper seeding rates for optimum stand establishment and yield is important; however, excess stands may encourage foliar and head diseases by reducing air circulation and light penetration into the canopy later in the season.

Proper fertility. Maintaining optimum and balanced soil fertility is important for wheat growth and yield. Excessive or low fertility can lead to increased susceptibility of wheat to diseases in some cases.

Genetic Resistance

Genetic resistance includes planting wheat varieties that have resistance or partial resistance to certain pathogens.

Chemical Control

Chemical control includes the following:

- Application of chemicals (usually fungicides) to seed (seed treatments) to protect against pathogen infection.
- Application of chemicals (usually fungicides) to foliage and wheat heads to protect against pathogen infection.
- For information regarding specific fungicide products available for wheat disease management, please see the annually updated publication, "Fungicide Efficacy for Control of Wheat Diseases" available on the Crop Protection Network (https://cropprotectionnetwork.org/).

Biopesticide Control

Biopesticide control includes application of products that are derived from natural materials such as animals, plants, bacteria, and certain minerals for protection against pathogen infection. Although availability of commercial biopesticides for wheat is limited currently, commercial research and development is ongoing in this area.

Disease Descriptions

The following are general descriptions of the wheat diseases most common in Kentucky. Diseases are listed seasonally. More specific information on each disease is available through your county Extension office. If you are using picture sheets to help identify a disease, be aware that many diseases look similar and can be confused with one another. The University of Kentucky staffs two plant disease diagnostic laboratories to assist you, at no charge, in identifying plant diseases.

Diseases Caused by Viruses

Barley Yellow Dwarf (BYD)

Occurrence. Greenup through late milk.

Symptoms. Primary symptoms include plant stunting, reduced tillering, and yellow to red-purple discoloration of leaf tips and margins. Affected plants may have an unusually erect, "spiked," appearance. Symptoms can occur in the fall or spring but are most common in the spring on the top two leaves of the plants. Infected plants frequently occur in random, small groups. Large portions of fields or entire fields can be affected in severe cases.

Damage. BYD reduces grain yield and test weight.

Key features of disease cycle. Barley yellow dwarf virus (BYDV) is transmitted from infected grasses into wheat and barley by several species of aphids. In Kentucky, the bird cherry-oat aphid and, to a lesser extent, the corn leaf aphid are the most important vectors in the fall. In the spring, overwintered bird cherry-oat aphids and English grain aphids are the most important vectors. Regardless of the aphid species, winged adults immigrate into wheat fields from neighboring and distant sites, feed, and deposit live young on plants. The migratory behavior of winged vectors is the reason why initial BYD symptoms are often seen along field edges and in randomly occurring spots. Typically, the young aphids deposited by winged migrant adults develop into wingless adults that produce more offspring over several generations. These wingless aphids, in turn, produce a small number of winged aphids which fly locally and a larger number of unwinged offspring that gradually spread in fields by crawling from plant to plant.

BYDV is transmitted to wheat through the feeding activities of both winged and wingless aphids. Aphids acquire the virus by feeding on diseased plants for as little as 30 minutes. BYDV cannot be transmitted from adult to young aphids. For this reason, the percentage of winged aphids originally carrying the virus into a field is an important piece of the picture. This percentage can vary greatly from field to field and from season to season. Although you can never tell which aphids are carrying BYDV and which are not, having knowledge of seasonal aphid activities can help you assess the potential for BYDV to occur.

Photo 7-2. Barley yellow dwarf yellow reaction.

Photo 7-3. Barley yellow dwarf purple reaction.

Fall infestation. The numbers of aphids arriving in the fall depend largely on two factors: general growing conditions the preceding summer and when the first hard frost occurs in relation to wheat seedling emergence in the fall. Normal or greater rainfall during the summer usually benefits the aphid population. In drier summers, fewer aphids are produced due to reduced host plant quality. For the same reasons, a greater proportion of BYDV-infected host plants die due to the extra stress.

Crops that emerge long before a hard freeze have a greater potential for aphid infestation (and exposure to BYDV) than those emerging after a hard freeze. The fly-free date, which is used to control Hessian fly infestation, is based on that principle and works well if the freeze occurs when expected.

Winter survival. Aphids arriving in the field during the fall continue to move, feed, and reproduce as long as temperatures remain above about 48°F. Mild temperatures or insulating snow cover during cold spells, usually result in significant survival of the aphids during the winter. Harsher weather results in greater mortality. BYDV-infested aphids that survive the winter months are a primary source of BYD increase in the spring.

Spring infestation. The English grain aphid has a spring flight and arrives about the same time that winter wheat is greening up and the overwintering bird cherry-oat aphid becomes active, in early spring. The numbers of winged adults of the English grain aphid depend on the same factors that determine survival of the bird cherry-oat aphid. Good conditions for survival should produce larger spring flights and, possibly, increase the movement of BYDV within and among wheat fields. Because of this timing the English grain aphid is less likely to be important in the movement of BYDV.

Management. Plant after the Hessian fly-free date. Plant wheat varieties with resistance to BYDV. Limit BYDV infection by controlling aphids with insecticides if aphids reach treatment threshold within 30 days after planting in the fall, or in early spring. As reported in Chapter 8, six (6) aphids per foot of row in wheat 30 to 60 days after emergence justifies an insecticide treatment. If wheat is greater than 60 days past emergence, then 10 aphids per foot of row justifies an insecticide treatment. The greatest probability for the successful use of insecticides exists when the following criteria are met: the crop is planted prior to the fly-free date or first killing frost; drought stress the previous summer was not widespread; there is an extended period of mild weather in the fall; there is a mild winter or good snow cover during cold periods; there is an early, mild spring; at least ten aphids per row foot are observed in the crop; the crop is at the stage prior to flag leaf emergence; and there is high crop yield potential.

If the aphids-per-row-foot level is reached in the fall or spring, it is an indication that at least some of the above criteria have been met. If this aphid level is reached in the fall especially within 30 days of seedling emergence, it may be advisable to make an insecticide application. If it turns cold after the application, wait and scout again in the spring. If the fall and / or winter is mild and winged aphids continue to arrive in the field, continue to scout. It is possible that a second fall application might be needed to achieve acceptable BYD control. Regardless of what was done in the fall, a spring application may be needed if greenup is early and the aphid treatment guideline is reached prior to flag leaf emergence. Failure to make the necessary spring applications may negate any gains associated with fall applications.

Soilborne Wheat Mosaic (SBWM)

Occurrence. Symptoms are most prominent from green-up through stem elongation, but plants may remain permanently stunted.

Symptoms. Leaves of infected plants exhibit a mild green to prominent yellow mosaic. Small green islands and short streaks may be evident on an otherwise yellowed leaf. Infected leaves may be somewhat elongated and have rolled edges; tillering of plants is commonly reduced. SBWM can occur throughout fields but is usually most severe in poorly drained or low areas in fields. Symptoms are most prominent early to mid-season when day temperatures are between 55°F and 70°F. Symptoms tend to fade somewhat as the weather warms up, but in severe cases, plants can remain permanently stunted.

Damage. SBWM reduces yield.

Key features of disease cycle.

Soilborne wheat mosaic virus (SBWMV) is transmitted by a protozoan that lives in the soil, known as *Polymyxa graminis*, which is common throughout Kentucky. Infection can occur in the fall, winter, or spring, but fall infections lead to the most serious problems. High soil moisture favors infection.

Management. Plant resistant wheat varieties. Delay planting past the Hessian fly-free date to limit fall infections. Improve internal and surface drainage of fields where problems exist. Avoid crop production practices that encourage soil compaction.

Wheat Spindle Streak Mosaic (WSSM)

Occurrence. Greenup through flowering.

Symptoms. Symptoms are highly variable, depending on the wheat variety and growing conditions. Foliar symptoms appear as random, yellow to light green dashes running parallel with the leaf veins. Early in the spring, the dashes may have a nondescript appearance. With age, however, some dashes are pointed at one or both ends, hence the name spindle streak. Spindles may have an island of green tissue in their centers. Plant stunting and reduced tillering can be associated with severe infection by the virus. Symptoms usually appear during green up in early spring. Symptoms are frequently uniformly distributed across fields and usually fade as temperatures warm in mid-spring. During cool springs, symptoms may be evident throughout the season.

Damage. WSSM reduces yield.

Key features of disease cycle. *Wheat spindle streak mosaic virus* (WSSMV) is transmitted by a protozoan that lives in the soil, known as *Polymyxa graminis*, which is common throughout Kentucky. Infection can take place in the fall, winter, or early spring. The onset and degree of symptom expression can be highly variable in a field from one year to the next, even though *P. graminis* and the virus are present at relatively constant levels. This is related to the time of year wheat becomes infected and the range and consistency of winter and early s pring temperatures. Disease is favored in wet soils, although excessive moisture is not required for severe disease to occur.

Management. Same as wheat soil-borne mosaic.

Wheat Streak Mosaic (WSM)

Occurrence. Greenup through late milk. Infections evident before heading will have the greatest impact on crop yield. Severe infections are rare in Kentucky and usually only occur in the year following drought conditions when abandoned corn and or soybean fields exist in the vicinity of emerging wheat (fall).

Symptoms. Leaves turn pale green to yellow and exhibit white to cream-colored parallel streaks of varying lengths. Plants may appear flaccid when symptoms develop during stem elongation to flag leaf extension. Severe infections can be evident across an entire field, or symptoms may be evident in hot spots, especially near field edges . Symptoms

Photo 7-4. Wheat spindle streak mosaic.

Photo 7-5. Wheat streak mosaic.

are frequently confused with those associated with other viral diseases, such as barley yellow dwarf (because of leaf yellowing) wheat spindle streak mosaic (WSSM), or soil-borne wheat mosaic (SBWM); because of the streaks which are produced. However, a side-by-side comparison of these diseases indicates notable unique features associated with each disease. Specifically, BYD does not show streaks, and WSSM and SBWM do not show characteristic yellowing of leaf tissue.

Damage. Yield and test weight are reduced. Fields showing extensive foliar symptoms prior to flag leaf extension are frequently destroyed and replanted to either corn or soybean. Plants exhibiting symptoms after flag leaf extension may not have full yield potential, but an acceptable yield can often be produced as long as other stress and diseases are not a factor.

Key features of disease cycle. Wheat streak mosaic virus (WSM) is transmitted through the feeding of wheat curl mites. This pest is not an insect but a mite, more closely related to ticks and spiders. The mite (and therefore the virus) requires a "green bridge" of volunteer wheat or corn (another host crop) that grows in late summer allowing the mite to survive in large numbers until the next wheat crop emerges in the fall. Mites are deposited from near or distant sources into wheat during the fall or spring. Mites that carry the virus feed on plants and spread the virus.

