RICE GROWTH & DEVELOPMENT

Introduction

So, you want to grow a 12,000 lb/acre rice crop? The modern short-statured varieties for California certainly are capable of producing yields this high or higher. Of course, not all the conditions to achieve such yields will be under your control. Most notably, untimely rainfall, cold temperatures and many other weather-related events are simply out of your control. But many things are under your control, and most all of them require a good knowledge of how the rice plant grows from seedling to grain filling. This knowledge will help you make informed decisions and better use the many practices and tools that are available. This section will be a lesson in applied rice botany for the primary purpose of understanding what goes into the making of a rice grain crop.

The Yield Components

Generally, one thinks of yield as the total weight of rough rice from a field, usually in "sacks" or cwt per acre. At harvest you may think in terms of trailer loads to compare a field's performance from the previous year as sort of a "back of the envelope" estimate of yield. But just how is all that grain in the trailer made?

Generally, crop health is assessed at the whole field level and not at the details of the plant. However, the clues to what went right or wrong in a season can often be determined from the yield components. Rice grain yields are the product of the plant's yield components. Why is it important to know about yield components? Every management practice affects the yield components—but the question is, which ones and when? So, before trying to understand where yield components fit into the life cycle of the plant and how to maximize them, it's important to know what they are.

Yield components are:

1) the number of panicles per given area (often called fertile panicles)
2) the number of spikelets or grains per panicle
3) the percentage of filled kernels or grains and
4) the weight of the kernel—each grain.

Yield, then, is the product of each of the four components.

YIELD = Panicles/area x spiklets (grains)/panicle x % filled pikelets x kernel wt

Let's use an example of yield components converted to a per acre basis to see how they all add up to yield.

Your crop has 60 panicles per square foot and each has 70 kernels. The kernel weight is 30 grams/1000 grains, there is 10% blanking, what is the yield?

Conversion Factors: 1 lb = 454 grams

1 ac = 43,560 ft2 Abbreviations: grams = g

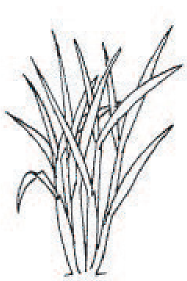
Pound = lb Square foot = ft2

Step 1:
60 panicle/ft2 x 70 kernel/panicle x 90% filled spikelets = 3780 kernels/ft2

Step 2:
30 g/1000 kernels x 3780 kernel/ft2/ 454 g/lb = 0.250 lb/ft2

Step 3:
0.250 lb/ft2 x 43,560 ft2/acre = 10,880 lb/acre

Panicles per unit area



The total number of panicles in a given area is a product of the number of established seedlings and the number of fertile tillers produced by each seedling. A fertile tiller is one that produces a panicle. In some cases, such as in very dense stands, many of the tillers are shaded out and die shortly after panicle initiation (PI) and therefore do not produce panicles. Of all the yield components, the number of panicles per unit area is the most easily influenced by management practices. The number of seedlings per unit area, we commonly call "stand," is directly related to the seeding rate. Seeding rates of 125 lb/ac to 200 lb/ac typically provide seed densities as shown in Table 1.

These seedling densities based on seeding rates are ballpark estimates. The number of seeds/ft^2 can range widely depending on the seed size of the varieties. Koshihikari is the smallest and S-102 the largest of grown varieties (see Figure 2 later in this chapter). Thus, some adjustment in seeding rate may be necessary to compensate for seed size. One seedling can produce a number of tillers (depends of stand density - see Figure 5 later in chapter) and ultimately panicles; however, 60 to 70 panicles/ft^2 are about optimum for good yields with Calrose type varieties (Table 2).

Importantly, in water seeded rice systems seed density does not translate into plant density as many seeds (up to 50%) fail to produce a viable seedling due to wind, pests and diseases (see Chapter 4 for more information on this). For example, M-206 at a seeding rate of 150 lb/ac, would give 50+ seeds/ft^2 almost enough, if they all survived, to provide an adequate number of panicles without tillering. However, we all are familiar with damage to stands from wind, tadpole shrimp, bakanae and many other things that can cause moderate to heavy stand losses. High seeding rates are a form of insurance against stand losses. As a cautionary note, however, too high seeding rates can result in weak stems and increased incidence of foliar disease. The bottom line is that to achieve panicles densities high enough for good yields, tillers must be produced by each seedling. Varieties vary in their tillering capacity, ranging from high tillering tropical indicas to our relatively lower tillering calrose or japonica types. All of California varieties, however, have more than adequate tillering capacity to produce high yields in direct-seeded culture. If conditions are good during the tillering stage, the plant is capable of producing many more tillers than are needed for

Table 1. Field seed densities from typical seeding rates. The seed densities range due to differences in seed size (Figure 2). Densities for M-206 are shown for comparison.

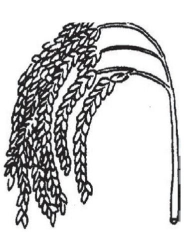
Seeding rate (lb/ac)	Density range (seeds/ft^2)	M206 (seeds/ft^2)
125	40-58	45
150	48-69	54
175	60-81	63
200	65-92	72

Table 2: Rice stand, yield and yield components.

