GROWTH AND DEVELOPMENT GUIDE FOR

Spring Wheat

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Introduction

Wheat (*Triticum aestivum* L.) can be classified as winter or spring growth habit based on flowering responses to cold temperatures. Winter wheat development is promoted by exposure of the seedlings to temperatures in the 38° to 46° F (3° to 8° C) range. Such types are usually planted in the fall which exposes the seedlings to cold temperatures during late fall and winter. Spring-types, however, do not require exposure to cold temperatures for normal development and can be planted in spring. Both winter- and spring-types, when properly grown in Minnesota, head in the late spring or early summer and mature by mid- to late-summer.

The description of wheat development provided here applies mostly to spring wheat, although the basic development patterns for all cereals are similar. Figure 1 shows major developmental stages in spring wheat and approximate time intervals between them in Minnesota. A difference in maturity may exist among varieties or between seasons.

Growth staging systems

A number of staging systems have evolved for describing wheat development. The Zadoks system, which is becoming the most universally accepted, will be described in detail. In addition, the Haun and the Feekes-Large staging systems will be introduced.

The Zadoks system applies to any small grain and its stages are easy to identify in the field. It is more detailed than other systems and allows for precise staging. The first digit of this two-digit code shown in table 1 refers to the principal stage of development beginning with germination (stage 0) and ending with kernel ripening (stage 9). Use of the second digit between 0 and 9 subdivides each principal growth stage. A second digit value of 5 usually indicates the midpoint of the principal stage. For example, a 75 refers to medium milk stage of kernel development. In seedling growth, (principal growth stage 1) the second digit refers to the number of emerged leaves. To be counted, a leaf must be at least 50 percent emerged. A 13, for example, indicates that three leaves are at least

Table 1. Condensed summary of the Zadoks two-digit code system for growth staging in wheat with corresponding Feekes scale

Zadoks code			
Principal stage	Secondary stage	Description	Corresponding Feekes code
0		Germination	
	0	Dry kernel	
	1	Start of imbibition (water absorption)	
	5	Radicle emerged	
	7	Coleoptile emerged	
	9	Leaf just at coleoptile tip	
1		Seedling development	1
	0	First leaf through coleoptile	
	1	First leaf at least 50% emerged	
	2	Second leaf at least 50% emerged	
	3	Third leaf at least 50% emerged	

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Figure 1. Spring wheat growth and development in Minnesota with approximate time to various growth stages. Zadoks code for each stage is shown in parentheses.

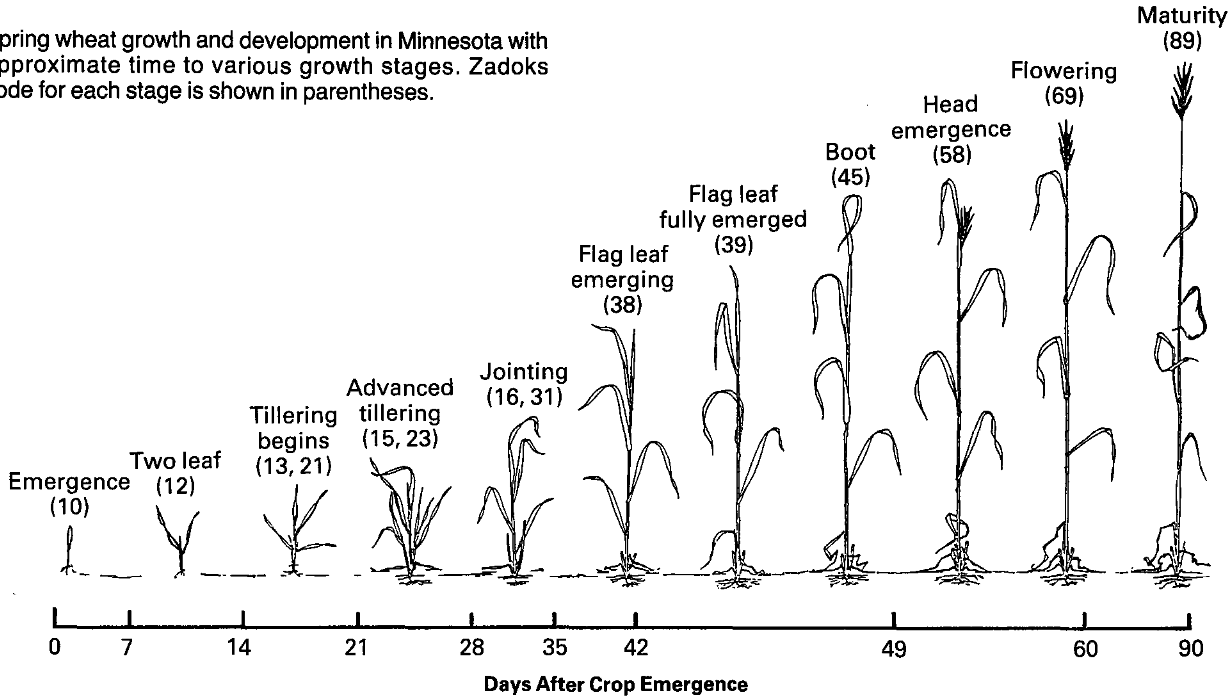
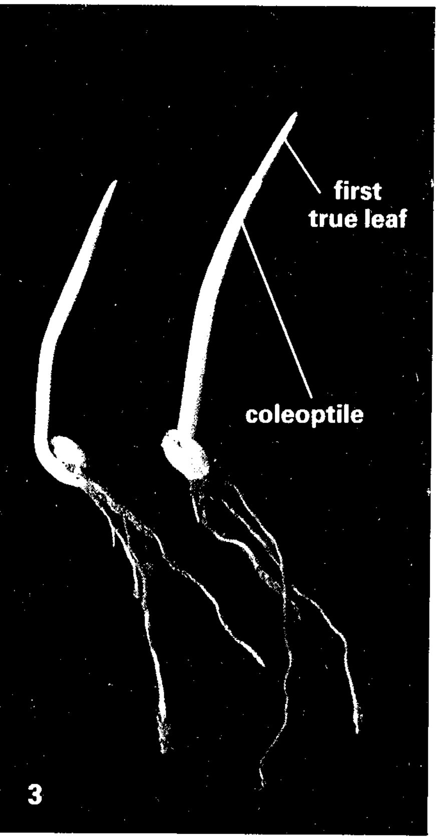