Management. Varieties differ in susceptibility to WSMV, but because the virus occurs so infrequently in Kentucky seed companies usually cannot provide reliable WSM ratings. Thus, it is best to assume that all soft red winter wheat varieties are susceptible to WSMV. The best and most reliable means of managing WSM is to eliminate volunteer wheat and corn from your farm for a period of 30 days before wheat emerges in the fall. This break in the green bridge will greatly reduce the potential for WSM to occur. However, in years where volunteer wheat and/or corn are common on a regional basis, be aware that mites can be spread from distant fields and deposited on your farm, sometime in significant quantities.

Diseases Caused by Bacteria

Bacterial Leaf Streak/Black Chaff

Occurrence. Bacterial leaf streak occurs from flag leaf emergence through grain fill.

Symptoms. Leaves will develop water-soaked streaks of varying lengths that eventually turn necrotic (brown). Severely diseased leaves can die, but this is not typical in Kentucky and may only occur on very susceptible varieties when conditions are favorable for infection and disease development. Black chaff occurs on wheat heads when they are infected by the same bacterium that causes bacterial leaf streak. Infected heads will have glumes with black streaks that follow the glume veins.

Damage. Test weight reduction and possible yield reduction, depending on severity.

Key features of disease cycle. The causal agent, *Xanthomonas translucens*, is seedborne and can overwinter in infested crop debris and on alternative hosts. The disease may be more likely to occur in fields where plants receive wounding from high winds and hail. The causal bacterium is unable to directly infect plants and requires a wound in order to gain entrance into tissue.

Management. Varieties appear to differ in susceptibility to bacterial leaf streak/black chaff, but seed companies typically do not provide ratings for this disease.

Bacterial Mosaic

Occurrence. Bacterial mosaic occurs from flag leaf emergence through grain fill.

Symptoms. Symptoms cause yellow parallel streaks (mosaic symptoms) on leaves, which look very similar to mosaic symptoms caused by viruses.

Damage. Unknown.

Key features of disease cycle. It is presumed that the pathogen survives on infested residues and may contaminate glumes and seeds.

Photo 7-6. Bacterial streak.

Photo 7-7. Wheat head scab.

Management. No management tactics are known. Planting new seed (avoiding bin-run seed) may help reduce the occurrence of bacterial mosaic.

Diseases Caused by Fungi

Fusarium Head Blight (FHB, Head Scab)

Occurrence. Early milk through maturity.

Symptoms. Individual spikelets or groups of spikelets turn cream to white on otherwise green heads. Entire heads may become diseased when extended periods of warm, wet weather occur during flowering and early grain fill. Salmon-colored patches of fungal growth frequently can be seen at the base of infected spikelets. Infected spikelets often fail to develop grain, or grain is extremely shriveled and of low test weight. Shriveled grain may have a pinkish discoloration.

Damage. Yield loss, low test weight, shriveled grain is produced in diseased heads. Germination and viability of seed and milling qualities of grain are also reduced. "Scabby" grain is usually contaminated with mycotoxins, especially deoxynivalenol (DON; a.k.a. "vomitoxin"), which affects feed and food uses. Grain with extremely high DON levels may not be marketable in some regions.

Key features of disease cycle. In Kentucky, the FHB fungus, *Fusarium graminearum*, overwinters primarily in corn stubble. Spores are produced in stubble when temperature and moisture requirements are met. When conditions favor spore production and release, spores blown into fields from remote or local sources and/or are splashed onto nearby heads. If spores are deposited on heads when conditions are warm and moist and wheat is in the early flowering to early grain fill stages, heads can become infected and the characteristic disease symptoms will be evident after a 5- to 7-day incubation period. Epidemics can occur when extended periods of disease-favorable weather occur when much of the Kentucky wheat crop is in the early flowering stages (Feekes growth stage 10.51 and beyond).

Management. Although no completely resistant varieties are available, high-yielding varieties with moderate resistance to FHB are available. Several fungicide products are registered for use on wheat and include FHB as a target disease on their labels (see the most current "Fungicide Efficacy for Control of Wheat Diseases" publication available on the Crop Protection Network, https://cropprotectionnetwork.org/). Foliar fungicides provide the best management effect when applied at early anthesis (flowering; Feekes growth stage 10.51) or within a few days after anthesis begins. Fungicide active ingredient selection is extremely important in FHB management, since some fungicide active ingredients in the strobilurin (quinone outside inhibitor; QoI) class may actually increase DON levels in grain when applied later in the season (heading and beyond). This highlights the importance of applying fungicide products that specifically include FHB on their labels. Although crop rotation and tillage may help reduce inoculum within a field, overall, they provide little effect on FHB because of the widespread occurrence of the causal fungus in Kentucky. Consequently, when conditions favor spore production and dispersal, there are so many spores of the FHB fungus blowing around, that anything that is done on an individual field basis has only a minor impact on FHB/DON. Planting different varieties that flower at different times may reduce the overall incidence of FHB in a moderate to light disease year. Multi-state research has shown that the greatest management effects occur when different management practices are integrated (i.e., planting moderately-resistant varieties and spraying an effective foliar fungicide at the right timing). An online FHB risk map tool is available during the growing season to help with fungicide application decisions for FHB management (https://www.wheatscab.psu.edu/).

Photo 7-8. FHB effect on seed.

Photo 7-9. Stagonospora leaf and glume blotch.

Glume Blotch

Occurrence. Early milk through maturity.

Symptoms. Infected glumes and awns develop gray-brown blotches, usually starting at the tips of glumes.

Damage . Infected heads develop low test weight and shriveled grain. Seed quality can be reduced, which can result in problems with stand establishment if a high percentage of diseased or infested seeds are planted.

Key features of disease cycle. Spores of *Parastagonospora nodorum* blow to or are splashed onto wheat heads. Spores originate from diseased foliage (see leaf blotch complex) or infested wheat stubble. Infections occur during periods of extended wetness, especially when nighttime temperatures are warmer than normal.

Management. No highly resistant varieties are available. Plant moderately resistant varieties and high-quality, well-cleaned, disease-free (e.g., certified) seed. Control foliar and head infections on susceptible varieties with fungicides applied prior to the appearance of widespread symptoms. Avoid nitrogen excesses and deficiencies, which encourage glume blotch.

Leaf Blotch Complex (Stagonospora nodorum blotch, Septoria tritici blotch)

Occurrence. Stem elongation through late dough.

Symptoms. Foliar symptoms of Stagonospora nodorum blotch and Septoria tritici blotch are similar and can occur simultaneously, thus, they are referred together as the leaf blotch complex. Symptoms include brown, elongated rectangular to lens-shaped lesions with irregular margins and yellow halos. Lesions have numerous pinpoint black specks (pycnidia) throughout. Pycnidia are most evident in the morning following heavy dew or after rain. Symptoms usually start in the lower leaves and move upward. Lesions are often first found at the tips of leaves.

Photo 7-10. Speckled leaf blotch.

Damage. Yield and test weight are reduced.

Key features of disease cycle. *Parastagonospora nodorum* and *Zymyseptoria tritici* are the causal agents of Stagonospora nodorum blotch and Septoria tritici blotch, respectively. Both fungi overwinter in wheat stubble of previously diseased crops or on infested seed. Spores are produced during wet weather and are either splashed or wind-blown onto leaf surfaces. Infection of plants by *Z. tritici* is greatest during cool to moderate temperatures. Infections by *P. nodorum* can occur over a wide range of temperatures but are favored in the mid to late stages of crop development. The fungi that cause leaf blotch complex can occur individually in a crop or at the same time, even on the same leaves.

Management. Plant resistant varieties and high-quality, well-cleaned, disease-free seed that is treated with a fungicide (e.g., certified seed). Avoid excessive seeding rates as well as nitrogen deficiencies and excesses. Protect the upper two leaves and heads of susceptible varieties with fungicides. Strains of both *P. nodorum* and *Z. tritici* that are resistant to strobilurin (quinone outside inhibitor; QoI) fungicides have been observed in Kentucky wheat fields. Crop rotation and tillage of infested wheat stubble may help in leaf blotch management, but neither provides a high degree of control.

Leaf and Stripe Rust

Occurrence. Seedling emergence through maturity.

Symptoms. Leaf rust is initially evident as pinpoint, yellow flecks on upper leaf surfaces. After about one week, flecks develop into orange pustules, each containing many thousands of spores. Many things can cause wheat leaves to fleck, so flecks are a good indicator of leaf rust only when at least some mature pustules are also visible. Leaf rust pustules usually form in random patterns, primarily on the upper surfaces of leaves. Stripe rust appears in linear rows, of varying lengths, of bright yellow-orange pustules that are oriented with leaf veins. Symptoms can also develop on glumes.

Damage. Yield and test weight are reduced. Indirect losses associated with crop lodging can occur when rust is severe.

Key features of disease cycle. *Puccinia triticina* and *Puccinia striiformis* cause leaf rust and stripe rust, respectively. Both rust fungi can overwinter in Kentucky, but more commonly spores are blown into Kentucky from the south. Stripe rust can develop at lower temperatures than leaf rust, so it frequently can be found prior to head emergence. Leaf rust spores blow in and infect foliage during moderate to warm temperatures, and six or more hours of continuous leaf wetness. Leaf rust is a potentially explosive disease and requires just a short time to go from low to epidemic levels on a susceptible variety. Symptoms are often first evident in hot spots 5 to 10 ft in diameter. From a distance, these affected areas will appear yellow. Close inspection of plants will reveal characteristic stripe rust lesions, with pustules. If left to develop unchecked, leaf or stripe rust can develop to the point where entire fields are affected.

Photo 7-11. Wheat leaf rust.

Photo 7-12. Wheat stripe rust.

Photo 7-13. Loose smut.

Management. For both diseases, plant resistant or moderately resistant wheat varieties. Avoid excessive stands, which tend to decrease air circulation and light penetration into the crop canopy. Protect the upper two leaves of susceptible varieties with foliar fungicides. Most modern foliar fungicides do an excellent job with managing rust diseases, but they must be applied before significant infection has occurred to perform acceptably. Crop scouting plays a key role in rust management.

Loose Smut

Occurrence. Head emergence through maturity.

Symptoms. Floral parts of infected plants are transformed into a mass of black, powdery spores. Diseased tillers develop heads before healthy tillers.

Damage. Seed infected with the smut fungus will produce smutted heads, with 100 percent grain loss being experienced by those heads.

Key features of disease cycle. Spores produced by diseased heads blow to and infect the flowers of healthy heads during rainy weather. Infected flowers give rise to infected grain. Infected grain develops normally but harbors the loose smut fungus. The fungus remains dormant until the seed is planted and germinates. Infected plants appear to be normal but develop smutted heads.