Seeding Rate	Yield Components					
	Established Plant Stand	Panicle Density	Grain Weight	Spikelets/Panicle	Filled Spikelet	Yield
seeds/ft^2	plants/ft^2	ft^2	mg	no.	%	lbs/ac
11	11	53	25.2	90.8	86.6	8692
22	21	65	25.6	74.8	85.8	9267
33	27	61	25.8	71.6	86.2	9438
45	34	66	25.5	64.3	85.6	9393
56	34	68	25.9	63.1	86.2	9423
78	43	75	25.9	58.9	86.8	9456

high yields (see Figure 6 later in chapter). If conditions are not good, then an inadequate number of tillers will be developed and yields will suffer. Fortunately, the rice plant has a remarkable ability to compensate for low stands. As stand density goes down, tillers per plant increase. For example, in a Butte County nitrogen by variety trial in 1984 and 1985, 12 plants/ft^2 produced 4.8 tillers per plant, 21 plants/ft^2 produced 3.1 tillers per plant and 27 up to 34 plants/ft^2 produced about 2 tillers per plant. In a more recent study using M-206 at the RES, similar findings were reported with 16 tillers per plant at the lowest plant density (3 plants/ft^2) and between 2 and 3 tillers per plant at plant densities of 25 to 55 plants/ft^2 (Table 3). At optimal plant densities, tiller density is about 60 tillers/ft^2 or more (Table 3) and will give a panicle density of about 60 panicles/ft^2 or more (Tables 2 and 3).

Spikelets Per Panicle



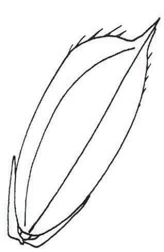
Spikelets are formed when the apical meristem or growing point changes from producing leaves to producing the panicle (reproductive structures). This occurs late in the tillering stage and triggers panicle initiation or reproductive growth. The entire panicle—branches and spikelets are developed at this time. Although they cannot be seen with the naked eye, under a microscope, their surface appears as a series of small nodes, each to become a spikelet or grain. Typically, we identify PI by cutting the stem or culm longitudinally with a pocketknife. At the start of PI, the panicle is not visible but a green band is visible above the top node (thus referred to as "green-ring"). The green band is only visible for a couple of days so it is easy to miss it. Once the panicle is produced, the top node begins to elongate and move up the stem, increasing the space between the nodes (Figure 1). Usually by the time we see the young panicle it is several days after PI.

The maximum panicle size of most California Calrose types is around 100 spikelets per panicle, but is more on the order of 70 spikelets per panicle with typical densities of 60 to 70 panicles/ft^2. The number of spikelets per panicle, however, can vary genetically from varieties with relatively small panicles to varieties with panicles of over 150 spikelets or more. Some of the Chinese hybrids, for example, have very large panicles. Man-

Figure 1. Young panicle

agement practices can influence the number of spikelets per panicle. Most commonly, stand density has the greatest influence on panicle size. Rice plants will compensate for low stand densities by producing more spikelets per panicle (as well as by producing more tillers per plant) as shown in Table 2. Usually, however, panicle size will not increase enough to overcome lower yields from poor stands.

Percentage Filled Grains



The percentage of filled spikelets per panicle can be greatly reduced by cold air temperature. Low water temperature can also reduce the number of filled spikelets. California varieties are among the most cold tolerant in the world, but they can still be damaged during meiosis (occurs during period about 10 days after PI and 10 days before heading) by temperatures below 55º and 60º F (depending on variety). When this occurs, the spikelets become sterile and result in "blanks". Blanking can be as high as 40-50% when low nighttime temperatures continue for four or five consecutive days. Blanking on a "normal" year is around 12%. Increasing water height during the critical meiosis stage can greatly reduce cold damage. Water should be raised to a level above the developing panicle (8-10 inches) to act as a heat sink and thus keep temperatures above the critical level.

Kernel weight

Kernel weight differs among varieties from a 1000 kernel weight for the small-seeded Calhikari and Koshihikari varieties (22.5 to 24.9 g), to S-102 at over 32 g (Figure 2). Common medium grains range between 27 and 30 g/1000 kernels. In the field, kernel weights are the least variable yield component. They generally cannot be increased by good management practices to compensate for poor tillering or smaller panicles. For example, Table 2 shows that across all seeding rates and resulting panicle densities, and even at the lowest seeding rate where panicle size increases, grain weight remains constant at about 25 g per 1000 kernels. Kernel weight, however, can be reduced by bad management or bad luck (such as draining too soon or from drying north winds). Fields that are too dry at the end of the harvest can limit grain filling and reduce kernel weight as well as quality.

