Chapter 2

Rice Growth and Development

Karen Moldenhauer, Paul Counce and Jarrod Hardke

Rice is an annual grass (Figure 2-1) with round, hollow, jointed culms; narrow, flat, sessile leaf blades joined to the leaf sheaths with collars; well-defined, sickle-shaped, hairy auricles; small acute to acuminate or two cleft ligules (Figure 2-2); and terminal panicles. The life cycle of rice cultivars in Arkansas ranges from 105 to 145 days from germination to maturity, depending on the variety and the environment.

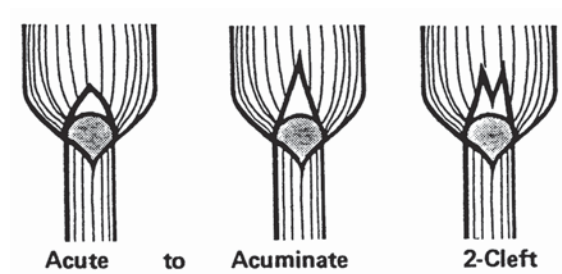


Figure 2-2. Ligule shapes of U.S. rice cultivars.

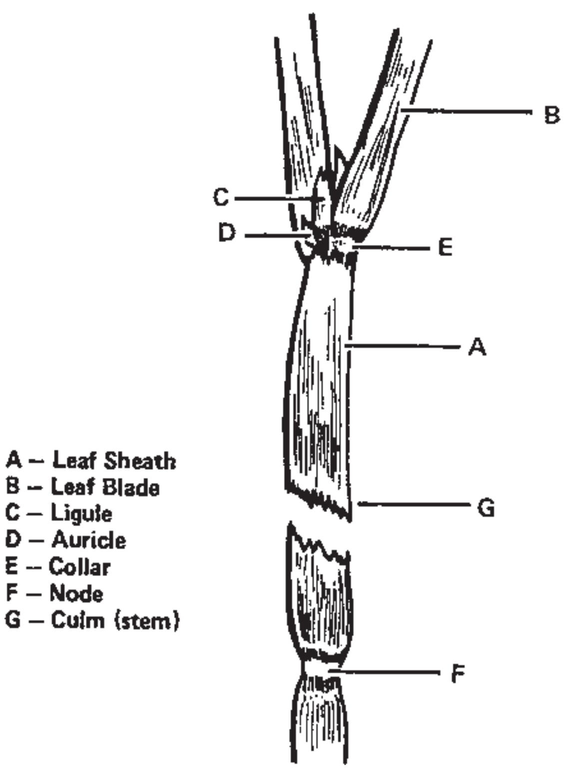


Figure 2-1. Leaf and culm morphology.

Management Key

Identification of plant parts is essential in differentiating rice plants from weeds.

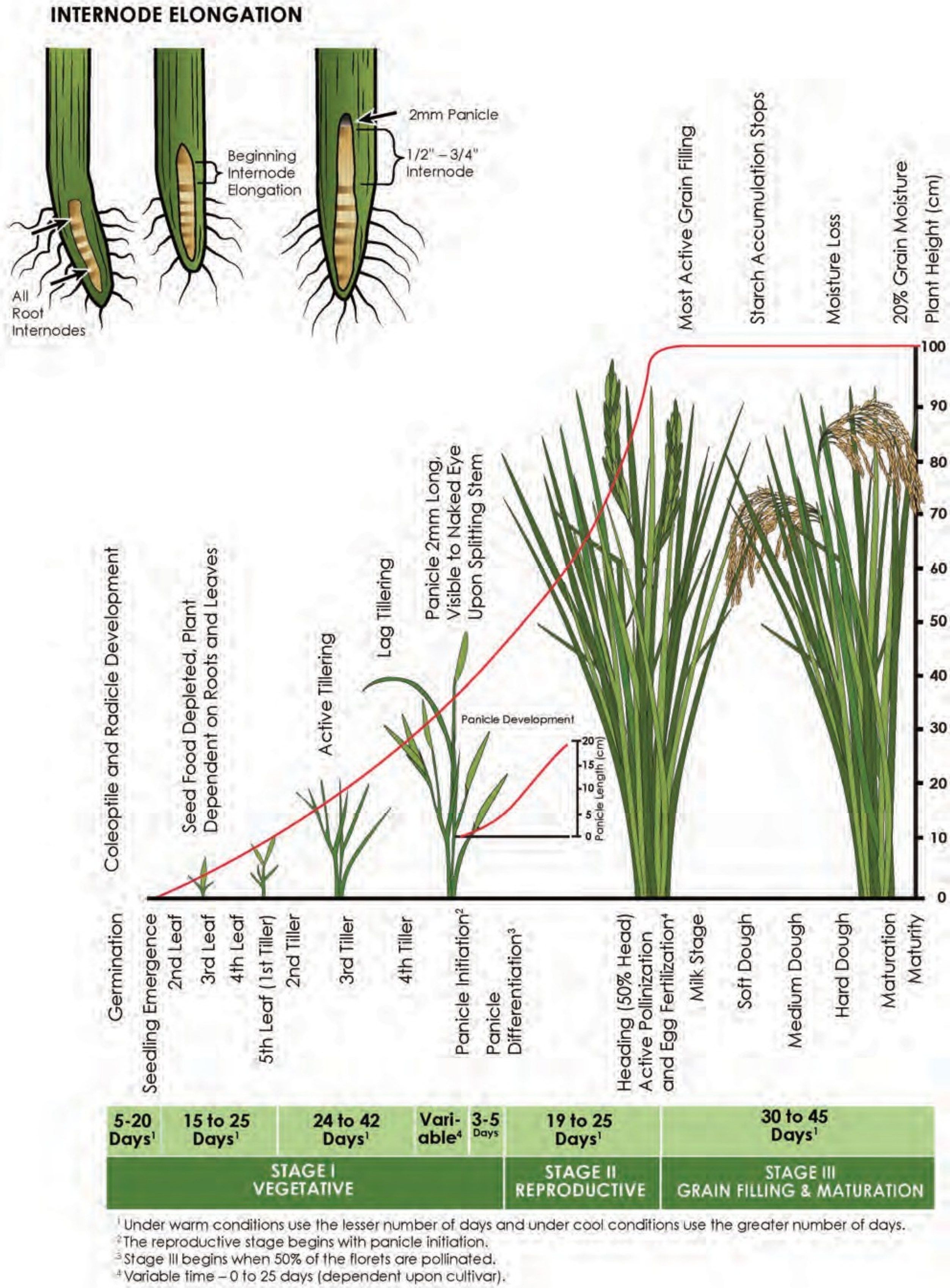
Rice plant growth can be divided into three agronomic phases of development (Figure 2-3):