Management. Plant certified or otherwise high-quality, disease-free seed. Infections in seed can be eradicated by treating seed with various systemic fungicides.

Powdery Mildew

Occurrence. Stem elongation through maturity.

Symptoms. White, powdery patches form on upper leaf surfaces of lower leaves and eventually can spread to all aboveground portions of plants. Patches turn dull graybrown with age.

Damage. Yield and test weight are reduced, directly due to infection and indirectly due to harvest losses associated with lodging.

Key features of disease cycle. *Blumeria graminis* is the causal agent of powdery mildew of wheat and overwinters in wheat residue. Spores of the fungus are blown onto leaves, and infections can take place in the Fall or Spring. Infections occur during periods of high moisture (not necessarily rain) and cool to moderate temperatures.

Management. Plant resistant or moderately resistant varieties, and avoid farming practices that favor excessively dense, lush stands. If necessary, protect upper leaves and heads of susceptible varieties by using foliar fungicides.

Take-all

Occurrence. Stem elongation through maturity.

Symptoms. Infected plants appear normal through crop greenup, but eventually become stunted and uneven in height, with some premature death of tillers. Tillers that head out are sterile and turn white or buff colored. Affected plants easily can be pulled out of the soil because of extensive root rotting. A shiny black discoloration is evident under the leaf sheaths at the bases of diseased plants. Infected plants can occur individually, but more typically occur in small to large groups. Entire fields or large portions of fields can be diseased in severe situations.

Damage. Diseased plants yield little or no grain.

Key features of disease cycle. *Gaeumannomyces graminis* var. *avenae* and *tritici* survive from season to season in infested wheat and barley stubble and residue of grassy weeds. Infections are favored in neutral to alkaline, infertile, poorly drained soils.

Photo 7-14. Powdery mildew.

Photo 7-15. Take-all crown symptoms.

Photo 7-16. Early take-all.

Management. Allow at least one year (preferably two years) between wheat (or barley) crops. Soybean, corn, grain sorghum, and oats are non-host crops. Maintain excellent control of grassy weeds and volunteer wheat in fields that are part of your farm's wheat operation. Fertilize fields and lime fields according to soil test recommendations. Do not allow fall or spring nitrogen deficiencies in the small grain crops. Improve surface and internal drainage of fields.

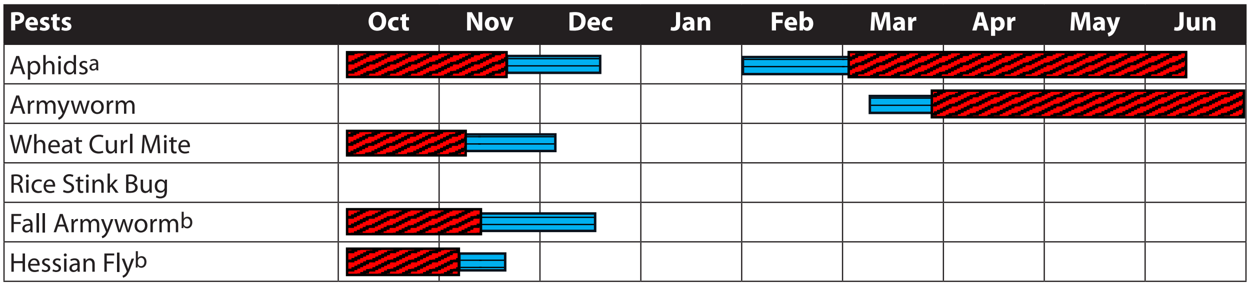
Photo 8-1. Lady beetle C-7 is a beneficial insect that feeds on aphids. Proper identification of insects is critical to pest management.

Chapter 8

Insect Management: Insect Pests

Raul T. Villanueva

From mid-October to June there are several arthropod pests that can cause injuries or transmit pathogens in wheat in Kentucky. Among them, there are at least five key pest groups that may become abundant and affect wheat production: aphids, wheat curl mites, armyworms, rice stink bug, and Hessian flies. Any of these pests may cause yield losses in small cereals when populations increase. Injuries can be caused directly to foliage, stems, heads, or through transmission of viruses. When farmers follow integrated pest management practices including cultural practices (crop rotation, planting resistant varieties, planting after the fly-free planting date, and judicious nitrogen use), regular monitoring of pests, use of economic thresholds, and necessary pesticide treatments, the risk of economic losses are low. Figure 8-1 indicates periods when insects should be monitored.



The red bars with diagonal stripes indicate periods when population outbreaks may occur and cause economic losses, whereas the blue bar with horizontal stripes indicate periods when populations may be low.
[a]Early planting and warm fall weather increases potential for aphids and barley yellow dwarf virus.
[b]Wheat planted before the fly-free Hessian fly dates may be subject to attack by this pest

Figure 8-1. Seasonal insect and mite occurrence in Kentucky wheat.

Key Considerations to Reduce Insects and Mites Pests of Small Cereals

Cultural practices such as the use of resistant cultivars to pests or viruses, elimination of weeds which serve as alternative hosts, or modifying planting dates can be powerful tools to reduce pests or damage. For example, effects of barley yellow dwarf virus (BYDV), one of the most important diseases in wheat, can be reduced with resistant cultivars, likewise, the fly-free planting dates to control Hessian flies still hold and reduces risk to fall armyworm. Weather is also important, the warmer fall temperatures and warmer temperatures during the winter months (temperatures >55°F (>10°C)) favor aphid reproduction and increase feeding activity. These climatic changes require farmers to scout for pests to determine the need to spray over a longer period of time.

Integrated Pest Management

IPM is based on the principle that pesticides should be used in combination with other tactics and be applied if pest populations approach economic levels and can potentially cause losses to the crop. Before the application of insecticides, pests need to be monitored and levels compared to research-based thresholds. Applicators must verify that the insecticide is labeled for the target pest and understand the directions for use and any restrictions listed on the label. Select a rate consistent with the level of the infestation and size of the insects present. Many labels may recommend low rates for light to moderate infestations or for insects in the early stages of development; high rates may be needed for severe infestations or pests in later, more damaging stages.

Field Scouting

Scouting is a major component of IPM, and in small grains this practice should be conducted throughout the growing season. Proper sampling and scouting procedures can help growers to make decisions to manage costs and avoid the unnecessary use of pesticides. For aphids, scouting may be conducted during emergence (two-leaf stage when stand counts are evaluated), at the four- to five-leaf stage, then routinely every one or two weeks. In the spring, pay close attention to the flag leaf and during flowering for armyworms or aphids. Locations to scout pests must be distributed across the entire field and can be done by following a "W" or a "Z" pattern in order to be representative of the entire field.

Field scouting procedures differ among the key pests. Use the appropriate sampling method for that specific pest so results can be compared to established treatment guidelines. In some cases, methods for a pest may change during crop development. As an example, aphid control prior to emergence of the flag leaf is based on the average number of aphids per foot of row. A different rating system is used for these insects after the head emerges. (See below).

Individuals that scout for pests should carry some basic tools to make identifications of pests; this may include a 10X handheld (for mites) or 3.5X headband magnifier, pocketknife, camera, or cellphone to help with pest ID, as well as container to collect insect or plant samples.

Major Pests

Aphids

Several aphid species are present in wheat fields in Kentucky (Table 8-1). Adults and nymphs can appear any time after plant emergence and can vectors of viruses into small grain crops. The bird cherry-oat aphid (BCOA) (Photo 8-1) is the most important vector, however, all of them can potentially transmit viruses.

The BCOA and corn leaf aphids are the most common fall species, followed by the English grain aphid. English grain aphid is most abundant during spring and early summer. Greenbug has caused a lot of damage in the past in the U.S. wheat industry, recently however, this species is relatively rare in Kentucky and many natural enemies might be reducing levels of this pest.

Occurrence. Aphids may be found any time after plant emergence, especially in cover crop fields and fields that are planted with seeds untreated with insecticide. Populations start to appear in early March as temperatures increase. Cover crop is usually planted with untreated seeds or purchased bulk seed, that can be refugia of insects (specifically aphids) and diseases.

Description and Management. Aphids are the most important insect pests of small grains in wheat in Kentucky. They are piercing sucking insects with a pear-shaped body form. Color of the aphid species in wheat varies from reddish green or green for the bird-cherry oat aphid, dark green for the corn aphid, green to light green or yellowish for the English grain aphid and the greenbug. Their piercing-sucking mouthpart looks like a small syringe (tube) arising from under the head. In addition, all have a pair of cornicles in the posterior end of the abdomen that can be used to identify some species. The bird-cherry oat aphid is the most abundant species observed in Kentucky. This species is a host-alternating aphid, but if the climate is sufficiently warm, asexual reproduction can continue year-round on graminaceous plants. Asexual populations of bird-cherry oat aphid can occur in Kentucky and when temperatures increase, they can colonize wheat fields very early in spring.

Insecticides spray may need to be conducted to reduce aphid populations. Sprays need to be well timed in the fall (if untreated insecticide seeds are used or warmer temperatures are 25 days after insecticide treated seeds are emerged), winter or spring. When scouting, attention may be put into parasitized aphids or aphids infected by entomopathogens (Photos 8-4 and 8-5), if any of them are present insecticide sprays may be skipped.

Table 8-1. Rating based on number of aphids per head.

Common Name	Scientific name	Key Characteristics
Bird-cherry oat aphid (BCOA) (Photo 8-1)	*Rhopalosiphum padi*	It is the most abundant aphid in wheat in KY and has an olive-green color and a red-orange patch on the rear end of the aphid. The color of these aphids found in winter and early spring may be totally black in color. The BCOA is a very efficient vector of the virus that causes barley yellow dwarf disease (BYD)
Corn leaf aphid	*Rhopalosiphum maidis*	It is dark green to bluish green, with black cornicles (tail pipe looking projections on the rear of the aphid) and black antennae and legs. It sometimes occurs in seedling wheat in autumn or on mature wheat in late spring.
English grain aphid	*Sitobion avenae*	This aphid is larger than greenbug and has long black legs and narrow, long black cornicles (tail pipe looking projections on the rear of the aphid). It is commonly found in the heads of wheat compared with where bird cherry-oat aphid occurs.
Greenbug aphid	*Schizaphis graminum*	Greenbug is lime-green colored with a darker green stripe running down the length of its back.
Rice root aphid	*Rhopalosiphum rufiabdominalis*	Not reported in KY. This aphid occasionally infests wheat in the southern states. This aphid is dark green with brown, red, or yellow tones. It causes injury mainly to the roots or stem.
Russian wheat aphid	*Diuraphis noxia*	Not reported in KY. Established in High Plains Region (OK, TX, CO). This species is wingless, pale yellow-green or gray-green insect lightly dusted with white wax. It feeds and develops on grass and cereal species. The legs, antennae and cornicles are short compared to other aphids on small grains.
Hedgehog grain aphid (Photo 8-2)	*Sipha maidis.*	Not reported in KY. Found in California (2007), Georgia (2012), Alabama (2015), and is established in Oklahoma. Aphid is recognized easily by its black color and completely sclerotized (hardened) dorsum (upper side or back), and spines.