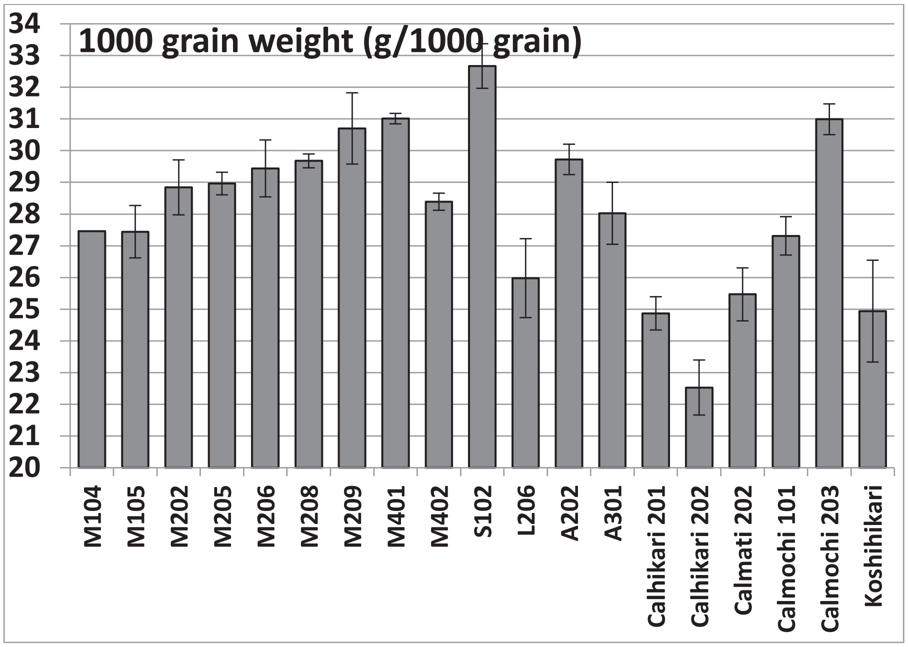


Figure 2. 1000 grain weights for common California rice varieties

Rice Growth and Formation of Yield Components

The yield components described above develop in different stages in the life cycle of the rice plant. Thus, management practices must be timed properly to positively influence the desired yield component. For example, once plant/crop growth is beyond the critical stage of tiller development, management practices, no matter how well intended, cannot increase the number of tillers. The growth of the rice plant can be divided into three stages: vegetative, from seed germination to PI; the reproductive stage from PI to flowering; and the ripening stage from flowering to grain maturity. The time required for each of these stages is dependent largely on the choice of variety, but is also affected by management practices, weather and other environmental conditions.

The Vegetative Stage

Vegetative growth begins with seed germination and lasts through the tillering stage (Figure 3). It can be subdivided into seedling growth and tillering. The best opportunity for management practices to influence yield is in the vegetative stage. In the seedling stage, good seedling emergence, stand establishment and seedling growth can be enhanced by the use of high-quality seed, proper seed soaking, land leveling, seedbed grooving (rolling) and other management practices that are described in detail in other sections of this workbook. Up to about the 2 or 3-leaf stage the seedling (Figure 4) is largely dependent on the stored seed reserves for growth.

At the 3 to 4-leaf stage the young rice plant becomes self-supporting or autotrophic, relying on the sun's energy and nutrients from the soil for growth. Practices to enhance rooting and allow for emergence through the water will enhance rice stands. Generally, plant stands of 20 to 25 seedlings per ft^2 will provide optimum tiller and panicle densities.

The seedling develops into the main stem. At tillering, the second stage of vegetative growth, the primary tillers develop in the axils (base) of each leaf beginning with the second leaf. Tillers typically begin to appear at about the fifth leaf stage.