1. Vegetative (germination to panicle initiation (PI));
2. Reproductive (PI to heading); and
3. Grain filling and ripening or maturation (heading to maturity).

These stages influence the three yield components: 1) number of panicles per unit land area, 2) the average number of grain produced per panicle and 3) the average weight of the individual grains. These three components determine grain yield.

The following descriptions and diagrams characterize the growth stages for rice plants.

Figure 2-3. **Developmental stages of the rice plant.**



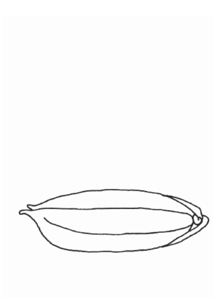
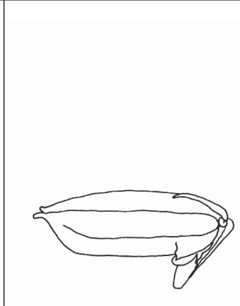
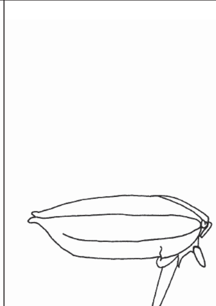
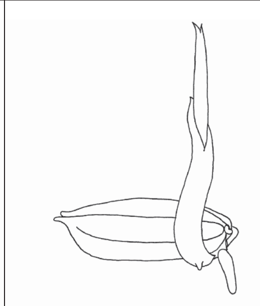
Vegetative Phase

The vegetative growth phase is characterized by active tillering, a gradual increase in plant height and leaf emergence at regular intervals. The length of this phase primarily determines the growth duration of cultivars. Some very-early-maturing cultivars have a shortened vegetative growth phase, while others have both shortened vegetative and reproductive growth phases. Panicle initiation (PI; R0 in the rice growth staging system) may occur before the maximum tiller number is reached in very-short-season and some short-season cultivars. Heading in these cultivars may be staggered due to later tillers which produce panicles. In midseason cultivars, the maximum tiller number is reached and followed by a vegetative lag phase before panicle initiation (PI) occurs.

The following distinct steps occur during the vegetative stage:

1. **Seed Germination** occurs when the seed coat has imbibed adequate water to become soft and elastic. The coleorhiza (the sheath covering the radicle or embryonic primary root) elongates slightly, emerging through the seed coat, allowing the radicle to break through the coleorhiza and become anchored in the soil. The coleoptile or primary leaf then elongates. Thus, under dry-seeded or aerobic conditions, the radicle emerges before the coleoptile. Under water-seeded or reduced oxygen (anaerobic) conditions, the coleoptile may emerge before the root (radicle or coleorhiza). This typically occurs within two days when temperatures are between 70° to 97°F. Below or above this temperature, germination requires more time. Germination occurs within the temperature range of 50° to 107°F with an optimum temperature of about 87°F. The rice growth staging system provides the terms S0, S1, S2 and S3 for the progressive stages of germination and seedling emergence (Figure 2-4).

Figure 2-4. Seedling growth stages.