Photo 8-1. A bird-cherry oat aphid is common in the fall, are dark green with a red band across the end of the abdomen.

Photo 8-2. Hedgehog grain aphid nymphs (left) and adult (right). Notice the dark coloration and spines.
(Photo: Melissa Franklin, Colorado State University)

Damage. Feeding of these aphids does not usually cause chlorosis or other visible damage to wheat plants, however, high populations may affect the quality of the grain lowering protein content and test weight. Aphids are important due to their role as vectors of BYDV and other viruses. Infection of BYDV during early growth stages is more damaging, as it can cause stunting and yellowing to purpling of the plants resulting in severe yield loss.

Scouting. Scouting should be conducted in the fall. If insecticide treated seeds are used, start to scout 20 to 25 days after planting. If untreated seeds are used scouting should be done since germination of seeds. Also, if temperatures are above 45°F in February and March scouting should be conducted weekly. Scouts should examine three separate 1-foot lengths of row at each 20 acres location within a field. An additional site should be added for each additional 10 acres. For example, there would be six locations in a 50-acre field, three sites for the first 20 acres and three more for the additional 30 acres. The samples should be collected from randomly selected sites away from field edges and waterways. To scout, look over the entire plant, especially near the soil line. Count and record the number of aphids within each 1-foot section of row, then calculate the average. This is used to make decisions on the need for insecticide application to reduce aphid populations and prevent BYDV infections (Table 8-2). After heads have emerged in the spring, examine 10 grain heads at each scouting location. Record a rating of infestation based on the number of aphids per head (Table 8-3). During this seed fill stage, a control should be considered if an average rating of 2-moderate (50-100 aphids per foot of row) or greater is observed.

Table 8-2. Aphid economic thresholds for insecticide applications to prevent infections of bydv.

Crop age (days post emergence)	Number of aphids per foot of row to justify insecticide treatment
≤ 30 days	3
30 to 60 days	6
> 60 days	10

Table 8-3. Rating based on number of aphids per head.

Rating	No. Aphids
0—none	none
1—slight	<50
2—moderate	50 - 100
3—severe	>100

Photo 8-3. Parasitized aphids. Note the tan color compared to the green healthy aphids. Tiny wasps emerge from these "mummified" aphids to attack other healthy aphids.

Photo 8-4. (top) Aphid nymph with fungal spores that start to colonize its body and (bottom) aphid killed by an entomopathogen fungus.

Wheat Curl Mite

Scientific name	Taxonomic classification
Aceria tosichella	Acari: Eriophyidae

The wheat curl mite (WCM) is microscopic (cannot be seen by the naked eye but 10X magnifiers lenses can help to detect its presence), cigar-shaped in appearance, white colored, and has two pairs of legs compared to other mites or ticks. It has been detected in many parts of the world including North and South America, Europe, Asia, and Oceania. Although it is in Kentucky, this mite has only been reported in low numbers. It is important in North Central states such us Nebraska, Montana, Ohio and in many provinces of Canada. This mite can vector at least four plant viruses among different cereal crops. It can transmit the wheat streak mosaic virus (WSMV), high plains wheat mosaic virus (HPWMoV), brome streak mosaic virus (BrSMV), and triticum mosaic virus (TriMV). This mite can feed on many grasses including corn grown near winter wheat. Corn in these locations is also affected by maize red stripe virus, which is synonym of HPWMoV, although infections do not affect yields. But corn serves as a summer bridge host favoring the spread of the WSMV year-round. This mite requires a "green bridge" or volunteer wheat in late summer which allows the survival of mites to survive until the Fall wheat crop emerges (See ENT-117). Management of grasses surrounding fields may be tool to reduce populations of wheat curl mites.

Occurrence. Wheat curl mite can infest plants any time before frost.

Description of injury. Feeding causes leaves to roll up, giving an "onion leaf" appearance. Mites can be seen by carefully unrolling the leaves and examining with a 10X hand lens. Taking a picture with a cell phone and enlarging the image may also reveal mites.

When to scout. There are no standardized scouting procedures for this pest. Wheat curl mites are commonly found on the stems and undersides of leaves. Plants should be examined from several locations on the W or Z pattern. In Kansas, this complex of diseases transmitted by the WCM caused a loss of 19.2 million bushels of wheat, that was 5.6% yield loss in 2017.

Comments. There is no rescue treatment for WSMV. Management recommendations include removing the "green bridge" plants that can allow mites to overwinter and over summer, such as removal or control of grassy weeds and volunteer wheat, altering planting date to avoid the mite vector, and use resistant cultivars.

Armyworm and Fall Armyworm

Common name	Scientific name	Taxonomic classification
Armyworm	*Mythimna unipuncta*	Lepidoptera: Noctuidae
Fall armyworm	*Spodoptera frugiperda*	Lepidoptera: Noctuidae

The **armyworm** (Photo 8-5) is a sporadic pest of wheat during later stages of development in the Spring, and other gramineous plants such as barley, fescue, rice, and other crops. In the past, widespread outbreaks have occurred in the United States at irregular intervals of 5 to 20 years. Reasons for these outbreaks are not clear but are most likely related to environmental factors favoring the overwintering and early-spring survival of armyworms. Young armyworm larvae feed on the surface of leaf blades leaving an epidermal layer, whereas older larvae consume the entire leaf blade. Under high armyworm populations, late-stage larvae may move from leaf feeding to feeding on the awns and developing seeds and may cut the wheat heads from the stems. Economic thresholds for armyworms on wheat are poorly defined, in part because of the sporadic nature of major armyworm outbreaks. The effects of leaf feeding on crop yield are neither easily determined nor well understood. Consequently, damage or treatment threshold recommendations vary from state to state.

Fall armyworm (FAW) is native to tropical and subtropical regions of the Americas, it has a strong flight capacity and can cause serious injury to corn, sorghum, forage, turf grasses and more than 350 other plant species (Photo 8-6). Two strains or races are known for the FAW, the corn-strain and rice-strain. The corn-strain FAW prefers corn, sorghum, barley, and wheat. In recent years, the corn-strain of FAW reported for the first time in Africa in 2016, then in India, Myanmar, Thailand, and other Southeast Asian countries including China in 2018. Nowadays, FAW is considered a global pest. The FAW rice strain is associated with rice and forage grasses.

Occurrence. Most armyworm feeding occurs from late May through early June. Damage starts at the leaf edge and progresses inward, giving a scalloped appearance. While this can reduce yields, the most serious losses occur when armyworms chew through stems and clip off the grain heads. (See ENT-111). FAW is also sporadically present that in some years reaches high populations. Unlike armyworm, FAW can cause damage to early stages of wheat development from October to December.

Historic data on the presence of these two pest populations can be tracked on the IPM web page, (See Historical UK-Insect Trap Data) https://ipm.ca.uky.edu/trapdata.

Description. Armyworm larvae are greenish brown with a narrow stripe down the middle of the back and two orange stripes along each side. The yellowish head is honeycombed with dark lines. Armyworms are about 1½ inches long when full grown. Larva of FAW has an inverted "Y" white mark on the dark head, The FAW head is not honeycombed.

Photo 8-5. Armyworms feed on the leaves and may clip awns.

Photo 8-6. Fall armyworms feed on emerging tillers.

Damage. Armyworms are primarily leaf feeders, but they will feed on awns and tender kernels or clip off the seed heads. Infestations are more common in barley than in wheat. Armyworms may feed on oats, rye, and some forages. FAW can consume emerging small cereals (Figure ENTO-7) and if outbreaks occurred, they may wipe out great portions of plants in fields.

When to scout. Mid-April through maturity for armyworms and October to December for FAW.

How to scout. Visit each field at least once a week. First, check field margins and lodged grain. For armyworms begin surveying in the standing grain. Monitoring for FAW in wheat is done searching for presence of window-paned leaves (Photo 8-7) or chewed leaves along the wheat field margin, FAW often move in from road ditches and weedy areas. A suggested treatment threshold by Kansas State University is two to three larvae per linear foot of row in winter wheat. Armyworms and FAW feed during late afternoon, night, and early morning, thus these are the periods to monitor for them. They may be hidden under debris on the ground when you are in the field during the day.

Photo 8-7. Fall armyworm "windowpane" feeding damage on wheat leaf. *(Photo by Holly Schwarting, Kentucky State University Research and Extension)*

For armyworms sample 4-square-foot areas at locations throughout the field using the number of sites determined by the "Field Scouting" section. Walk at least 30 paces into the field before sampling. Pick spots randomly and look at the leaves for signs of chewing damage. Armyworms feed from the edge of the leaf toward the mid rib. Examine the ground for dark fecal droppings and look for the larvae under surface litter or in soil cracks. For both, armyworms and FAW earlier instar larvae are harder to detect but noticing windowpane damage or fecal pellets may be easy to detect. Note average larval length. Walk to the remaining locations and repeat the process.

Record. Record the number of worms present in each sample. Note the average length of the armyworms in each area.

Economic threshold. An average of 16½- to ¾-inch-long armyworms per 4-square-foot sample is the economic threshold for Kentucky. In Arkansas, the recommended treatment threshold has been five to six larvae (size not specified) per 1 square foot or when head cutting is occurring. In contrast, the threshold in Maryland is one sixth-instar larva per foot of row.

Comments. Armyworms longer than 1¼ inch may have completed most of their feeding. If the grain is nearly mature and no head clipping has occurred, controls are not advised. Warm spring weather favors parasites and diseases that attack armyworms. Note on your scouting report the percentage of worms parasitized or diseased. Parasitism and larva with entomopathogens may indicate that an application of insecticides may be not necessary.

Hessian Fly

Common name	Scientific name
Hessian Fly	*Mayetiola destuctor*

The Hessian fly was one of the most destructive pests of wheat in the past. Hessian fly is found in most regions of the world. It originated in the Middle East and is one of the oldest documented invasive species in the US, first reported in New York in 1779. Many grasses serve as hosts, most of them belonging to the major small cereal crops such as wheat, barley, and rye. In choice tests, Hessian fly prefers wheat, followed by rye, then barley. It causes stand reduction at planting and stand loss and lodging of the plants in the spring. However, with the fly-free planting date (Figure 8-2) in different latitudes of Kentucky (and the rest of the states) and using resistant varieties, injuries by this pest has been diminished.