When the sixth leaf appears, the second tiller

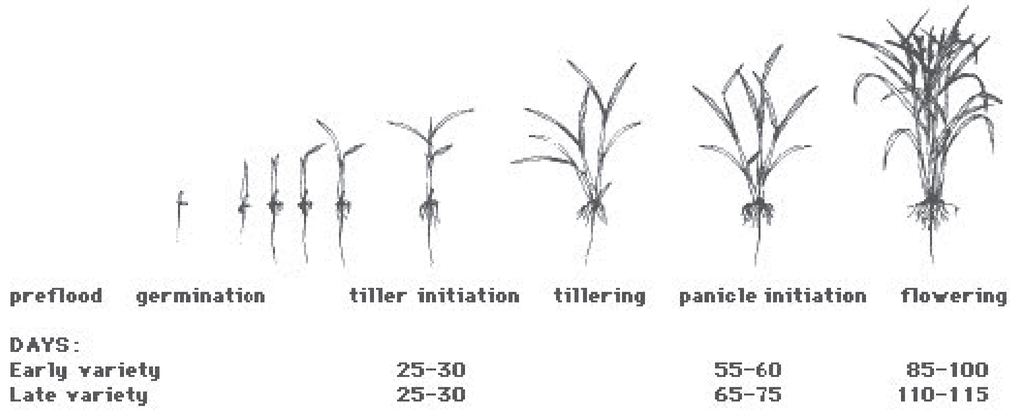


Figure 3. Growth stages of rice through flowering

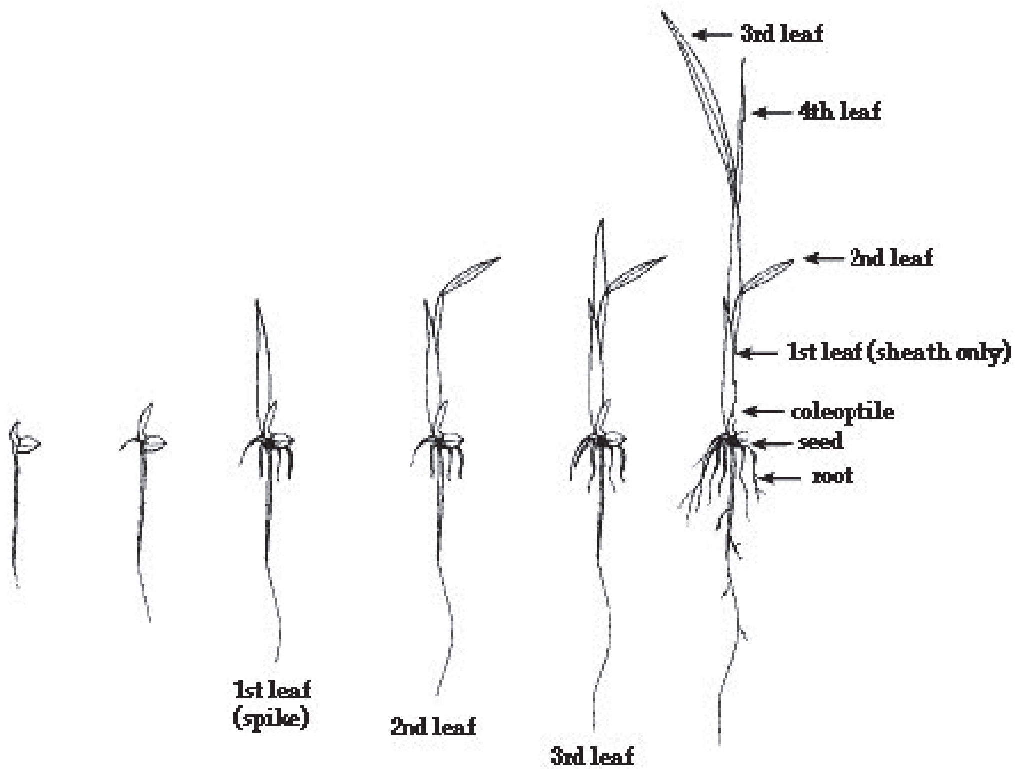


Figure 4. The stages of seedling development

emerges from the third leaf and so on. Each tiller is also capable of developing sub-tillers or secondary tillers. The total number of tillers developed from a single seedling depends on stand density, nitrogen (as well as status of other nutrients), weed competition and damage from pests. The tillering stage is even more important to final panicle density and yield than the number of seedlings established. It is also one of the critical stages that can be most influenced by management practices. The period of tillering does not vary much among varieties, although some of the very late varieties such as M-401, have a slightly longer vegetative stage, meaning that tiller initiation may extend over a longer period (see Table 3 later in chapter). The management factors affecting tiller formation include good nutrition, especially N management, water management (deep water reduces tillering, but usually not below critical levels when other

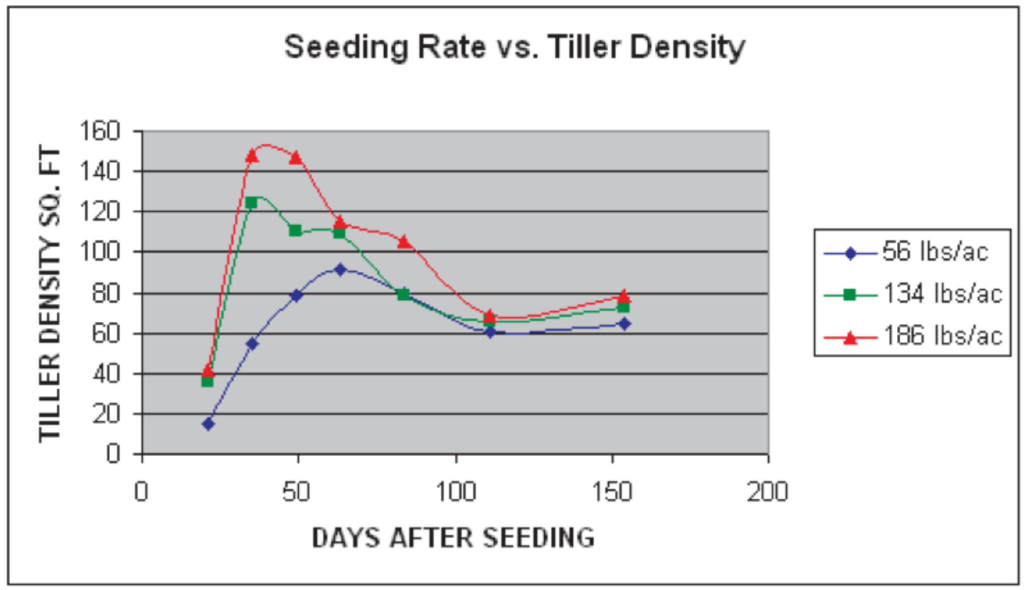


Figure 5. Tiller development over the season as affected by seeding rate

factors are well managed—see Water Management section), weed competition, insects and diseases. The management of these factors is discussed in other sections of this workbook. Generally, panicle densities should be in the range of 60 to 70 panicles (fertile tillers) per ft^2 to maximize yields. Under good conditions, the number of tillers formed on the plant at maximum tillering may be twice what is necessary for high yields. In this case, many of the tillers die before flowering. Figure 5 shows how tillers develop over the season at different seeding rates. Note that at very low seeding rates, all the tillers survive (and are needed for high yield) whereas at high seeding rates the number of tillers is very high at maximum tillering but about half die off from shading. Final tiller number is about constant across these seeding rates.