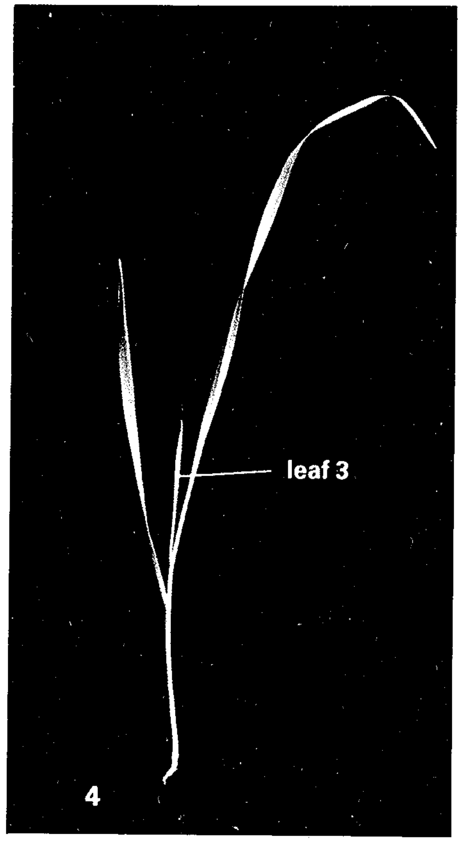
Table 1 (continued).