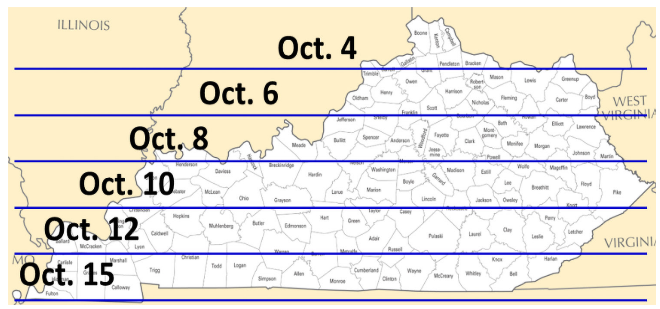


Figure 8-2. Fly free planting dates for small grains for Kentucky.

Occurrence. Fall and spring.

Description. Hessian fly adults may be brownish to dark. On occasions, females have a reddish-brown coloration due to the presence of orange eggs developing inside the body. Eggs (Photo 8-8) are orange colored, elliptical shape, and found in the grooves on the upper side of the plant leaf, and they can hatch on day 3-12 depending on the temperature. Larvae are legless and are the overwintering stage. The third instar and pupae develop in the cuticle of the second instar larva, this instar is called the puparium or the "flaxseed" stage (Photo 8-9), due to the hardened, sclerotized, dark brown color, and shape of the cuticle, which resembles a seed of flax,

Damage. A fall infestation can result in stand loss and broken (lodged) plants (Photo 8-10). Spring infestations usually result in plants of reduced vigor and bad color.

When to scout. Survey fields one time after the first frost and from early spring until June.

How to scout. Look for thin, stunted, chlorotic patches in the field. Examine the base of these plants for presence of the flaxseed.

Record. Record the number of flaxseed found per 10 stems examined at each sample site. Note the presence of adults or larvae.

Economic threshold. There is no rescue treatment; however, preventive measures may be used to avoid future infestations.

Photo 8-8. Hessian fly adult.

Photo 8-9. The "flaxseed" or pupal stage of the Hessian fly can be found behind lower leaf sheaths of infested plants or below the soil line.

Photo 8-10. Hessian fly-infested plants (center) appear stunted. There is no stem elongation and the leaves are usually broad and green.

Rice Stink Bug

The rice stink bug, *Oebalus pugnax* (Hemiptera: Pentatomidae) (Photo 8-11), is an important pest of rice in the southern United States, but it is well distributed from Gulf Coast states and many northern states including Kentucky. Both adults and nymphs feed on developing grains of rice but are known to attack wheat and other small grains in the USA and Brazil.

Description. Adults are straw colored, shield-shaped with two sharply pointed shoulder spines which project forward. Males live for 30 days. Females for up to 40 days, while laying 70 to 80 eggs per female.

When to scout. There are no standardized scouting procedures for this pest.

Damage. Infestation occurs in the spring when grains start to fill. Rice stink bugs can feed on grains leaving some spots; however, it is rare to see severe damages by this pest.

When to scout. This species is the early stink bugs that appear in Kentucky and is the most common insect in wheat present from Mid-May to June.

Economic threshold. There is no known economic threshold for this insect.

Comments. Rice stink bugs rarely cause damages to wheat, but their abundant presence on top of small grain heads may be worrisome for farmers. Although damages were observed when they were placed on nets for up to 24 hours, there is no necessity for application of pesticides in Kentucky.

Photo 8-11. Rice stink bugs on a barley head.

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Chapter 9

Economics of Winter Wheat Production and Marketing in Kentucky

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Estimating the profitability of any commodity, including wheat production, begins with understanding the production cycle, costs, and revenues. Enterprise budgeting allows a producer to estimate projected input costs of production and anticipated revenues from wheat sales based on a production plan for the upcoming cropping season. Given the projected costs and revenues for the upcoming year, an enterprise budget estimates the profitability of the existing production plan. By outlining costs, a producer can determine and manage inputs accordingly. For example, the largest cash expense on rented ground is typically land rent. Enterprise budgeting helps producers determine what they can afford to pay for rented ground and remain profitable. Kentucky wheat production is often part of a double cropping system, which adds complexity to agronomic management and projecting economic returns.

Figure 9-1. Storing wheat and scheduling deliveries for later in the year is part of an overall grain marketing strategy.

Wheat Enterprise Budget

Enterprise budgets for wheat are easily accessible online at the University of Kentucky, Department of Agricultural Economics Extension website under Budgets and Decision Tools. The wheat enterprise budget can be used to budget for no-till wheat on its own or no-till wheat/soybean double crop. However, wheat is rarely planted without the intention of double-cropping soybeans, so the double-crop budget will usually be used. The budgets are updated annually and outline costs and revenues on a per-acre basis for wheat and double-crop wheat/soybean production. These budgets represent a typical operation in Kentucky and should be adjusted to represent individual farms more accurately. To change inputs in the budget, adjust the highlighted blue cells to depict the user's operation and production plan. The information that can be modified includes both production costs and anticipated revenues. It is worth noting that the double-crop budget includes separate cells for yield, price, and seed costs for both soybeans and wheat, but other input costs are aggregate, meaning that the costs should reflect the input costs of both crops. For example, herbicide costs should reflect the herbicide used for soybeans and wheat. An example of 2023-2024 costs and returns is illustrated in Table 11-1. Additional resources from the Martin-Gatton College of Agriculture, Food and Environment include:

Wheat Double-Crop Soybean Budgets:
https://agecon.mgcafe.uky.edu/budget/wheat-double-crop-soybean-budget-2024-2025

A Comprehensive Guide to Soybean Management in Kentucky:
https://publications.mgcafe.uky.edu/id-249

Fertilizer Price Calculator and Economic Value of Poultry Litter:
https://agecon.mgcafe.uky.edu/dt/fertilizer-price-calculator

Variable Costs of Production

Variable costs of wheat production include operating expenses that typically last one production season. The production season is split between two calendar years and includes a dormancy phase during winter. The above UK Enterprise Budgets allow the user to customize the spreadsheet to reflect the variable cost of their operation by changing the input's quantity or the input's unit price (blue in the budget). The first variable cost in the wheat 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. Seed prices vary tremendously. Certified seed will be more costly but typically results in more predictable germination percentages and a more robust stand (you usually get what you pay for). The double crop budget includes separate input rows for wheat and soybean seed costs.

Next is the fertilizer cost, specifically nitrogen, phosphorus, and potassium required for wheat production. All fertilizer quantities are actual (100%) fertilizer required (regardless of fertilizer source) and unit price for one pound of the elemental nutrient. The "Fertilizer Price Calculator" can help determine the unit price given a particular source of fertilizer. If utilizing poultry litter as a nutrient source, "The Economic Value of Poultry Litter: Grain Crops" can help determine the per unit and per acre fertilizer cost.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. Lime is typically applied every two years, and thus, costs must be pro-rated by year. Fertilizer costs in the double-crop budget should reflect aggregate fertilizer costs for soybean and wheat crops.

Pest management costs should also be reflected in the budget. Pest management costs include any costs for herbicides, insecticides, and fungicides applied during the cropping season to control weeds, insects, or wheat diseases. The per acre cost of pest management products should be reflected in this budget portion. The application cost of either fertilizer or pest control is on the machinery side of the budget. As mentioned above, the double-crop budget should reflect the wheat and soybean aggregate herbicide costs.

Machinery costs include fuel, repairs and maintenance, and labor required for wheat production. If the user has accurate estimates of their machinery costs, their per acre costs can be entered into the budgets. However, users can enter a "Y" in the machinery section if they want the tool to estimate machinery costs. Field operations include the application of fertilizer and lime, a burn-down herbicide application, nitrogen application, planting, post-emergence herbicide application, fungicide application, and harvesting 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 10-20% 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. Again, the double crop budget should reflect the aggregate machinery costs of both wheat and soybean production.

Other variable costs in the wheat budget include drying, crop insurance, cash rent, and operating interest. Crop insurance will vary substantially by policy type, APH (actual production history) yield, coverage level, and unit structure and should be reflected appropriately in the budget. Aggregate policy costs for wheat and soybeans should be used in the double crop budget. Furthermore, cash rent can vary by productivity, accessibility, and competition. Therefore, use the average of all rented land in the budget or specific farm rents if evaluating at the farm level. Cash rent costs reflect the price per acre per year, meaning an aggregate value should not be needed in the double crop budget. Drying, crop insurance, and operating interests should again reflect the aggregate costs of both crops in the double-crop budget.

Fixed Costs of Production

Fixed costs are costs that must be paid but are not dependent on the level of production. Many fixed costs, such as ownership cost and overhead, of wheat production are often "non-cash" costs and are not immediately seen or paid annually. An example of fixed costs in wheat production is machinery depreciation, meaning machinery slowly loses value over time. To help determine the deprecation of a farm asset, refer to "Estimating the Economic Depreciation of Farm Assets." Fixed costs have a limited effect on decision-making in the short term (within a season); however, all economic costs should be considered in the long term. Fixed costs are sometimes difficult to estimate across various crops. For instance, the same tractor may be used for wheat/soybean double crop and corn production. Thus, the depreciation must be spread between both budgets. To simplify this step, the fixed costs portion of the budget operates similarly to 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 wheat production. Farm size and the number of days typically required to conduct an operation must be considered to determine the appropriate machinery size. Determining the number of days will vary, and "Estimating the Field Capacity of Farm Machines" can assist in calculating field capacity for each field operation. The risk of detrimental weather hindering a farm task/operation should be considered, especially for critical time-affected tasks like planting and harvest. The publication "Days Suitable for Fieldwork in Kentucky" discusses how many days of the year are typically suitable for fieldwork and can aid in machinery size decisions. Controlling fixed costs through appropriate machinery sizing is vital for long-term profitability.

Estimating the Economic Depreciation of Farm Assets:
https://agecon.mgcafe.uky.edu/pub/estimating-economic-depreciation-farm-assets

Estimating the Field Capacity of Farm Machines:
https://www.extension.iastate.edu/agdm/crops/html/a3-24.html

Days Suitable for Fieldwork in Kentucky:
https://agecon.mgcafe.uky.edu/pub/days-suitable-field-work-kentucky

Additional Tools for Wheat Management

In addition to enterprise budgets, other economic tools that aid in cost management are available. One key element discussed above is machinery costs, depreciation, and overhead. There are alternatives to acquiring machinery for Kentucky wheat producers that could reduce or eliminate the fixed costs incurred from machinery ownership. Kentucky wheat 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 production costs and the risk of timely completion. 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 in "Custom Machinery Rates Applicable to Kentucky." These rates are based on reported surveys from surrounding states and adjusted to account for changes in fuel prices, machinery costs, and wages from the time of the surveys. Each grain crop operation, including wheat (labeled as small grains), is listed along with the three rates. The average final rate is highlighted in blue. The report additionally indicates rates 15% below and 30% above the average. These rates are updated annually and estimate the variable costs for hiring custom work in wheat production.