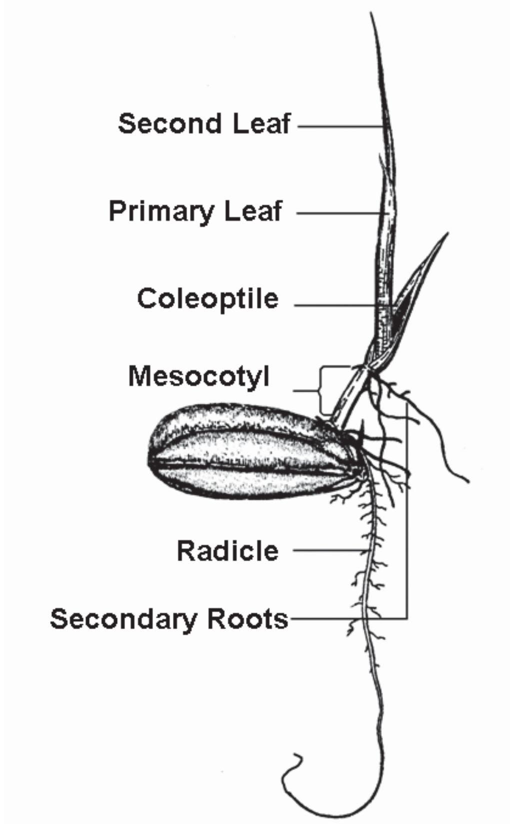
Seedling growth stages with morphological markers				
Growth Stage	**SO**	**S1**	**S2**	**S3**
Morphological Marker	**Dry, unimbibed seed**	**Emergence of coleoptile**	**Emergence of radicle†**	**Emergence of prophyll from coleoptile††**
Illustration				

† The sequence of normally occurring seedling developmental events is presented above. There are exceptions to the sequence of events. In some cases, the coleoptile emerges first; in other cases, the radicle emerges first. When either emerges alone, then the growth stage is S1. When both have emerged, the growth stage is S2. If the prophyll emerges from the coleoptile before the radicle emerges from the seed, then the growth stage is S3.

†† The prophyll is the first leaf to emerge, but it lacks a blade and a collar and consists only of the leaf sheath.

Nodal roots form at the coleoptile base and lateral roots form off the radicle (seminal root) (Figure 2-5). Subsequent roots form at each node.

Figure 2-5. **Parts of a germinating seedling.**

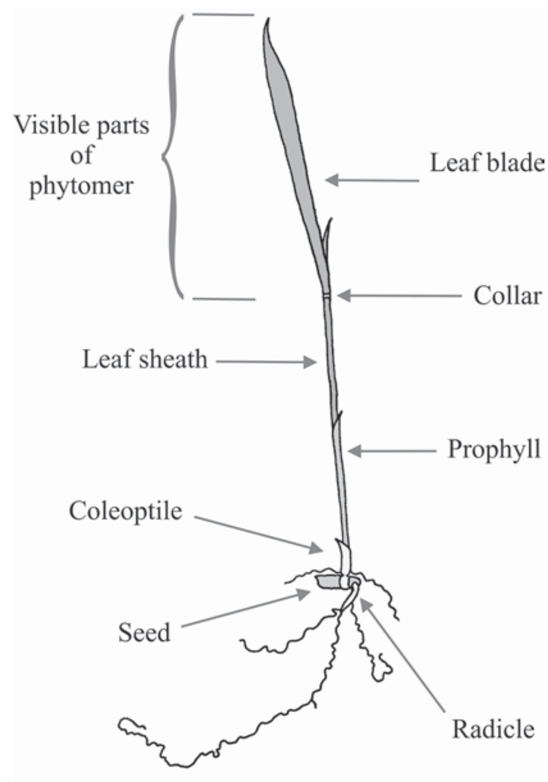


Management Key

(1) Imbibition of water by the seed is essential before application of the preemergence herbicides Prowl or Bolero to prevent injury. (2) There will be minimal seedling emergence from rice seed covered with both soil and water because of lack of O_2. (3) Higher seeding rates will not compensate for low temperatures or other adverse environmental conditions.

2. **Seedling Emergence** occurs when the first internode, called the mesocotyl, has elongated and pushed the tip of the rice coleoptile (epiblast) through the soil surface. The prophyll (first sheathing leaf) emerges through the coleoptile. It is not a true leaf because it lacks a leaf blade. The length of the mesocotyl varies with cultivars. Some semi-dwarf cultivars may have a very short mesocotyl and generally will not emerge if covered by more than ½ to ¾ inch of soil. The mesocotyl only develops in the dark and doesn't show up in water-seeded rice (Figure 2-5). The V1 growth stage (Figure 2-6) occurs when the first complete leaf pushes through the prophyll and forms a collar. At this point, the seedling has five roots formed from the coleoptilar node. The V2 growth stage occurs when the second leaf is fully emerged and progresses accordingly.

Figure 2-6. **Parts of a V1 rice plant.**



Management Key

(1) Semi-dwarf cultivars with short mesocotyls may not emerge if covered with more than ½ to ¾ inch soil. When growing these cultivars, a gibberellic acid seed treatment (Release or GibGro) may be used to increase the mesocotyl length and, thus, emergence. (2) Emergence for starting the DD50 program is defined as the date when 10 of the rice coleoptiles per square foot have emerged above the soil surface. (3) Seedling germination and emergence typically vary from 5 to 28 days depending on the environment.

