Section 2

Growth and Development

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Wheat responds best to inputs at certain stages of plant development. Therefore, it is important to understand wheat development and recognize wheat growth stages in order to properly time applications of pesticides, nitrogen, and other inputs.

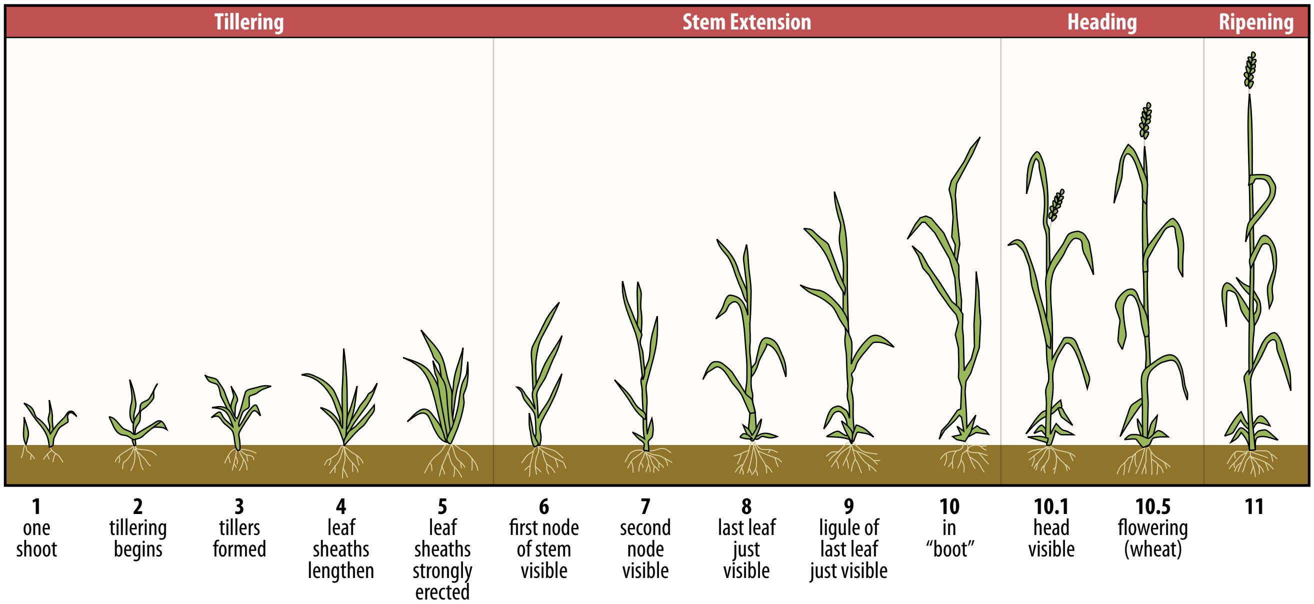
Wheat plants progress through several growth stages, which are described in terms of developmental events. Wheat plant growth and development can be broadly divided into the following progressive stages: germination/seedling emergence, tillering, stem elongation, boot, heading/anthesis, and grain-fill/ripening. Several different systems have been developed to identify wheat growth stages. These systems use a numerical designation for the development or formation of specific plant parts. The two most widely used methods for identification of wheat growth stages are the Feekes scale and the Zadoks scale. The Feekes scale is the traditional, most common scale and has been widely used by Kentucky growers. 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 (ripening). Both the Zadoks and Feekes scales are shown for comparison (Figure 2-1 and Table 2-1).

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; temperatures between 54° and 77°F are considered optimum for rapid germination and growth. Germination begins when the seed imbibes water from the soil and reaches 35 to 45 percent 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

Photo 2-1. Wheat at about Feekes 2 (Zadoks 21) in corn residue.

Figure 2-1. The Feekes scale of wheat development.



first true leaf emerges from its tip. Under favorable conditions, seedling emergence occurs within seven days. 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 (coleoptilar 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. 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.

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.*

Photo 2-2. Wheat field at about Feekes 4 or 5 (Zadoks 30).

Spring tillers generally contribute less to yield potential than do fall tillers. Consequently, fall tillering is important for winter wheat to achieve maximum yield potential.

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.