The Reproductive Stage

The reproductive stage begins at PI (Figure 1) and extends through flowering. The duration of the reproductive stage varies quite a bit among varieties of different duration with longer duration varieties having a longer reproductive period (Table 4) Furthermore, some varieties (e.g. M-401) are sensitive to day length and PI must be induced by shorter days. These varieties tend to be much longer duration than many varieties which are not photo-period sensitive. The panicle develops within each tiller at the base of the plant just above the soil surface. The start of PI can be seen by the formation of a green ring just above the top node when the stem is cut longitudinally (thus referred to as "green-ring"). The green band is only visible for a couple of days so it is easy to miss it. At about one week following PI the young panicle is large enough to see when the stem is sliced longitudinally through the base. At this time jointing or stem elongation of the upper internodes begins. The young panicle is about 1-2 inches above the soil surface and differentiating into spikelets; the number of spikelets per panicle are determined at this time.

In the final stages of differentiation, pollen is formed within each immature spikelet and this is the most sensitive period to cold temperatures. Cold temperatures of 55 to 60°F (depending on variety) or less can cause sterility by inhibiting pollen formation and resulting in excessive blanking. This is referred to as cold-temperature induced blanking. Although field practices cannot increase the number of spikelets formed during PI, raising the water level above the developing panicle at PI to mitigate cold temperature can greatly increase the percentage of spikelets that become filled grains. This is the most important management practice available at PI to maintain good yields. To be safe, keeping water high from about 10 days after PI to 10 days before heading should help reduce cold blanking. Figure 6 shows how to identify the most cold sensitive period before flowering. Of lesser importance is spikelet sterility caused by too much N. Excessive N from over fertilization, particularly in a cool season or from fertilizer overlaps can increase sterility and blanking. This is why it is important to fertilize preplant only for a cool year and top-dress as needed if the season is warm. Other management practices such as herbicide treatments at PI may also have an effect on grainfilling.

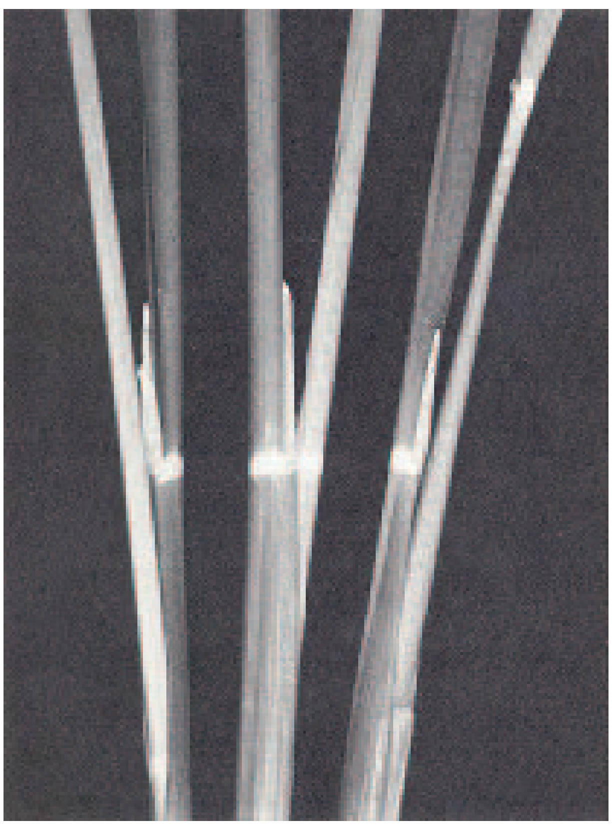


Figure 6. Pollen formation and cold sensitivity occurs when the collar of the flag leaf is aligned with the collar of the previous leaf (center).

Table 4 shows data from a greenhouse study comparing time to critical stages for a number of common CA varieties across a range of planting dates. Greenhouse studies tend to have warmer air temperatures than outdoor so the exact number of days shown in Table 4 is shorter than normal. Importantly though, the data show that across varieties, the time to PI is relatively similar (across varieties the time to PI may vary by about 10%). The big difference between varieties is the time from PI to 50% heading (over 30% variation in time). Finally, the time from 50% heading to R7 (when at least one grain on panicle has yellow hull and is about when growers should consider draining the field in preparation for harvest) also varies by quite a bit between varieties but the time is much shorter.

Flowering, the second part of the reproductive stage, occurs over two to three weeks. The time of flowering varies with the varietal maturity group (Table 5) and location (due to differing temperatures) (Figure 7).