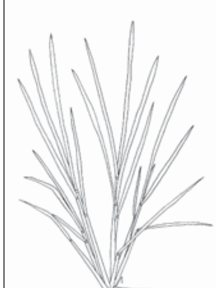
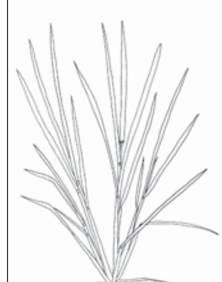
The complete set of V stages begin with the first complete leaf after the prophyll and end with collar formation on the final leaf (the “flag” leaf) on a culm (Figure 2-7).

3. **Pre-Tillering** – The period from the development of the first- to fourth-leaf stage (V1 – V4 stage) requires 15 to 25 days. During this time, the seminal root further develops, the secondary or lateral roots develop and the first four leaves appear (Figure 2-4). After seedling emergence, a new leaf emerges for every 100 to 175 accumulated DD50 units, normally every 3 to 7 days.

4. **Tillering** usually begins at the fifth-leaf stage (V5) when the first tiller is visible and emerges from the axillary bud of the second leaf on the culm. Tillering continues when the sixth leaf emerges and the second tiller comes from the

Figure 2-7. Vegetative growth stages.

Vegetative growth stages with morphological markers			
V5	**V6**	**V7**	**V8**
Collar formation on leaf 5 on main stem	Collar formation on leaf 6 on main stem	Collar formation on leaf 7 on main stem	Collar formation on leaf 8 on main stem
			

Vegetative growth stages				
V9 (VF-4)‡	**V10 (VF-3)‡**	**V11 (VF-2)‡**	**V12 (VF-1)‡**	**V13 (VF)‡**
Collar formation on leaf 9 on main stem	Collar formation on leaf 10 on main stem	Collar formation on leaf 11 on main stem	Collar formation on leaf 12 on main stem	Collar formation on leaf 13 on main stem
				

‡ Rice cultivars range from 10-20 leaves (V-stages) per main stem culm. This is an example for one with 13 leaves on the main stem.

axillary bud of the third leaf. Tillering continues in a synchronous manner with the nth leaf of the main culm and tiller emerging from the axillary bud of the (n-3)th leaf. During this period, the secondary roots grow down until flooding. Once flooded, these roots grow both vertically and laterally. The lateral growth is probably due to the availability of O_2, light and nutrients at the soil-water interface. During active tillering new leaves on the main culm emerge at a faster rate, requiring about 75 to 150 DD50 units or normally every 3 to 5 days.

Management Key

Tillering is necessary with low plant population (5 to 10 plants per square foot) and can be stimulated by extra preflood nitrogen during the rapid tillering stage as defined by the DD50 program.

5. **Maximum Tillering** – Tillering increases in a sigmoidal-shaped curve until the maximum tiller number is reached. At this point, the main culm may be difficult to distinguish from the tiller. In direct-seeded rice fields with a normal plant population (10 to 20 plants per square foot), rice plants generally produce two to five panicle-bearing tillers per plant compared to 10 to 30 tillers per plant in transplanted rice where more space is available between plants. After maximum tillering has occurred, no more effective tillers are produced. A portion of the late tillers will generally die due to competition effects. The first yield component, potential panicles per unit area, is determined at this time.

Management Key

Because of rapid growth during the active tillering stage, avoid using phenoxy herbicides (2,4-D) during this growth stage to prevent excessive injury.

6. **Vegetative Lag Phase** – The period from the end of active tillering to the beginning of the reproductive phase. Tiller number decreases; height and stem diameter continue to increase but at a slower rate. This is the time when phenoxy herbicides should be applied. The length of this period is a function of the maturation period of the cultivar. For very-short-season cultivars with 105-day maturity, this period may not be evident. In this situation, the maximum tillering stage and the beginning of reproductive growth may overlap. In a 145-day rice cultivar, the lag phase period may last more than two weeks. During this slow growth period, the number of DD50 units required for a new leaf to emerge increases to about 200 per leaf and continues to increase with each new leaf produced or, under normal growing conditions, 5 to 10 days.

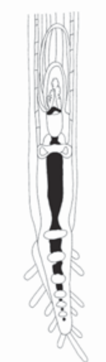
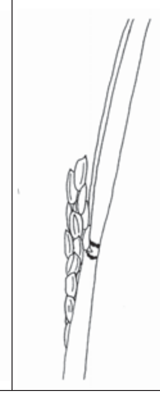
Management Key

The vegetative lag phase in midseason cultivars is characterized by yellowing plants. There is not much activity occurring in the rice; therefore, there is a low nitrogen demand and extra fertilization is not needed. Most of the common cultivars currently grown have a short or unnoticeable vegetative lag period.

Reproductive Phase

The reproductive phase is characterized by culm elongation, a decline in tiller number, booting, emergence of the flag leaf, heading and flowering. The reproductive phase usually lasts approximately 30 days in most cultivars. The beginning of this phase is sometimes referred to as the internode elongation or jointing stage and varies slightly by cultivar and weather conditions. Successive reproductive growth stages provide useful terms so that any two individuals can clearly communicate about the stage of rice (Figure 2-8).