The number of tillers a plant develops is not a constant and will vary because of two factors: genetic potential 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 of 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 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. During vernalization, 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, 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. 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; Zadoks 30-39). The leaves of overwintering (dormant) wheat 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 give a strongly erect appearance known as a pseudostem (not a real stem) (Feekes 4-5; Zadoks 30). At this time, and prior to actual stem elongation, each main stem and tiller of the young plant is a succession of leaves wrapped around each other (i.e., a pseudostem). 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 (jointing) occurs as a result 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 move 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 as a result 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 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; Zadoks 31). 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, Zadoks 37-39). 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 a large proportion (estimates of at least 75%) of the photosynthate (carbohydrates) for filling grain. It must be protected from diseases, insects, and defoliation in order 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, Zadoks 45) occurs shortly after flag leaf emergence and indicates that the head is about to emerge. The flag leaf sheath (the tubular portion of the leaf that extends below the leaf blade and encloses the stem) and the peduncle (the internode which supports the head) 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

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

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

and ends when the awns (or the heads in awnless varieties) are first visible at the flag leaf collar (junction of the leaf blade and leaf sheath) and the leaf sheath is forced open by the head.

Heading/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 as to when the initiation of the various shoots occurred (i.e. tiller initiation occurs later than the main stem). However, throughout the pre-heading period, differences also occur in the duration of the various developmental phases among the shoots (i.e. developmental phases for tillers are shortened), which serves to synchronize tiller development with the main stem so that tiller head emergence and 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; Zadoks 50), and emergence continues until the head is completely emerged (Feekes 10.5; Zadoks 58). The heading date in most wheat varieties is determined by temperature (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. However, flowering and pollination in cereals may occur either before or after head emergence, depending on plant species and variety. Thus, cereals are classified as either open-flowering or closed-flowering types. Flowering occurs in open-flowering types shortly after head emergence. Most varieties of wheat are of the open-flowering type. Generally, flowering in wheat begins within three or four days after head emergence. Open flowering is characterized by extrusion of the anther (reproductive portion of the flower which produces pollen) from each floret on the head. In contrast, closed-flowering types of varieties or cereals (i.e. 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 is normally very quick, lasting only about three to five days. Pollination occurs slightly later on 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.

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 and also provide the photosynthetic factory necessary for maximum yield. The second stage is the grain-filling period in which the potential yield created in the first stage is realized. The extent to which the potential yield is realized will depend on the environment and on management inputs prior to and after anthesis.

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 (rudimentary, undeveloped plant in a seed) and endosperm (area of starch and protein storage in the seed) begin to form and photosynthates (products of photosynthesis) 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 (high temperatures, low soil moisture, nutrient deficiencies, and diseases) occurring during grain fill. 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 (hot and dry weather, heavy disease, and nutrient deficiencies) and may exceed 35 days in high yield, low stress environments (disease-free, high soil moisture, and moderate/cooler temperatures).

The grain development stages are listed in Table 2-1 (Feekes 10.54 to 11.4; Zadoks 70 to 92). 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 percent to 30 percent. At the end of the hard dough stage (Feekes 11.3; Zadoks 87-91), the kernel reaches its maximum dry weight and the wheat is said to be physiologically mature (no more weight is added to the grain). Physiological maturity often corresponds to kernel moisture content between 30 and 40 percent. Previous wheat swathing research at the University of Kentucky at various kernel moisture contents indicated physiological maturity occurred at a kernel moisture content of 38 to 42 percent (with no reduction in yield or test weight if cut at this stage). Harvesting can occur anytime after physiological maturity but often does not occur because of high kernel moisture.

Table 2-2. Key growth stages in Wheat for Yield Determination.

Critical Yield Component	Determined by:
Tiller and head number	Jointing (Feekes 6, Zadoks 31)
Head Size	Mid to late tillering (Feekes 3; Zadoks 23 to 29)
Kernel number per head	Jointing (Feekes 6; Zadoks 31)
Kernel Size	Beginning at flag leaf (Feekes 8; Zadoks 37) and continuing through grain fill

Ripening stage. Kernel moisture content is still high, usually ranging from 25 to 35 percent, when wheat begins to ripen but decreases rapidly with good 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 (usually less than 20%). Often harvest does not occur until grain moisture content is close to 15 percent, unless drying facilities are available.

It is important for grain quality that the harvest begins as soon as possible. Test weight (and hence grain yield) may be reduced during the ripening process. Decreased test weight results from the alternate wetting (rains or heavy dews) and drying of the grain after the wheat has physiologically matured.

Wheat yield components

Critical yield components include tiller and head number, head size, kernel number per head and kernel size. Table 2-2 highlights the key growth stages that affect yield determination. For maximum wheat yields, proper management and favorable weather are necessary during these key growth stages. The final yield of a wheat crop is a function of the yield components in the following formula:

number of heads/acre
x number of seeds/head
x weight/seed
= **grain yield/acre**