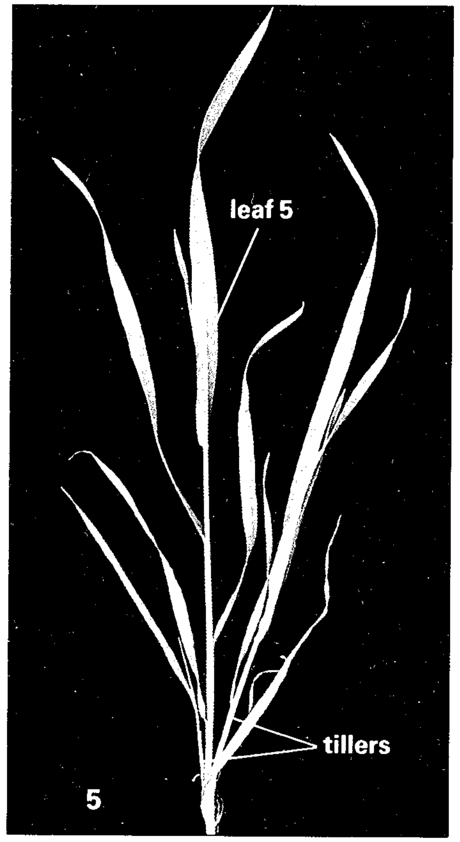
Zadoks code: Principal stage	Zadoks code: Secondary stage	Description	Corresponding Feekes code
	4	Fourth leaf at least 50% emerged	
	5	Fifth leaf at least 50% emerged	
2		Tillering	2
	0	Main shoot only	
	1	Main shoot plus 1 tiller visible	
	2	Main shoot plus 2 tillers	
	3	Main shoot plus 3 tillers	
	4	Main shoot plus 4 tillers	
	5	Main shoot plus 5 tillers	3
3		Stem elongation	
	1	First node detectable	6
	2	Second node detectable	7
	3	Third node detectable	
	7	Flag leaf just visible	8
	9	Flag leaf collar just visible	9
4		Boot	
	1	Flag leaf sheath extending	
	3	Boot just beginning to swell	
	5	Boot swollen	10
	7	Flag leaf sheath opening	
	9	First awns visible	
5		Head emergence	
	1	First spikelet of head just visible	10.1
	3	One-fourth of head emerged	10.2

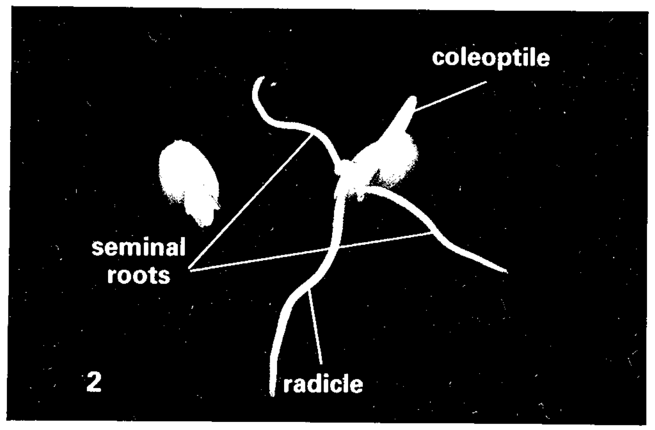
Table 1 (continued).

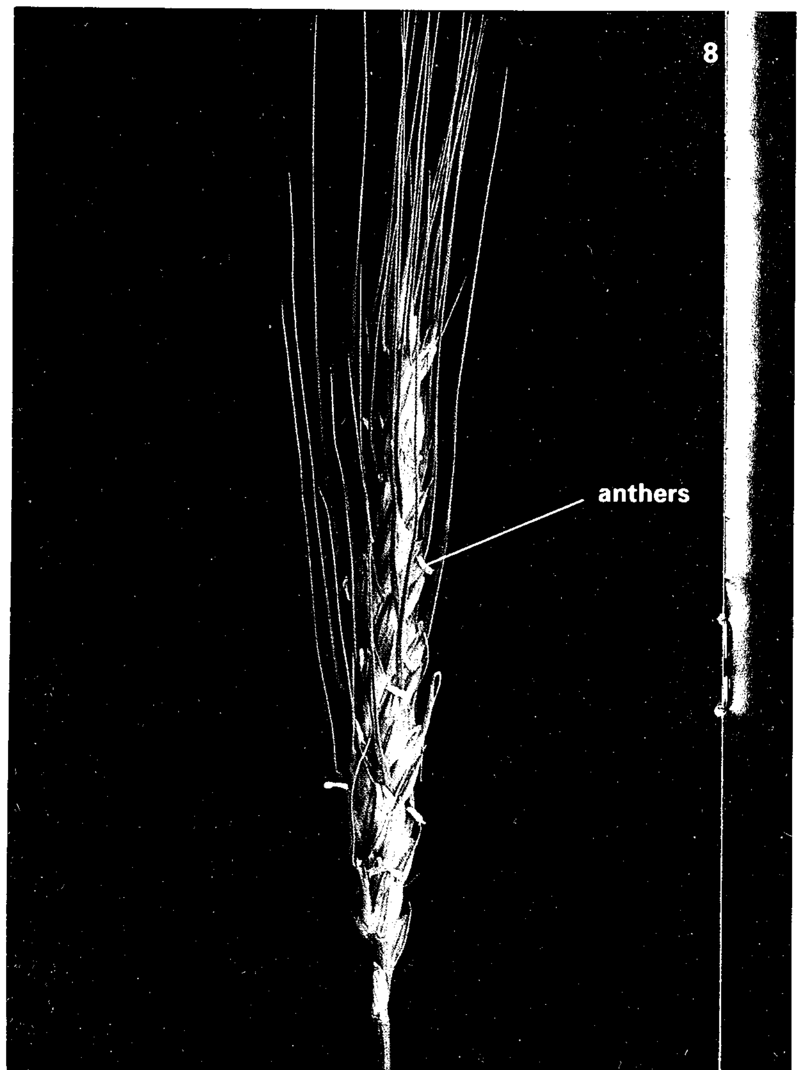
Zadoks code: Principal stage	Zadoks code: Secondary stage	Description	Corresponding Feekes code
	5	One-half of head emerged	10.3
	7	Three-fourths of head emerged	10.4
	9	Head emergence complete	10.5
6		Flowering (not readily visible in barley)	
	1	Beginning of flowering	10.5.1
	5	Half of florets have flowered	10.5.2
	9	Flowering complete	
7		Milk development in kernel	
	1	Kernel watery ripe	10.5.4
	3	Early milk	
	5	Medium milk	11.1
	7	Late milk	
8		Dough development in kernel	
	3	Early dough	
	5	Soft dough	11.2
	7	Hard dough, head losing green color	
	9	Approximate physiological maturity	
9		Ripening	
	1	Kernel hard (difficult to divide with thumbnail)	11.3
	2	Kernel cannot be dented by thumbnail—harvest ripe	11.4