Figure 2-8. Reproductive growth stages with keys for determining growth stage R0 to R9.

Reproductive growth stages with morphological markers						
Growth Stage	**RO**	**R1**	**R2**	**R3**	**R4**	**R5**
Morphological Marker	**Panicle development has initiated**	**Panicle branches have formed**	**Collar formation on flag leaf**	**Panicle exsertion from boot, tip of panicle is above collar of flag leaf**	**One or more florets on the main stem panicle has reached anthesis**	**At least one caryopsis on the main stem panicle is elongating to the end of the hull**
Illustration						

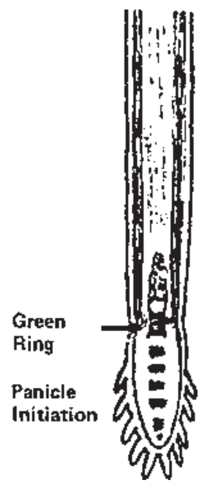
Reproductive growth stages with morphological markers				
Growth Stage	**R6**	**R7**	**R8**	**R9**
Morphological Marker	**At least one caryopsis on the main stem panicle has elongated to the end of the hull**	**At least one grain on the main stem panicle has a yellow hull**	**At least one grain on the main stem has a brown hull**	**All grains which reached R6 have a brown hull**
Illustration				

The following processes occur during the reproductive phase:

1. **Panicle Initiation** (PI; R0 growth stage, Figure 2-9) is the time when the panicle pre-mordia initiate the production of a panicle in the uppermost node of the culm.

   At this point, the panicle is not visible to the naked eye. It is sometimes referred to as the green ring stage in rice (Figure 2-9). A thin green band is visible just above the top node and represents the very beginning of internode elongation and is evident for only a couple of days. The duration from R0 to R1 is normally 20 to 30 days and about 200 DD50 units and also the period it takes for growth stage VF-4 to VF-3.

Figure 2-9. Green ring or panicle initiation.



Management Key

Beginning internode elongation (BIE) or panicle initiation (PI) is the time to begin scouting for sheath blight as outlined by the DD50 program.

2. **Internode Elongation** (IE) begins about the time panicle initiation is occurring, continues until full plant height is reached and is followed by heading. The top five internodes are associated with the final five leaves. The first of these elongates before panicle elongation. This stage is also referred to as the "jointing stage" (Figure 2-6). Stem internodes can be distinguished from root internodes by the green color in the stem wall.

3. **Panicle Differentiation** (PD; R1 growth stage, Figure 2-10) is closely associated with "jointing" or the internode elongation stage. PD is roughly equivalent to ½- to ¾-inch internode elongation (Figure 2-10). The duration from the R1 to R2 growth stage is 20 to 30 days and about 600 DD50 units. This means from when the panicle differentiates to when the collar is formed on the flag leaf. It is also the time period required for collar formation on leaves VF-2, VF-1 and VF after the leaf has formed on VF-3. The final five leaves form concurrently with the development of the panicle underneath the sheath.

   At this point, the panicle is 1 to 2 mm in length and the branching of the panicle is visible (Figure 2-11). This is a critical stage during rice plant development.

   At this stage, the environment can have a major effect on rice plant development. The second yield component, number of potential grains per panicle, is set by the time this development stage occurs.

Figure 2-10. **Beginning internode elongation through panicle differentiation.**

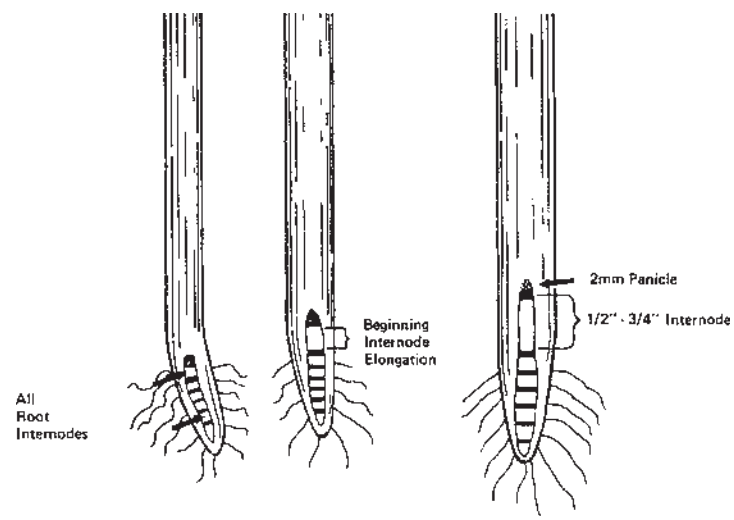
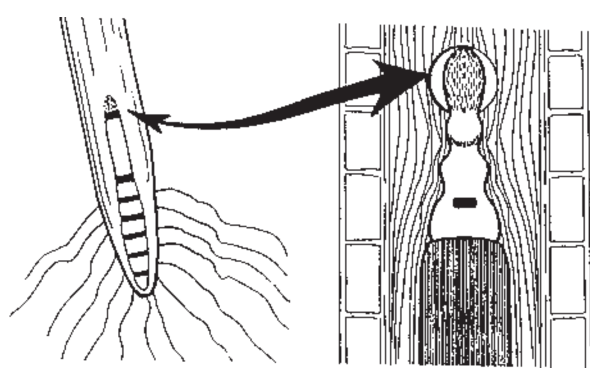


Figure 2-11. **The panicle at the panicle differentiation state of development (2 mm in length). (Left) Panicle exposed by splitting culm lengthwise. (Right) Location within the main culm of the rice plant.**



Management Key

Panicle differentiation is the cut-off time for herbicides such as 2,4-D and propanil. Applications should be made prior to this time to avoid injury to rice.