Custom Hire Rates:
https://agecon.mgcafe.uky.edu/pub/custom-machinery-rates-applicable-kentucky-2024

Land Rental Tools

There are two ways to acquire land for wheat production. One way is to own the land, and the other is to lease the land. For Kentucky producers leasing land for wheat production, rental rates could be the highest variable cost of production. Also, the productivity and quality of the land will influence what a producer can afford to pay for the rental arrangement. Various leasing arrangements can be used. The most common for Kentucky producers is a cash rental arrangement. For a guide, a periodic cash rent survey is conducted by University of Kentucky Agricultural and Natural Resources Extension Agents to estimate local land rents. These results are then summarized by eight regions and reported based on good or fair cropland. See "Kentucky ANR Agent Land Value and Cash Rent Survey" for the most recent Kentucky cash rent estimates.

Cash Rent Survey:
https://publications.mgcafe.uky.edu/aec-102

In addition to cash rental arrangements, Kentucky wheat producers also use traditional crop share arrangements (20-33% of gross revenue). However, a hybrid arrangement, or a flexible cash lease (a.k.a. flex lease), is becoming more popular. Flex leases provide a base rent or a floor that is lower than the equivalent cash rent. The landowner also receives a bonus or revenue percentage based on the production and market prices for that season. There are many variations to a flex lease, which may or may not work for both the landowner and producer. If you are considering a flex lease, the "Flexible Cash Lease Decision-Aid" is available online to assist landowners and producers with rental arrangements.

Flexible Cash Lease Decision-Aid:
https://agecon.mgcafe.uky.edu/dt/flexible-cash-lease-decision-aid

Grain Transportation

Determining the optimal wheat market is a complex decision. Most producers only consider one key factor when choosing a market (e.g., the 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 the net price per bushel. Most producers, particularly in western Kentucky, have multiple markets to sell their wheat. This decision process begins with identifying all markets in the area. The "Kentucky Grain and Oilseed Markets" map is available online and displays over eighty grain markets in Kentucky and bordering states.

Kentucky Grain Market Map:
https://agecon.mgcafe.uky.edu/ext/map-kentucky-grain-and-oilseed-markets

Once the buyer(s) are identified, the user needs to determine the cost to transport wheat, each buyer's cash price, and quality discounts. Cash prices and quality discount information can be acquired by contacting each potential buyer. Determining the cost of transportation can be more difficult. Two tools are available online that will aid in determining these costs. "Post-Harvest Management: The Economics of Grain Transportation" walks through the expenses of transporting grain and how to calculate both operating costs and fixed costs. The "Grain Hauling Decision Guide" is a spreadsheet tool that will help determine the most profitable buyer based on the abovementioned key factors. The spreadsheet tool can compare up to six buyers and estimate transportation costs and net price received for each buyer. Also, wheat discounts for each buyer are calculated based on moisture content and discount schedule. The grain transportation tool is online at the link below.

Post-Harvest Management: The Economics of Grain Transportation:
https://agecon.mgcafe.uky.edu/pub/post-harvest-management-economics-grain-transportation

Grain Hauling Decision Guide:
https://agecon.mgcafe.uky.edu/budget/grain-hauling-decision-guide

Storage and Marketing

The marketing of wheat in Kentucky varies by location. Generally, one of two situations occur depending on local demand:

1. Elevators quit accepting wheat delivery before or during corn/soybean harvest to free storage capacity for corn and soybeans.

or

2. End-users of the grain (i.e., local mills and distilleries) and elevators near the end-users accept wheat delivery throughout the entire marketing year.

Situation (1.) is typical for most Kentucky wheat-producing counties. Due to smaller local supply and demand, elevators stop taking wheat delivery before or during corn and soybean harvest to free up storage capacity for corn and soybeans. Situation (1.) creates an environment where most wheat is sold at harvest when the futures and the spot prices are typically low. To ensure strong wheat pricing in these areas, a producer should avoid the spot price and focus on the early pricing of grain throughout the marketing season. Some methods to lock in grain prices include forward contracting, hedge-to-arrive contracts, or hedging using the futures market.

Situation (2.) typically occurs in Southwestern Kentucky due to the proximity to flour mills that use wheat as feedstock or Kentucky distilleries that use wheat as an ingredient in bourbon/whiskey. In both cases, the local demand for wheat incentivizes wheat storage to capitalize on higher prices later in the marketing season.

Mills in southwestern Kentucky utilize more wheat throughout the marketing year than they can store. Thus, producers in this area can market directly to mills throughout the entire marketing year. Elevators in the area may also accept delivery throughout the marketing year due to their proximity to the mills and the Mississippi River, which can be utilized for wheat export. Producers' ability to market grain throughout the entire marketing year incentivizes wheat storage, which can be utilized in two ways. First, producers can use storage to capitalize on higher prices later in the marketing season by using a forward contract or simply taking the spot price. Additionally, producers with storage can use hedge-to-arrive contracts or hedge using the futures market to reduce futures price risk and to capitalize on a strengthening basis. If storage is unavailable, producers can also utilize off-farm storage at elevators or the methods discussed in situation (1.) to sell at harvest.

Due to fewer bushels of wheat being used for bourbon or whiskey production, distillery contracts can be difficult to obtain. Distilleries can be selective of wheat suppliers because they need a dependable source of wheat meeting their quality standards year after year. Many producers supplying the bourbon industry have had long-term commitments to the distillery. As the Kentucky Bourbon industry expands, distilleries will need more wheat; however, these contracts are limited. If the opportunity arises to market wheat directly to distilleries, the contract can be lucrative and should be considered. However, without a distillery contract, producers will likely need to sell at harvest, in which case marketing strategies resemble situation (1.), or to deliver to Southwestern Kentucky, where marketing strategies resemble situation (2.).

Summary and Conclusions

Managing wheat profitability begins with understanding the costs and returns to production. Enterprise budgeting is a vital tool to outline the costs and returns for a production plan. Specifying these costs allows producers to determine and manage input costs accordingly. The UK Wheat Double-Crop Soybeans 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. Wheat marketing is highly dependent upon location and access to storage. Determining how long elevators in your area accept wheat delivery is a logical place to start. Depending on the outcome, a historical analysis of local prices and basis throughout the marketing year can be used to develop your marketing plan.

Chapter 10

Harvesting, Drying, and Storing Wheat

Sam McNeill and Mike Montross

The biggest challenge to storing wheat in Kentucky is controlling insects. As with production management, the best post-harvest management practices involve an integrated approach. Good sanitation of the equipment and facilities before harvest is the first step towards controlling insects during storage. Timely drying, careful handling, and safe monitoring practices complete the steps needed for producers to minimize insect infestations in the bin and potential price discounts when the crop is delivered to the elevator, flour mill, distillery, or brewer. This chapter describes the steps needed to reduce harvest losses and maintain crop quality when drying and storing wheat on the farm.

Harvesting

Although wheat is often harvested in the 13% to 15% moisture-content range in Kentucky, it can be successfully harvested at higher moisture contents (as shown in the previous section), provided it is dried quickly enough to prevent spoilage and/or sprouting. The moisture content at which harvest begins will depend heavily on the drying system available. Each farmer's goal should be to harvest as early as possible provided the grain can be dried quickly and safely. Some guidelines for matching the beginning harvest moisture content to the drying system available are given in Table 10-1. If this is your first time harvesting high moisture wheat, start at a low moisture content and gradually increase it as you gain experience.

Table 10-1. Guidelines for matching wheat moisture at harvest to drying systems.

Drying System	Temperature Range (F)	Moisture Content (% w.b.)
High temperature dryers	140 – 180	21 – 24
Bin dryers with heat/ stirring equipment	90 – 140	15 – 20
Bin dryers with no/ low heat	0 – 5 above ambient	<15

Photo 10-1. Wheat harvest is one of the busiest times of the year for grain farmers in Kentucky.

Table 10-2. Changes in soybean and wheat yields, wheat-drying costs, and net returns to the double crop enterprise during a four-week harvest period with no extreme weather losses and a variable production cost of $750 per acre.

Week +/-	Soybeans		Wheat							Net DC Return $/ac
	Yield bu/ac	Gross Return $/ac	Yield bu/ac	Gross Return $/ac	DHS				Net Return $/ac	
					MC %wb	Costs, $/ac		+YLD $/ac		
						Yield	D & H			
-1	55.0	$ 605	79.6	$ 478	23.5	2	82	$ 84	$ 394	$ 249
0	55.0	$ 605	76.8	$ 461	18.3	19	37	$ 56	$ 405	$ 260
+1	47.7	$ 525	74.0	$ 444	13.0	36	5	$ 41	$ 403	$ 178
+2	41.5	$ 456	71.2	$ 359	10.8	53	16	$ 69	$ 358	$ 64

When to Start?

Wheat harvest should begin as soon as the crop has field-dried enough that it can be handled safely. A moisture meter is very useful to give a quick determination of crop condition. Most hand-held meters are calibrated for soft red winter wheat or have charts for converting readings from other crops. If a meter is not available, weigh a ¼-½ lb sample, dry it on a cookie sheet in a 260°F oven overnight (about 10 hours), and re-weigh the sample. Calculate the moisture content (% wet basis) by the following formula:

(wet weight – dry weight) ÷ wet weight × 100 = seed moisture (% w.b.)

For example, if a 0.5 lb sample weighs 0.4 lb after drying, seed moisture is 20%:

(0.5 – 0.4) ÷ 0.5 × 100 = 20%

An early wheat harvest can avoid concerns for planting delays of double crop soybeans and provides motivation to consider drying wheat with heated air. A decision tool was developed to help producers weigh the costs of wheat drying with the probable loss in soybean yields due to delayed planting. It accounts for grain and energy prices along with a few other related factors that are then used to calculate gross profits from both crops and net returns to the double crop enterprise after subtracting drying costs and other input costs. Potential yields, price and yield loss per day are considered for both crops. For wheat, a field drying rate is assumed to calculate the decrease in drying cost as harvest progresses. Towards the end of harvest, wheat will usually be dry enough to store or market directly from the field (but may result in over-drying which is an additional cost due to excess shrinkage) and by that time potential soybean yields would fall off dramatically.