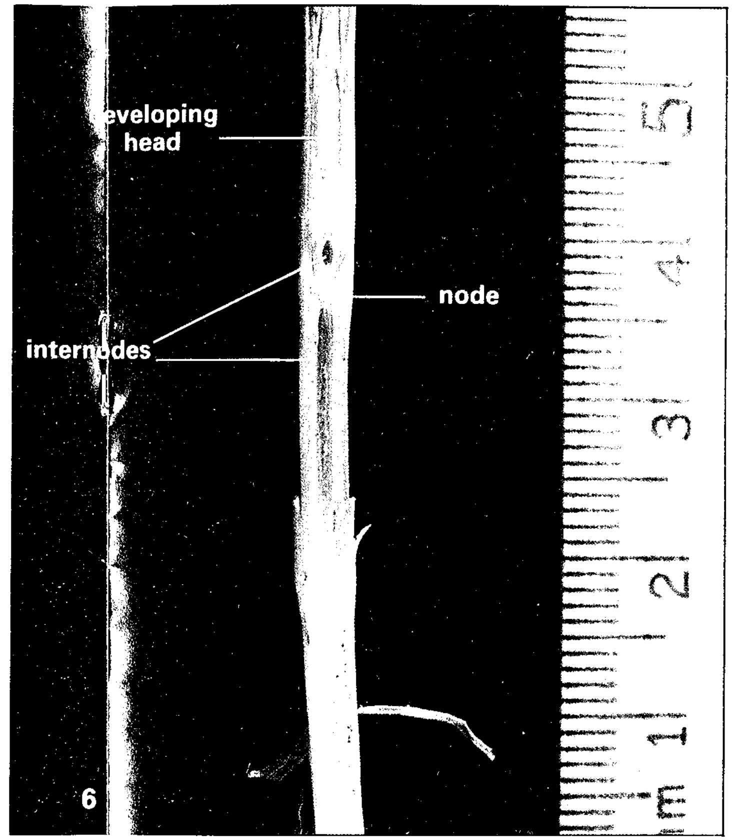


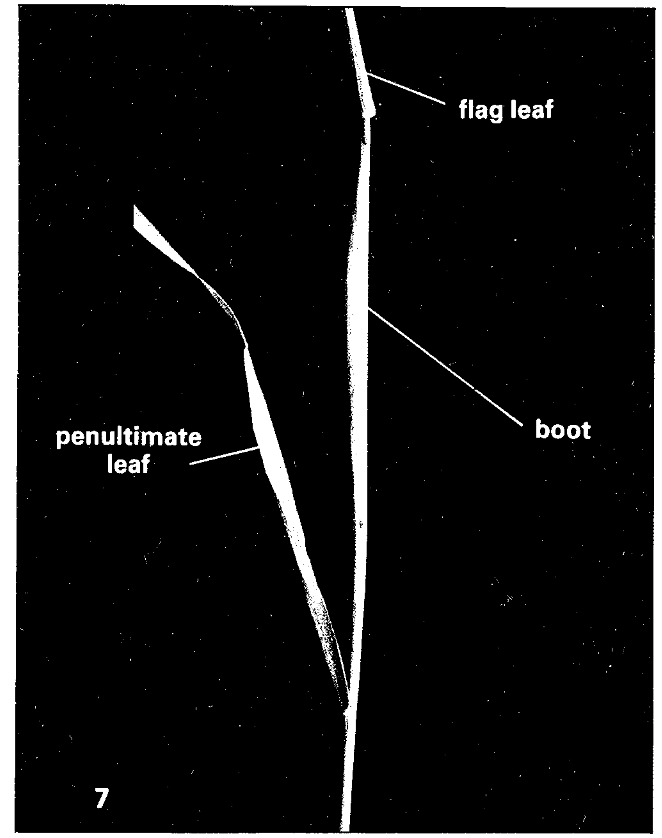












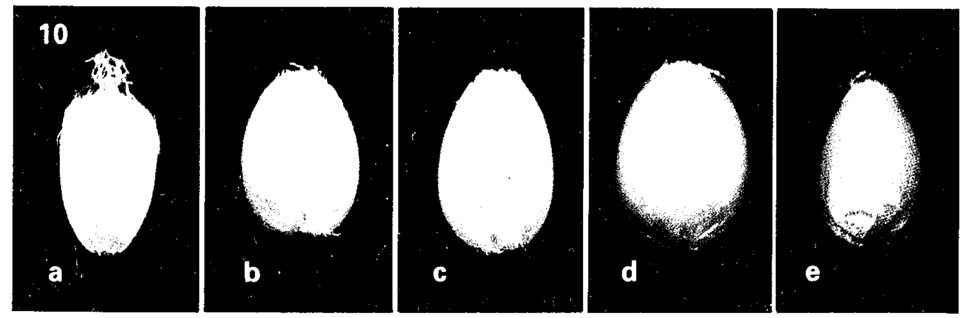


Figure 2. Germinating wheat kernels showing radicle, seminal roots and coleoptile. Kernel on left is at Zadoks stage 04 and kernel on right is at stage 07.

Figure 3. Wheat seedlings at Zadoks stage 10. Note first leaf emerging from tip of coleoptile.

Figure 4. Seedling at two-leaf stage (Zadoks stage 12). Note that the third leaf is not yet 50 percent emerged.

Figure 5. Wheat plant just after jointing (Zadoks stage 31).

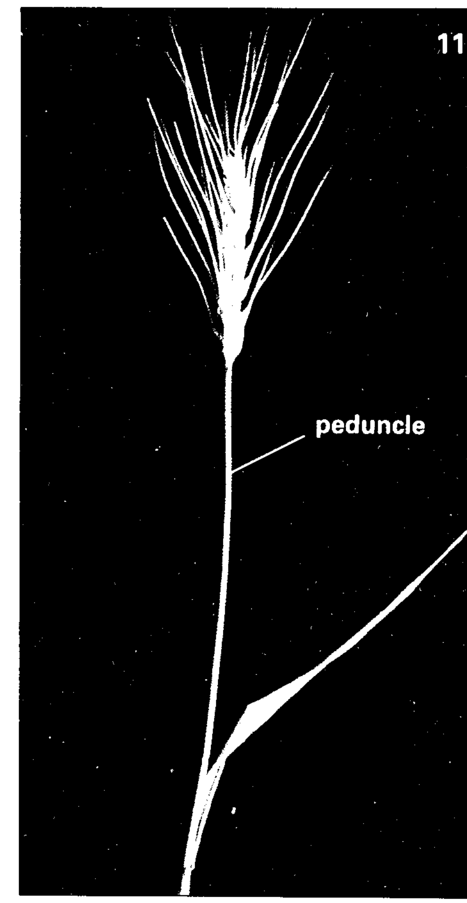
Figure 6. Base of wheat plant during early stem elongation. Individual stem internodes are elongating in sequence. Note the developing head.

Figure 7. The upper half of a plant at boot stage (Zadoks stage 45). Note swelling of sheath indicating the position of the developing head.

Figure 8. Head at flowering (Zadoks stage 68) showing extruded anthers along most of head's length.

Figure 10. Kernels at various times during grain filling: a) kernel at watery ripe (Zadoks stage 71), b) kernel at late milk (Zadoks stage 77), c) kernel at soft dough (Zadoks stage 85), d) kernel at hard dough (Zadoks stage 87) showing loss of green color, and e) kernel ripe for harvest (Zadoks stage 92).