4. **Booting** (R2 growth stage, Figure 2-12) – This stage is loosely defined as that period characterized by a swelling of the flag leaf sheath which is caused by an increase in the size of the panicle as it grows up the leaf sheath. Full or late boot occurs when the flag leaf has completely extended. Booting is the stage in which meiosis occurs. Environmental stress during this stage may reduce rice grain yield. Late boot occurs about 6 days prior to heading. This date can be predicted by the DD50.

Management Key

Application of propiconizole fungicides should be made to prevent kernel smut during this growth stage.

5. **Heading** (R3 growth stage, Figure 2-8) – The time when the panicle begins to exsert from the boot. (Figure 2-8 shows common types of panicle exsertion.) Heading over an individual field may take over 10 to 14 days due to variations within tillers on the same plant and between plants in the field. Agronomically, ***"heading date"*** or ***"50 percent heading"*** is defined as the time when 50 percent of the panicles have at least partially exserted from the boot. This is in contrast to ***"headed,"*** which refers to the time when 100 percent of the panicles have completely emerged from the boot. Some panicles may never emerge completely from the boot. Across a range of cultivars and conditions, the interval between R3 and R4 is 37 DD50 units and 2.3 days. The duration of this interval depends greatly on sunlight, temperature and humidity conditions. In sunny conditions, the duration of the period from R3 to R4 is shorter and can occur within the same day on some plants. In cloudy, rainy conditions, the period is longer: 5 to 7 days depending on light conditions.

Management Key

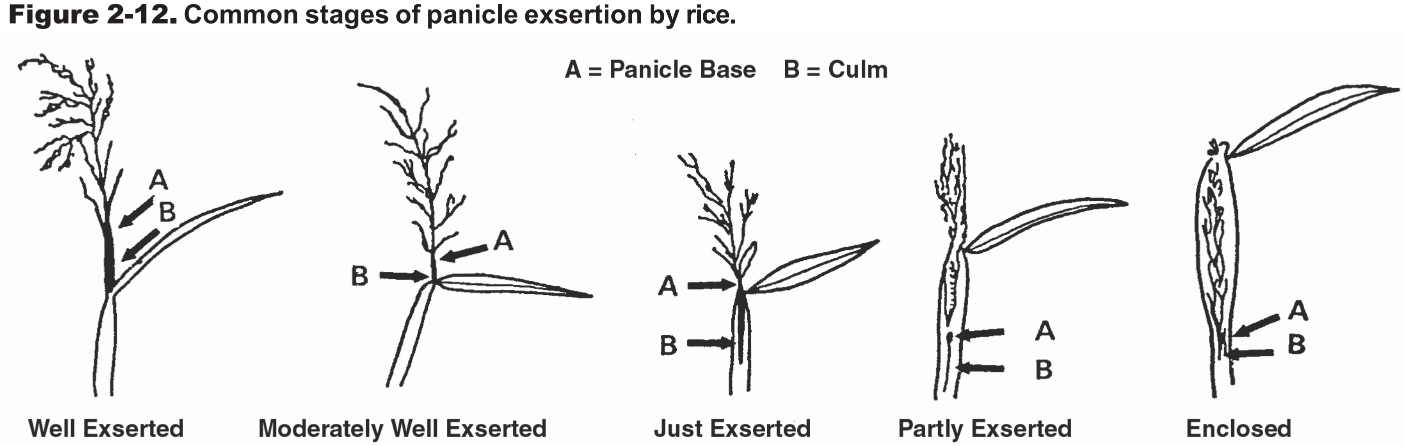
The Arkansas DD50 Management Program uses this same definition of ***"heading date,"*** i.e., when 50 percent of the panicles have at least partially exserted from the boot. Heading date is the last visual check for DD50 accuracy and can be used to predict approximate draining and harvest dates.

The panicle does not fully exsert from the boot at heading. Panicles from some cultivars extend partially out of the boot while others extend 3 to 4 inches beyond the panicle base.

Management Key

Long periods of low sunlight three weeks before and after heading may cause poor exsertion of the panicles and lead to poor grain filling.