To look at an example, consider the 'pivot' harvest date where potential soybean yields reach a break point. This varies from year to year depending on available heat units or degree days for crop development. Wheat harvest should start several days earlier to avoid working much beyond that date to allow for daily harvest capacity and a few delays due to inevitable weather and/or occasional mechanical/equipment problems. With soybeans at $11 per bushel, an average yield of 55 bushels per acre, and daily yield loss of 1.8% (1 bushel per acre per day), the costs of delayed planting for soybeans can be easily calculated. For wheat, an average price of $6 per bushel, yield of 80 bushels per acre, and a 0.5% loss per day for delayed harvest can be assumed as a starting point. Drying costs vary between systems, but with a fixed cost of 10 cents per bushel for the dryer, average recent energy prices ($1.50 per gallon for LP gas), and an initial moisture level of 23.5%, an average drying and handling cost would be about $1.03 per bushel (or $82 per acre). The gross returns for soybeans and wheat would be $605 and $478 per acre, respectively. This should cover the total variable production costs of the double crop enterprise of $750 per acre (determined by the corresponding budget from the UK Agricultural Economics Department https://agecon.ca.uky.edu/budgets) and results in a net return of $249 per acre (shown in Table 10-2) when harvest begins one week before the 'pivot' harvest date (week -1). Each row in the table shows how these costs and returns change through a four-week harvest period. Note that it falls off dramatically after the second week past the optimal harvest window.

In the example above, the net return to the double crop enterprise can average a loss of $14 per acre per day when soybeans are planted during the two-week period after the optimum date. A similar scenario holds true from year to year and can be determined for specific conditions by entering data into the spreadsheet available at the UK Biosystems and Agricultural Engineering website (uky.edu/bae).

Operating the Combine

The most important combine adjustments for harvesting wheat are at the header (cutter bar height, and reel speed for conventional headers/cutterbars, and rotor speed for stripper headers), then cylinder speed, concave clearance, screen openings, and fan speed. Set the combine according to the manufacturer's recommendations before harvest and check harvest losses at least a couple of times the first day. Then, if necessary, adjust the header position, cylinder, or fan speed in the field to reduce shatter losses and improve threshing and cleaning. Lower cylinder speeds will reduce kernel damage. Increased fan speed will clean wet chaff more easily, but more grain may be blown out with the chaff. Be willing to dry some chaff if your drying system has adequate air flow. Finding the 'sweet spot' of ground speed and combine settings is the goal for timely harvest with machine losses below 3% of yield.

Shatter at the header is the major source of wheat harvest loss regardless of the type of header that is used. One USDA study with a conventional cutter bar header showed that shatter losses were reduced in high moisture wheat. Researchers have observed that header losses increase as much as 1.7 bushels per acre as wheat dries in the field from 23% to 13%.

Figure 10-1. Effect of ground speed (mph) and header rotor speed (rpm) on wheat harvest losses (%) at the header.

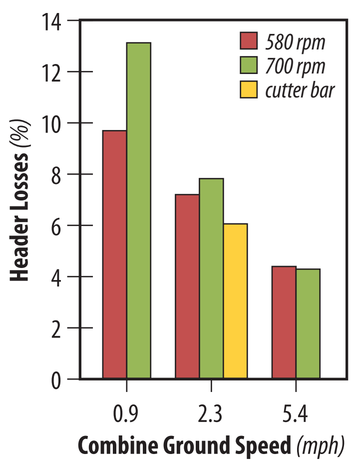
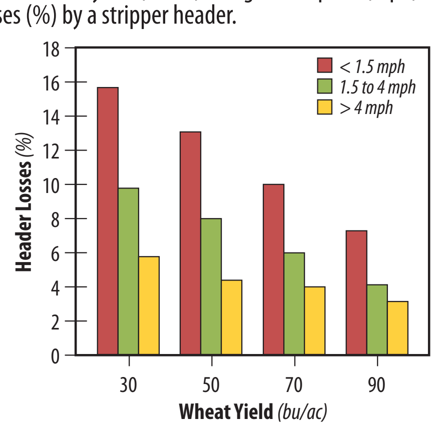


Figure 10-2. Effect of yield (bu/ac) and ground speed (mph) on wheat harvest losses (%) by a stripper header.



Header Choices

Few studies have been conducted to compare the performance of rotor stripper headers and conventional cutter bars for soft red winter wheat. However, a report from the Northwestern United States for different types of wheat indicates that ground speed has more influence on header losses than the speed of the header rotor. Compared to a conventional cutter bar header, the stripper header had higher losses at low ground speeds but comparable losses as ground speed increased (Figure 10-1). The average loss for all ground speed was 7.8% of the total yield for the stripper header and 5.8% for the cutter bar. As ground speed increased, header losses were nearly equal for both units. Losses for the stripper header were also determined for various yield levels in this study and are shown in Figure 10-2. Losses generally decreased as yields and ground speed increased. Ground speeds that resulted in the lowest header losses for the stripper header were 1.7 times higher than those observed for the combine with a conventional cutter bar.

Check Harvest Losses

Measure field losses by counting loose kernels on the ground. Look in front of the combine in standing wheat to measure pre-harvest losses. Wheat kernels found under the combine are both pre-harvest losses and header losses, and kernels behind the combine are total losses (pre-harvest, header, threshing, and separating losses). About 20 kernels found in a square foot area represent 1 bushel per acre loss. A good goal is to limit harvest losses to no more than 3 percent of the crop yield. Table 10-3 shows different loss levels over a range of typical wheat yields. Adjust ground speed, header height, reel speed and reel position to minimize header losses. Also, inspect cutter bars for sharp knives and replace dull blades when necessary. Bear in mind that a 2% reduction in harvest losses adds to $960 on 100 acres when wheat at $6 per bushel yields 80 bushels per acre. Guidelines for measuring and minimizing wheat harvest losses are provided in a publication from South Dakota State University (https://extension.sdstate.edu/sites/default/files/2020-03/S-0005-28-Wheat.pdf).

Table 10-3. Number of kernels per square foot that represent 1%, 3%, and 5% yield loss over a typical range of wheat yields (bu/ac).

Wheat Yield (bu/ac)	1% HL	3% HL	5% HL
60	12	36	60
80	16	48	80
100	20	60	100
120	24	72	120

Table 10-4. Amount of water in a bushel of corn and wheat (lb/bu) at various grain moisture levels (%).[a]

Grain type	Moisture Content (% wb)														
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Amount of water (lb/bu)														
Corn	5.3	5.9	6.5	7.1	7.8	8.4	9.1	9.8	10.5	11.2	11.9	12.7	13.4	14.2	15.0
Wheat	5.8	6.4	7.1	7.8	8.5	9.2	9.9	10.6	11.4	12.2	13.0	13.8	14.6	15.5	16.4

[a] *Using a base moisture level and test weight of 15.0% and 56 lb/bu for corn and 13.5% and 60 lb/bu for wheat.*

Drying

Freshly harvested wheat grain should be dried to a moisture content of 14% or less within 48 hours to prevent sprouting and spoilage. High moisture wheat (>15%) can be dried with either in-bin or high temperature equipment. Corn drying systems can be used to dry wheat if some adjustments are made to maintain adequate air flow. The amount of water in a bushel of corn and wheat at different moisture levels is shown in Table 10-4. Wheat has a higher resistance to air flow than corn, but there are usually fewer bushels to be dried. For commercial wheat, drying air temperatures should be below 140°F to avoid damage to milling quality. In contrast, seed and brewer/distiller wheat should be dried at 110°F or lower.

In-bin Drying. Bin-drying methods are easily adapted for wheat if adjustments are made to compensate for the increased resistance to air flow (measured as static pressure in inches of water). A rule of thumb is to limit wheat depth to half that used for corn. Centrifugal fans may be used to deliver higher airflow rates under higher static pressures. However, as shown in Table 10-5 for a 30-ft bin, wheat depths greater than 20 feet will generally reduce airflow rates to less than 1 cubic feet per minute for each bushel (cfm/bu) in the bin, even with up to three 15-hp fans. Heat is required in the bin if wheat to be dried is over 17% moisture content, as shown in Table 10-1. Stirring devices, recirculators, or automatic unloading augers can be used to increase capacities. Generally moderate air flows (2-5 cubic feet of air per bushel) and temperature rise (less than 20°F) are used. Excess heat can cause severe over-drying. If high moisture wheat is to be dried and stored in the same bin, extra care is advised. If the initial moisture is 20%, use heat to dry the top layer below 17% before adding more grain. Several bins may be needed to dry a large crop. After drying to 17%, use unheated air to dry the wheat to about 15%. During this period, run the fan continuously to provide a uniform moisture content. Run the fan only during low humidity hours to finish drying to around 13% moisture. This management scheme minimizes the amount of over-dried grain in the bottom of the bin. Table 10-6 shows the moisture content that soft red winter wheat will approach when exposed to the temperature and relative humidity levels shown. Moisture levels decrease with lower humidity and higher temperature conditions.

Table 10-5. Airflow and static pressure (sp in inches of water) at different grain depths in a 30-ft diameter bin of wheat with a full perforated floor using 1-, 2- and 3- 15 hp centrifugal fans.

Depth (ft)	Bu.	1-15 hp fans			2-15 hp fans			3-15 hp fans		
		Airflow		SP	Airflow		SP	Airflow		SP
		(cfm)	(cfm/bu)		(cfm)	(cfm/bu)		(cfm)	(cfm/bu)	
2	1,131	17,282	15.28	1.80	30,651	27.10	3.87	40,426	35.74	5.72
4	2,262	15,955	7.05	3.24	25,913	11.46	6.15	29,886	13.21	7.48
6	3,393	14,784	4.36	4.42	21,617	6.37	7.23	23,436	6.91	8.06
8	4,524	13,801	3.05	5.40	18,264	4.04	7.73	19,229	4.25	8.26
10	5,655	12,888	2.28	6.19	15,846	2.80	8.04	16,399	2.90	8.40
12	6,786	11,960	1.76	6.78	13,915	2.05	8.18	14,344	2.11	8.50
14	7,917	11,041	1.39	7.16	12,431	1.57	8.29	12,777	1.61	8.58
16	9,048	10,180	1.13	7.42	11,250	1.24	8.38	11,535	1.27	8.64
18	10,179	9,453	0.93	7.63	10,285	1.01	8.45	10,525	1.03	8.69
20	11,310	8,830	0.78	7.81	9,480	0.84	8.51	9,686	0.86	8.73

Source: FANS software from the University of Minnesota Department of Bioproducts and Biosystems Engineering (https://bbefans.cfans.umn.edu/).

Table 10-6. Equilibrium moisture content (emc) of soft red winter wheat at different temperature and relative humidity levels.