Very high temperatures at flowering can dry the germinating pollen tube before fertilization and cause blanking. Generally, these temperatures must be above 104 °F. Heat induced sterility is of far less consequence to yield than is cold temperature induced floret sterility which occurs between PI and flowering. Nothing can be done to mitigate high temperature damage by management practices.

The Ripening Stage

The fourth and final yield component, kernel weight, is determined at ripening. Ripening begins at the completion of flowering and lasts through physiological maturity. The developing kernel is filled from materials stored in the leaves and stem and from new carbohydrate produced from photosynthesis in the upper-

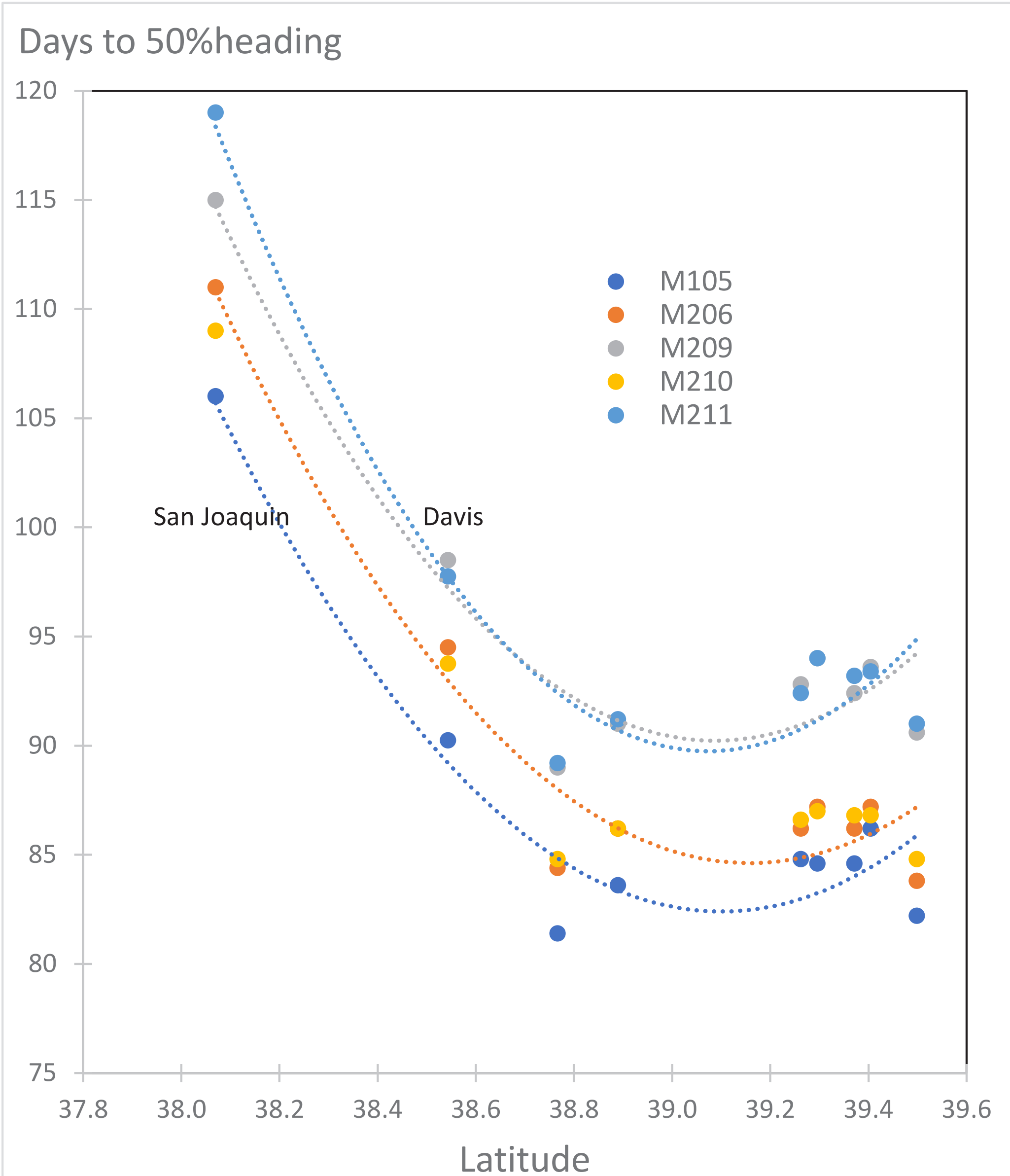


Figure 7. Days to 50% heading for common California medium grains. Data are from state wide variety trials and are averaged from 2017 to 2021. The San Joaquin variety trial is drill-seeded which increases the time to heading.

most leaves and developing kernel. The kernel reaches physiological maturity at about 30% moisture. For translocation of stored materials and photosynthesis to remain active, the maturing plant must have adequate soil moisture for a long enough period to ripen late maturing kernels. While it is not possible to increase kernel weight above the genetic potential of the variety, it is possible to lower kernel weight by soil drying too soon. Thus, decisions about when to drain the field are critical. Early draining facilitates harvest but may allow the field to dry too soon to complete grain filling, thus reducing both kernel weight and milling quality. This decision is often a tradeoff between a smooth harvest and lower head rice or "mucking" out the harvest to achieve higher head rice.