Figure 11. Head at approximately physiological maturity when the kernels have attained maximum dry weight (Zadoks stage 89). Note the green color is gone from the peduncle and head parts.



50 percent emerged on the main shoot. Tiller leaves are not counted.

For the tillering principal stage (stage 2), the second digit indicates the number of emerged tillers present on the plant. Since stages may overlap, it is possible to combine Zadoks indexes to provide a more complete description of a plant's appearance. For example, a plant with one tiller and three leaves could be described by either or both of the Zadoks stages 13 and 21 (figure 1). As the plant matures, the Zadoks stages describing kernel development are usually used alone. For purposes of herbicide application, the seedling stage (stage 1) identifying the leaf numbers is useful. A complete description of the Zadoks system is available in the reference (5) by Zadoks, Chang and Konzak cited at the end of this publication.

The Haun system is concerned mainly with the leaf production stage of development. The length of each emerging leaf is expressed as a fraction of the length of the preceding fully emerged leaf. For example, a 3.2 indicates that three leaves are fully emerged, and a fourth leaf has emerged two-tenths of the length of the third. Although this system can be modified, it is not as useful in the field where decisions are made using development indicators other than leaf numbers. A recent publication by Bauer et al (2) has described early wheat development in relation to the Haun system.

The Feekes-Large system has been widely used, but is becoming less popular. It numerically identifies stages such as tillering, jointing, and ripening, but lacks the more detailed attributes of the Zadoks and Haun systems. Table 1 shows stages of the Feekes scale next to the corresponding Zadoks stages.

Growth and development

The growth cycle of wheat has the following divisions: germination, seedling establishment and leaf production, tillering and head differentiation, stem and head growth, head emergence and flowering, and grain filling and maturity.

Germination, seedling establishment and leaf production

When a kernel is sown, the germination process begins. The radicle and seminal roots first extend, followed by the coleoptile (figure 2). Roots can be initiated from several positions on the seedling, both at the level of the seed and at the crown. The crown is usually separated from the seed by a sub-crown internode. The length of this internode is greater as the depth of planting increases. As the coleoptile emerges from the soil its growth stops and the first true leaf pushes through the tip (figure 3).

After seedling emergence, leaves are produced at a rate of about one every 4 to 5 days. Figure 4 shows a young seedling at the two-leaf stage. A total of eight or nine leaves are usually produced: later maturing varieties have the larger number. Emergence of the last leaf (termed the flag leaf) is an important stage for timing the application of certain plant growth regulators.

Tillering and head differentiation

Tillering is an important development stage that allows plants to compensate for low plant populations or take advantage of good growing conditions. Tiller appearance is closely coordinated with the appearance of leaves on the main shoot. Tillers can form at the points of attachment of the coleoptile and the lower leaves on the main shoot. The number of tillers formed depends on the variety and growing conditions. Under usual field conditions a plant may produce a total of three tillers in addition to the main shoot, although not all will necessarily produce grain. The capability also exists to produce tillers from tillers (termed secondary tillers) if the plant is not crowded or is heavily fertilized. Tillers that appear at the time that the fourth, fifth, and sixth leaves emerge on the main shoot are most likely to complete development and form grain. Tillers formed later are likely to abort without producing grain. Tillers that produce more than three leaves and initiate their own root system are most likely to survive. The proportion of initiated tillers that abort differs with the variety and can increase if the crop encounters stress conditions.

During the time that tillering occurs, another less obvious but extremely important event occurs: the initiation of heads on the main shoot and tillers. Although the head at this time is microscopic, the parts that will become the floral structures and kernels are already being formed. When head formation is complete the stem begins elongating. This corresponds to the "jointing" stage (figure 5). A plant usually has about five leaves at this time.

Stem and head growth

Lower stem internodes on the plant remain short throughout development. The fourth internode is usually the first to elongate in a plant with nine total leaves. This is followed in sequence by the internodes above it (figure 6). Each stem internode up the plant becomes progressively longer, and the last stem segment to elongate, the peduncle, accounts for a considerable proportion of the total stem length. Growth regulators that are designed to shorten plant stature and increase resistance to lodging are timed to influence stem elongation. Some regulators act as growth retardants and reduce elongation of the last two or three stem internodes, resulting in a shorter, stiffer stemmed plant that lodges less readily.