Figure 2-12. **Common stages of panicle exsertion by rice.**



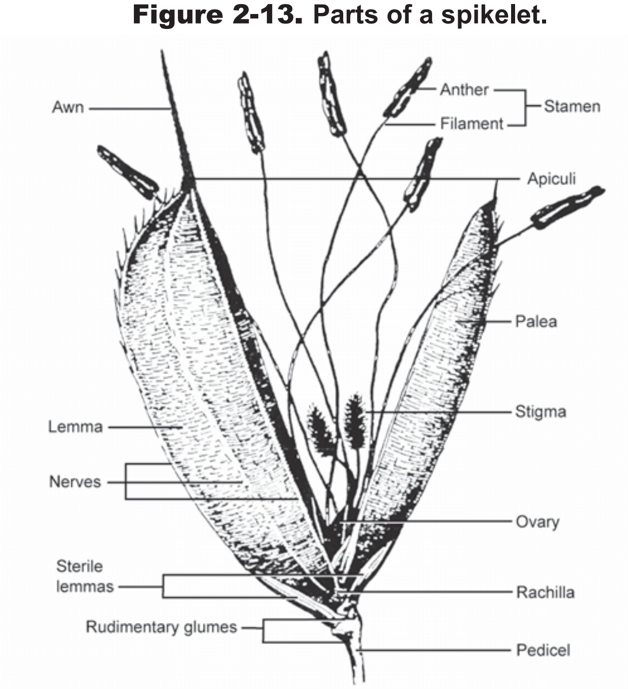
6. **Anthesis** (R4 growth stage, Figure 2-13) or flowering refers to the events between the opening and closing of the spikelet (floret) and lasts for 1 to 2½ hours during which time pollination occurs. Flowering generally begins upon panicle exsertion or on the following day and is consequently considered synonymous with heading.

Anthesis generally occurs between 9 a.m. and 3 p.m. in Arkansas.

The steps involved in anthesis are:

a. The tips of the lemma and palea (hulls) open.
b. The filaments elongate.
c. The anthers exsert from the lemma and palea.
d. As the lemma and palea open further, the tips of the feathery stigma become visible.
e. The filaments elongate past the tips of lemma and palea.
f. The spikelet closes, leaving the anther outside. Anther dehiscence (pollen shed) usually occurs just prior to or at the time the lemma and palea open (step a).

Figure 2-13. Parts of a spikelet.

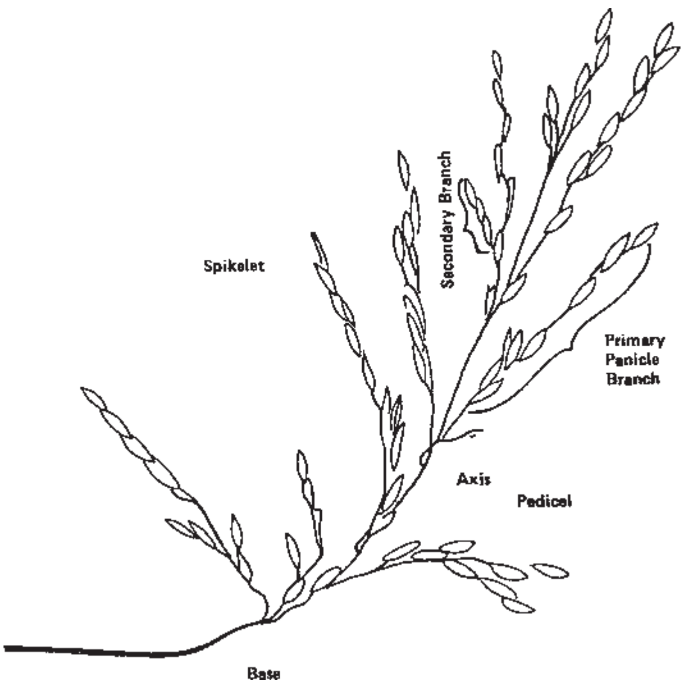


Pollen grains are viable for about 5 minutes after emerging from the anther, whereas the stigma may be fertilized for 3 to 7 days. Rice is primarily a self-pollinating plant. Because it is usually pollinated before the lemma and palea open to release pollen into the air, cross-pollination usually only occurs at a rate of about 1 percent. Fertilization of the ovary by the pollen grain is generally completed within 5 to 6 hours after pollination; at that point, the ovary becomes brown rice. Flowering begins at the tip of the panicle branches and moves down the branch to the panicle base (Figure 2-14). The DD50 interval for R4 to R5 growth stages is about 54, or about three days. Flowering will begin on the upper branches as they emerge from the boot and continue down the panicle to the lower branches. The time interval for flowering of an entire panicle is normally 4 to 7 days. The potential number of filled grains per panicle has been essentially established by the number of fertilized flowers (kernels). Most, but by no means all, grains which are fertilized will eventually fill. The number of filled grains per panicle is primarily determined by conditions and events during this stage since only flowers fertilized can become filled grains.

Management Key

Extremes in temperatures, such as 50°F or less, for two consecutive nights 2 weeks prior to and/or at flowering can cause excessive sterility or blanks. Also, strong winds, rain showers, fertilizer or pesticide applications while blooming is occurring (9 a.m. to 3 p.m.) can increase sterility. During flowering, air temperatures > 95°F may increase blanking.

Figure 2-14.
Parts of a rice panicle.