Temp. °F	Relative Humidity (%) 10	20	30	40	50	60	65	70	80	90
	Equilibrium Grain Moisture Content (%)									
35	7.3	8.9	10.2	11.3	12.3	13.4	14.0	14.7	16.1	18.2
40	7.1	8.7	10.0	11.1	12.1	13.2	13.8	14.4	15.9	18.0
50	6.8	8.4	9.6	10.7	11.8	12.9	13.4	14.1	15.5	17.6
60	6.5	8.1	9.3	10.4	11.4	12.5	13.1	13.7	15.1	17.2
70	6.2	7.8	9.0	10.1	11.1	12.2	12.8	13.4	14.8	16.9
80	6.0	7.5	8.7	9.8	10.8	11.9	12.5	13.1	14.5	16.6
90	5.8	7.3	8.5	9.6	10.6	11.6	12.2	12.8	14.2	16.3
100	5.6	7.1	8.3	9.3	10.3	11.4	12.0	12.6	14.0	16.0

Source: American Society of Agricultural and Biological Engineers Standard D245.4.

High-Speed Dryers. High temperature batch or continuous flow dryers usually have excess capacity for drying wheat. These units typically have very high air flow rates, so supplemental heat may not be required for daytime drying when harvesting in the 18-20 percent moisture range. If heat is used, the drying air temperature can be limited by cycling the burner on and off or by changing the gas burner orifices.

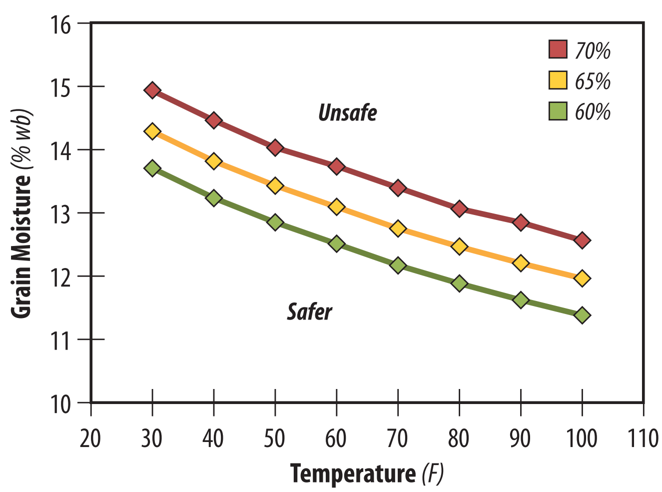
A Word of Caution. Some in-bin corn drying systems are operated by filling the bin completely full within 2-5 days. Under no circumstances should you attempt to follow this practice in drying high-moisture wheat. Rapid bin filling works for corn only when temperatures and moisture contents are low enough to prevent spoilage. Outside air temperatures (and grain temperatures) are 20 to 40 degrees higher when harvesting wheat than during the fall corn harvest. In-bin drying of high moisture wheat should only be done as a layer-fill, batch, or continuous flow process. Rapidly filling an entire bin with high moisture wheat is a sure route to spoilage.

Avoid Overdrying when Possible. Drying wheat below the base market level of 13.5% wet basis should be avoided if the crop is sold at harvest. The value of water in a bushel of wheat (and over-drying costs at $4.00 to $7.00/bu) are shown in Table 10-7. However, if the crop is held through the summer when average monthly temperatures approach 80°F, wheat should be dried to 12.5% to 13% to keep conditions in the bin dry enough to control mold growth (<65% relative humidity) and thereby prevent problems with mycotoxins and sprouting during storage (Table 10-6 and Fig. 10-3). Consequently, this additional cost should be considered as a cost of storage and not directly attributed to drying, since it is usually recovered when the crop is sold.

Table 10-7. Value of water in a bushel of wheat (cents/bu) at various grain price and moisture levels (%).

Price ($/bu)	Moisture Content (% wb) 10	11	12	13	14	15	16	17	18	19	20
	Value of water (cents/bu)										
$ 4.00	15.5	11.3	6.8	2.3	2.3	7.1	11.9	16.9	21.9	27.1	32.5
$ 5.00	19.4	14.1	8.5	2.8	2.9	8.8	14.9	21.1	27.4	33.9	40.7
$ 6.00	23.3	16.9	10.2	3.4	3.5	10.6	17.9	25.3	32.9	40.7	48.8
$ 7.00	27.2	19.7	11.9	4.0	4.1	12.4	20.9	29.5	38.4	47.5	56.9

Figure 10-3. Equilibrium moisture content (EMC) for soft red winter wheat at various temperatures and relative humidity levels of 60%, 65%, and 70%.



Storage

Sanitation, aeration, and monitoring are the watchwords for integrated postharvest management when storing grain during the summer. Totally remove the old crop before placing newly harvested wheat into a bin. Thoroughly sweep the bin wall and floor (including under aeration ducts, if possible) to remove grain kernels that may contain insect larvae and mold spores. Apply an approved insecticide both inside and outside the bin to delay insect population development before placing wheat in the bin. Aeration should be used to cool wheat after drying with heated air. To a small degree, aeration will control grain temperature if it starts heating during storage, but this may only be a short-term solution to avoid further damage to grain quality. If heating cannot be controlled by running the fan, the crop should be moved to another bin if possible. This process will break up hot spots in the bin that usually are the root cause of the problem. Consider adding temperature cables and/or carbon dioxide monitors to check conditions during storage. An automated controller for aeration fans can also be added to start cooling stored wheat below 60° F as soon as possible in late summer.

Check the condition of stored wheat once a week during warm weather to guard against deterioration from molds or insects. Run the fan for a few minutes to check for off-odors from the grain pile. Lock out unloading auger motor switches before looking inside any bin to check for wet spots on the grain surface. Feel the top 6 to 12 inches of wheat to monitor temperatures and insect and mold activity. Insert plastic insect pit traps below the grain surface (being sure to secure them to a ladder or other structural member of the bin) to monitor insect activity and check them during weekly inspections to stay ahead of damaging populations. Always wear a well-fitted respirator for dust protection when cleaning bins and a climbing harness with a restraining rope during an inspection.

References from the UK Entomology Department are updated annually and provide specific information on approved insecticide recommendations for controlling insects in stored wheat (ENT-47: *Insecticide Recommendations for Small Grains*). Dosing rates are based on either the volume of grain (bushels), volume of air below bin floors (ft^3), or surface area of the bin or grain pile (ft^2). A spreadsheet tool has been developed to quickly calculate these areas and volumes to assist licensed applicators. A few examples are shown in Tables 10-8, 10-9 and 10-10 for illustration and other combinations are available on the Biosystems and Agricultural Engineering Grain Calculators website.

Table 10-8. Surface area (ft^2) of the wall in round grain bins.

Height above floor, ft	Bin diameter, ft					
	18	24	30	36	48	60
	Surface area (square feet)					
6	339	452	565	679	905	1,131
12	679	905	1,131	1,357	1,810	2,262
18	1,018	1,357	1,696	2,036	2,714	3,393
24	1,357	1,810	2,262	2,714	3,619	4,524

Table 10-9. Surface area (ft^2) of corn (23^0), soybean (25^0), and wheat (29^0) in a full cone.

Angle of Repose	Bin diameter, ft					
	18	24	30	36	48	60
23	531	944	1,475	2,124	3,775	5,899
25	535	952	1,487	2,141	3,806	5,947
29	545	970	1,515	2,182	3,879	6,060

Table 10-10. Volume (ft^3) of the air space below perforated floors.

Floor height, in	Bin diameter, ft					
	18	24	30	36	48	60
	Volume, cubic feet					
14	297	528	825	1,188	2,111	3,299
18	382	679	1,060	1,527	2,714	4,241

Chapter 11

Supplemental Materials

Table 11-1. 2023-2024 Enterprise budget for no-till wheat and double-crop soybean, per acre costs and returns for western kentucky (these values are estimated averages and should be adjusted for specific farm scenarios.).

No-Till Wheat\Double-Crop Soybeans, Per Acre Costs, and Returns						
	Quantity	**Unit**	**Price**			**Total**
Gross Returns Per Acre						
Wheat	**75**	bu	**$6.15**			$461.25
Soybeans	**40**	bu	**$12.35**			$494.00
Crop Insurance Payment	1	acre	**$0.00**			$0.00
Government Program Payment	1	acre	**$0.00**			$0.00
Total Revenue						**$955.25**
Variable Costs Per Acre						
Seed (Wheat)	**135**	lbs	**$0.50**			$67.50
Seed (Soybean)	**1.00**	bags	**$60.00**			$60.00
Nitrogen[1]	**100**	units	**$0.50**			$50.00
Phosphorous (P_2O_5)	**75**	units	**$0.55**			$41.25
Potassium (K_2O)	**60**	units	**$0.43**			$25.80
Other Fertilizer	**0**	units	**$0.00**			$0.00
Lime - Delivered and Spread	**0.50**	ton	**$25.00**			$12.50
Herbicides	1	acre	**$100.00**			$100.00
Insecticides[2]	1	acre	**$5.00**			$5.00
Fungicides[2]	1	acre	**$5.00**			$5.00
Fuel and Lube	1	acre	**$0.00**	**Calculate Machinery Related Costs?**	**Y**	$41.27
Repairs	1	acre	**$0.00**			$66.81
Hired Labor	1	acre	**$0.00**			$0.00
Operator Labor (Variable Only)	1	acre	**$0.00**			$60.94
Machinery Rental	1	acre	**$0.00**			$0.00
Custom Work	1	acre	**$0.00**			$0.00
Drying (Wheat): LP, Electric, Maintenance & Labor	1	gallon LP	**$2.00**	**Pts Remove**	**1.0**	$3.13
Crop Insurance[3]	1	acre	**$40.00**			$40.00
Cash Rent[4]	1	acre	**$200.00**			$200.00
Other Variable Costs	1	acre	**$10.00**			$10.00
Operating Interest	$712	dollars	**6.0%**	**#Months**	**8**	$28.46
Total Variable Costs Per Acre						**$817.67**
Return Above Variable Costs Per Acre						**$138**
Budgeted Fixed Costs Per Acre						
Operator Labor (Fixed Only)			$0.00	**See Question Above**		$0.00
Machinery Depreciation and Overhead			$0.00			$105.65
Taxes and Insurance	1	acre	$5.00			$5.00
Other Fixed Costs	1	acre	$0.00			$5.00
Return Above All Specified Costs						**$22**

1 Assumes urea (NH_2). Adjust as needed for other forms of nitrogen.
2 Scout to detect and insect or disease problems and control as required.
3 Crop insurance varies substantially by policy type and coverage level.
4 Cash rent varies substantially by productivity level and region in Kentucky.