Table 3. Tiller, panicle and yield responses to seeding rate. Data from a 2015 study at the RES using M-206.
Data represent the mean of two planting dates.

Seed rate	**seeding stand**	**height**	**Tiller density**	**Panicle density**	**tillers**	**panicles**	**yield (lb/ac)**
seeds/ft2	seedlings/ft2	cm	tillers/ft2	panicles/ft2	tillers/plant	panicles/plant	lb/ac
5	3	98.8	41	36	15.9	14.0	7491
15	12	99.6	61	52	5.3	4.5	8829
25	17	97.8	67	58	4.0	3.5	9575
35	20	99.1	65	56	3.3	2.8	9311
45	25	97.1	76	66	3.0	2.6	9881
55	31	96.6	79	66	2.6	2.1	9744

Table 4: Days from planting to panicle initiation, heading and R7 (when at least one grain on panicle has yellow hull) for different California rice varieties and planting dates. Note that these data are from a greenhouse pot study where average daily temperatures were warmer than typical. Thus, the actual time to each stage are shorter than typical.Data represent the mean of two planting dates.

Variety	Planting Date	Panicle initiation	50% heading	PI to 50% heading	R7	50% heading to R7
		(days)	(days)	(days)	(days)	(days)
CM-101	1-May	48	73	25	94	21
S-102	1-May	44	71	27	90	19
M-104	1-May	48	73	25	92	19
M-105	1-May	44	71	27	92	21
M-202	1-May	44	76	32	94	18
M-205	1-May	48	78	30	101	23
M-206	1-May	48	76	28	98	22
M-401	1-May	50	108	58	125	17
L-206	1-May	44	71	27	87	16
CM-101	15-May	41	69	28	92	23
S-102	15-May	41	71	30	92	21
M-104	15-May	41	66	25	84	18
M-105	15-May	41	71	30	92	21
M-202	15-May	41	73	32	92	19
M-205	15-May	41	76	35	92	16
M-206	15-May	41	69	28	87	18
M-401	15-May	45	94	49	113	19
L-206	15-May	41	71	30	87	16
CM-101	29-May	43	78	35	94	16
S-102	29-May	43	70	27	91	21
M-104	29-May	43	70	27	87	17
M-105	29-May	43	73	30	87	14
M-202	29-May	43	78	35	94	16
M-205	29-May	43	78	35	94	16
M-206	29-May	45	70	25	91	21
M-401	29-May	48	94	46	115	21
L-206	29-May	43	73	30	85	12

Table 5. Average days to 50% heading for major CA medium rice varieties grown at the RES. Data are from variety trials conducted at the RES from 2017 to 2021.

M-105	M-206	M-209	M-210	M-211
Average days to 50% heading				
75	77	81	76	83
Range of days to 50% heading				
67-80	70-83	77-84	71-80	80-86

Developmental rate

The rate of rice development and progress from one growth stage to another is largely based on the accumulation of growing degree days (or heat units). Some rice varieties are photo-period sensitive and their flowering will depend on changes in day length. In California, it is thought that M-401 is at least partially photo-period sensitive, but most of the other commercial varieties flower based on growing degree day units (heat units) accumulated.

The accumulation of average daily temperatures is calculated as 'growing degree days (GDD)'. At its simplest it includes an average daily temperature [(Tmax-Tmin)/2] and a minimum development threshold that must be exceeded for growth to occur. This is the base temperature (Tbase) and below this temperature the plant does not continue to develop. For California rice varieties this temperature is 50^{o}F. The equation is:

$$GDD = [(Tmax+Tmin)/2] - Tbase.$$

Additional modifications exist for high temperature cutoffs. (The growth rate rice does not increase as temperature increases above a certain point.)

Understanding how temperature affects crop development helps explain a number of factors why there is variation in time to heading for the same variety.

1. In Table 5 we see that for the same variety the time to 50% heading can vary by over a week, even if the rice is planted on the same day of the year. This is just due to differences in temperature during the growing period.

2. Planting early in the season (late April or early May, tends to result in a longer growth duration because rice is being planted at a cool time of the year and hence growth is slower during this period.

3. It also explains why rice grown in the southern part of Sacramento Valley and in the Delta region where it is cooler, take a longer time to reach 50% heading (Figure 7).

4. It explains why dry-seeded rice takes about 5-7 days long to reach 50% heading than water seeded rice. Water temperatures early in the season are warmer than air temperatures and thus rice seedlings progress faster in a water seeded system where plants (especially the growing points of the rice) are under the water.

HARVEST INDEX: How much grain, how much straw?

The remarkable increases in California and world rice yields in the 1970's and 1980's were the result of major plant breeding programs to develop semi-dwarf or short statured varieties to more efficiently use the sun's energy. Agronomists refer to the measure of this trait as Harvest Index (HI) which is the ratio of grain to total plant biomass or biological yield (grain + straw). Harvest index is a measure of the partitioning of the sun's energy between the grain and the vegetative part of the plant (which eventually becomes the straw).