Ripening Phase

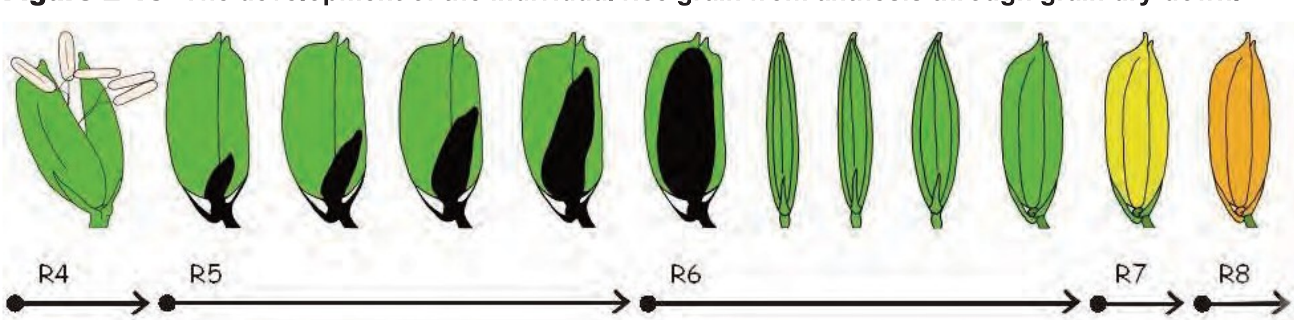
The grain filling and ripening or maturation phase (R6 – R8 growth stages) follows ovary fertilization and is characterized by grain growth. During this period, the grain increases in size and weight as the starch and sugars are translocated from the culms and leaf sheaths where they have accumulated, the grain changes color from green to gold or straw color at maturity and the leaves of the rice plant begin to senesce. Light intensity is very important during this interval since 60 percent or more of the carbohydrates used in grain filling are photosynthesized during this time interval. This period is also affected by temperature. In Arkansas, most long-grains ripen in 35 days, medium-grains in 45 days and short-grains in 50 days. The DD50 program supplies information for approximate maturity dates. The progress of an individual grain from fertilization to completion of grain filling is presented in Figure 2-15.

The final component, individual grain weight, is determined during the ripening stage. Although grain weight is relatively stable for a given cultivar, it can be influenced by the environment. High temperatures tend to reduce the grain-filling period and may reduce grain weight. Low temperatures tend to lengthen the time required for grain fill and ripening. The ripening process may cease after a significant frost occurs and normally slows dramatically when temperatures stay below 50°F for several days.

Steps in the ripening process are:

1. **Milk stage** (R6 growth stage) – At this stage, the developing starch grains in the kernel are soft and the interior of the kernel is filled with a white liquid resembling milk. The interval for development from R6 to R7 growth stages is about 90 DD50 units and 3 to 6 days.
2. **Soft dough stage** (R6 growth stage) – The starch in the grain is beginning to become firm but is still soft.
3. **Hard dough stage** (R7 growth stage) – This phase includes the end of grain filling (R7) and the grain-drying stage (R8). The whole grain is firm during this stage and almost ready for harvest. The moisture content for the entire crop is still above 22 percent. The interval for development from R7 to R8 growth stages is about 60 DD50 units or 2 to 5 days.

Figure 2-15. The development of the individual rice grain from anthesis through grain dry-down.



4. **Maturity** (R9 growth stage) – The whole grain is hard and ready for harvest. This stage is reached at approximately 20 to 22 percent moisture. The interval for development from R8 to R9 growth stages is about 200 DD50 units and 27 days. For presently used cultivars, temperatures have normally begun to decline from the highs for the growing season although growth stages R6, R7 and R8 are very susceptible to high nighttime air temperatures. Normally rice is harvested prior to R9 for the entire field as the earlier developing grains continue to dry as the later grains are still filling. Consequently, waiting until the last grains fill is impractical and results, normally, in reduced milling quality.

Management Key

Uniform maturity is the key to high milling yields so that harvest can be prompt.

Effect of Temperature on Growth and Development of Rice

Determining optimum temperatures for rice is difficult because the response to temperature varies by biotype (i.e., indica, japonica and javanica), cultivar and plant health before the temperature extreme. Most of the rice grown in the southern USA is a tropical japonica type. Both high and low temperature extremes can influence rice production in Arkansas. However, the overall effects can range from severely reduced yield to merely cosmetic leaf injury.

Japonica types common in the southern USA tend to have reasonably good cold tolerance. The freezing temperatures experienced in 2007 demonstrated this at seedling growth stages. Symptoms of low temperature stress include reduced germination, leaf discoloration, stunting, delayed maturity and increased sterility. The amount of the expression of these symptoms by the rice plant depends on growth stage, duration of the stress and extent of the extreme. Panicle initiation (R0), boot stage (R2) during microsporogenesis and anthesis (flowering – R4) are the stages that are most sensitive to low temperature stress.

High temperature stress causes increased sterility during flowering. High nighttime temperatures during grain filling result in increased respiration which causes the plant to consume more carbohydrates. This reduces the efficiency of photosynthesis during the day, resulting in less filled spikelets. This leads to reduced grain yields. It also results in increased chalky kernels, a thicker bran and aleurone layer, which result in reduced head rice yields.