Stem elongation coincides with the period of rapid head growth in which the individual florets become prepared to pollinate and be fertilized. Throughout the preheading period, differences in the duration of the various developmental phases among shoots on the same plant help synchronize development. This means a difference of several weeks between emergence of the main shoot and a tiller is reduced to a difference of only a few days by the time the heads emerge from the flag leaf sheaths. The "boot" stage is just prior to head emergence, when the flag leaf sheath encloses the growing head (figure 7).

Head emergence and flowering

As the stem continues to elongate, the head is pushed out of the flag leaf sheath, a stage referred to as "heading." Within a few days after heading, flowering (pollination) begins in the head, starting first with the florets in the central spikelets. Within the next few days flowering progresses both up and down the spike. Flowering is usually noted by extrusion of the anthers from each floret (figure 8), although this can change depending on the variety and weather conditions. If the anthers within a floret are yellow or gray rather than green, it is reasonably certain that pollination of the floret has occurred. The period of pollination within a single head is about four days. The young kernels within a head vary considerably in size at pollination and maintain this size variation throughout grain filling to maturity.

Kernel growth and maturity

Figure 9 shows the growth pattern for an individual wheat kernel. Growth progresses in three distinct phases spanning about four weeks under usual conditions. In the first phase, the "watery ripe" and "milk" stages, the number of cells in the endosperm (the major starch and protein storage portion of the kernel) is established. Not much weight is accumulated during this phase. Then 1 to 2 weeks after pollination, the kernel begins accumulating starch and protein rapidly and its dry weight increases in a nearly linear manner. This is when most of the final weight of the kernel is accumulated. The kernel consistency is "soft dough" during this time. Finally, growth of the kernel declines about three weeks into grain filling and its weight approaches a maximum attained at physiological maturity. As the kernel approaches maturity its consistency becomes "hard dough." Figure 10 illustrates the appearance of wheat kernels during this developmental sequence.

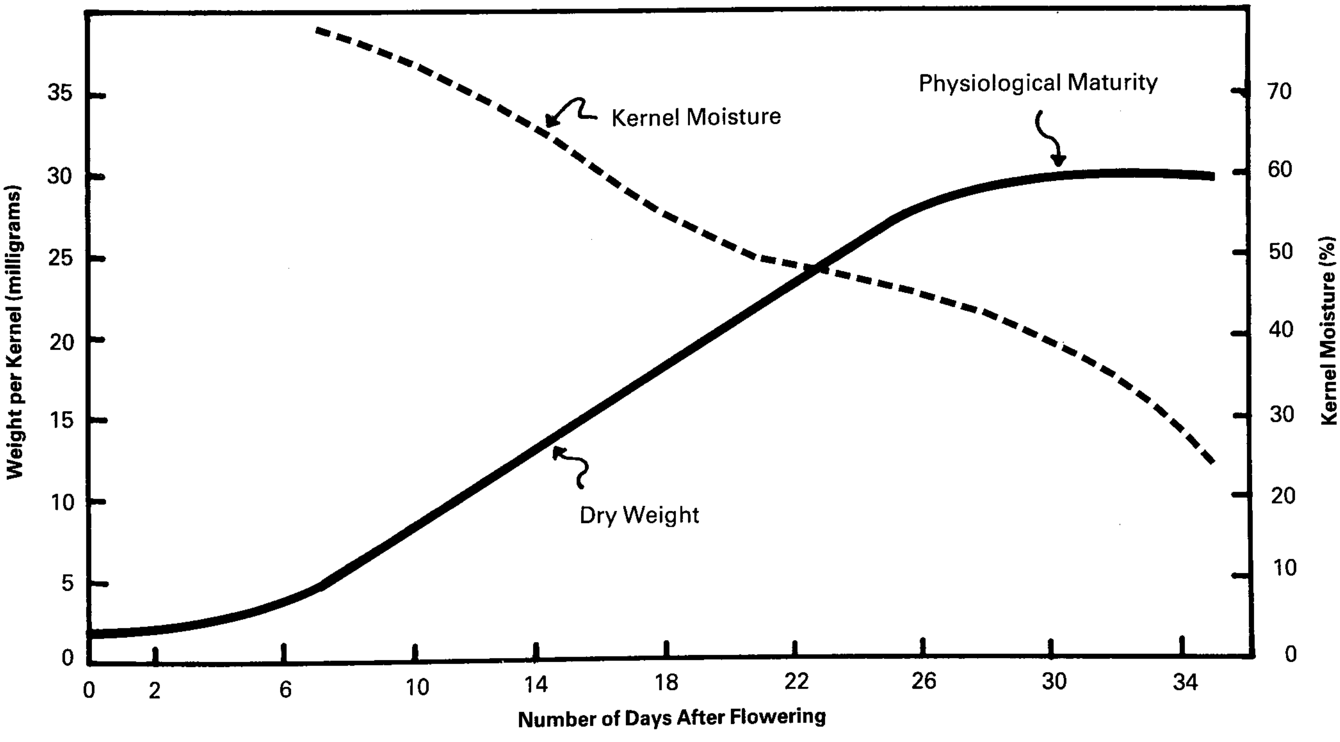
Adverse environmental conditions during any of the growth periods of a kernel can reduce the rate of dry matter accumulation and decrease yield. As a rule, the longer the adverse condition lasts, and the earlier it occurs during grain filling, the greater its effect on yield. For example, table 2 provides information from an experiment with two spring wheat varieties in Minnesota during two years with very different weather conditions. It shows that removal of the leaf blades early in grain development (at flowering) consistently reduced grain weight more than leaf removal 2 weeks later. Furthermore, the average

Table 2. Reductions in final weight per kernel for spring wheat in two years in response to leaf removal at different times during the grain filling period (average for varieties Era and Olaf)

Year	Reduction in kernel weight due to leaf removal at: Flowering	Two weeks after flowering	Average
		%	
1979	25	10	16
1980	16	4	11
Average	20	7	14

reduction due to leaf removal in 1979 was greater than in 1980. This is because 1980 was a particularly hot, dry year in which leaf removal, particularly later, was of less consequence. Although this experiment only measured effects of leaf removal on individual kernel weights the results approximate the effects on grain yield also.

Figure 9. Kernel growth curve for a typical medium maturity spring wheat variety based on actual field observations at St. Paul, Minnesota. Conditions of a specific crop season will modify this pattern somewhat as well as the final weight attained. Note the water percentage in the kernel and its decline at the approximate time of physiological maturity.



Throughout grain filling the kernel moisture percentage declines (figure 9), finally reaching a level between 30 and 40 percent at the time of maximum grain weight (physiological maturity). However, kernel moisture does not always determine when physiological maturity occurs. A better indicator of maturity is when the head and the peduncle lose their green color (figure 11). The green color is lost from the flag leaf blade when the kernel has attained about 95 percent of its final dry weight. Once the crop is at physiological maturity, no more kernel dry weight will accumulate and it can be swathed without reducing yield. After physiological maturity, moisture in the kernels declines rapidly (figure 9). The crop should be combined at 13 to 14 percent moisture to avoid post-harvest drying costs and assure safer storage.

Sources of photosynthate for grain yield

Approximately 70 to 90 percent of the final grain yield is derived from photosynthates (products of photosynthesis) produced by the plant during grain filling. The flag leaf and head usually contribute most, but certainly not all, of the photosynthate to the grain. Photosynthates produced by the flag leaf may contribute up to 50 percent of the grain yield, depending on seasonal conditions, but the head, penultimate leaf, and other leaves can also contribute significant quantities. Maintaining green and functional upper leaf blades, sheaths, and heads during grain filling is important for high yields.

Summary

Spring wheat proceeds through a sequence of easily recognized growth stages that are described by several staging schemes, the most comprehensive being the Zadoks system. Growing conditions and management decisions at any stage can have a bearing on the ultimate performance of the crop. An understanding of wheat growth and development is essential to achieving optimum productivity in spring wheat.

Glossary

Anther: The part of the flower that produces the pollen.

Coleoptile: The sheath that encloses the first main shoot leaf and provides protection as it emerges from the soil.

Flag leaf: The leaf immediately below the head.

Floret: An individual flower within the head.

Glumes: The pair of bracts located at the base of a spikelet in the head.

Internode: The part of a stem between two nodes.

Jointing: Stage of wheat development when stem nodes are first detected above the soil: Zadoks stage 31.

Leaf blade: The flattened portion of a leaf above the sheath.

Leaf sheath: The lower part of a leaf enclosing the stem.

Main shoot: The primary shoot which emerges first from the soil and from which tillers originate.

Node (Joint): A region on the stem where leaves are attached.

Peduncle: The top section of the stem between the flag leaf and the head.

Penultimate leaf: First leaf below the flag leaf.

Seminal roots: Roots arising at the level of the seed.

Spikelet: The flower of a grass consisting of a pair of glumes and one or more enclosed florets.

Tiller: A shoot originating from the base of the plant.

For further information

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