Harvest index (HI) is the ratio of grain weight to total plant weight and can be expressed as:

HI = GW/ GW + SW

Where: HI = Harvest Index

GW = Grain Weight

SW = Straw Weight

(GW + SW) = Biological Yield

NOTE: Root weight is not considered in the calculation of HI

Tall varieties are now grown in California only as specialty rice types. They exhibit lower HI than the modern short varieties commonly grown on most of California acreage. Short statured varieties have the advantage that they remain standing at higher nitrogen (N) levels. This is largely because their short stature provides less leverage to fall over due to a large grain weight on the top of the plant. As a result, N applications can be increased by about 30 lbs/acre relative to the taller types; and because higher N is important for photosynthesis, grain yield potential is increased. So what impact has this had on the amount of straw left after harvest? Some have suggested that by reducing the plant height by 30% we have also reduced straw remaining after harvest by 30%. This is not the case. We conducted several studies comparing short and tall varieties across different N rates. Figure 8 shows that Biological Yield (GW + SW) was similar for both tall and short varieties across all N levels. However, Figure 9 shows that grain yield for the short varieties was higher across all N rates. Of course, whether tall or short, rice varieties of both types will reach a plateau in yield at some level of N after which both will produce less rice due to lodging or blanking. Yields extrapolated from N rates of 120 lb/a typical for tall varieties and from N rates of 150 lb/a for short varieties were 6273 lb/a and 7262 lbs/a respectively with an increase in grain yield of 16%. Figure 10 shows that straw yields at these N rates are 7396 lb/ac for tall varieties and 7124 lbs/ac for the shorter types or a decrease of only 3.6%. Therefore, the adoption of short varieties has not likely reduced straw levels by all that much. These figures represent averages for many field trials over several years. However, grain and straw yields will vary by field and yields have increased since these data were taken with the original short types such as M- 7, M-9 and M-201. Importantly, however, is that tall variety HI should be used when calculating carbon conservation credits for returning straw to the soil. Using the HI for short varieties would show less straw than is actually produced. Figure 11 shows how HI varies over N level for both tall and short varieties.

SUMMARY

Yield components are the product of the number of panicles per unit area, the number of spikelets per panicle, the % filled spikelets and the kernel weight. Generally, a seeding density of 20 to 25 established seedlings/ft^2 result in an adequate density of 60 to 70 fertile panicles/ft^2. Management practices have the biggest influence on final yield during the vegetative stage when the panicle number is determined. This yield component is completely formed in the first 45-60 days of the season and cannot be changed after that time. The number of spikelets per panicle and the percentage of filled kernels are determined at, and shortly after PI. The panicle size and spikelet number cannot be increased, but good management of water to reduce exposure to cold temperatures can minimize excessive blanking. Similarly, kernel weight cannot be increased over the genetic potential of the variety, but management practices such as field draining for harvest can affect grain filling. Rice management practices are described in detail in the following sections of this workbook. It is important to think about when these occur in the life of the rice plant and what effect they might have on specific yield components. The knowledge of yield component formation can also help in diagnosing problems after the fact.

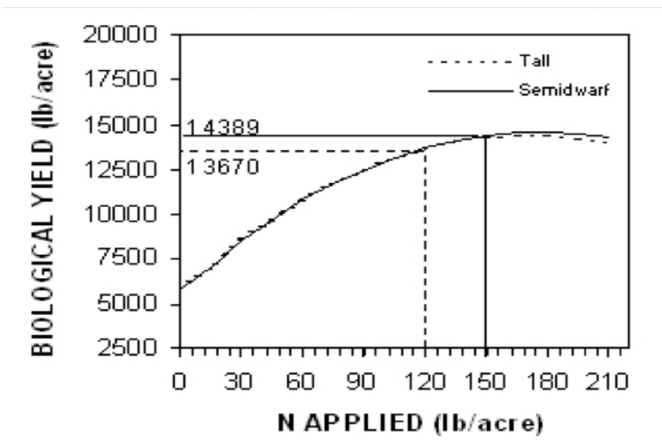


Figure 8. Biological yield (grain + straw) at N rates for tall (120 lb/ac) and short (150 lb/ac) varieties

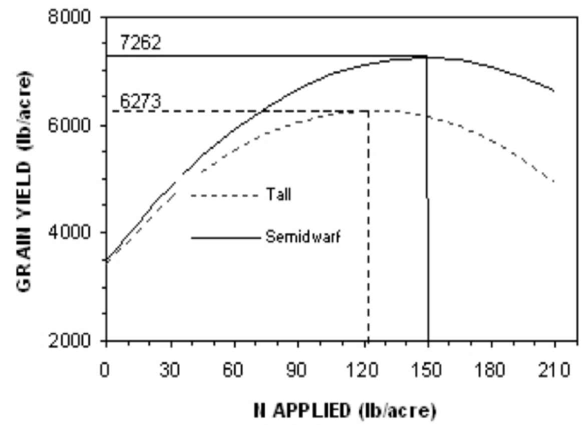


Figure 9. Grain yield at N rates for tall (120 lb/ac) and short (150 lb/ac) varieties

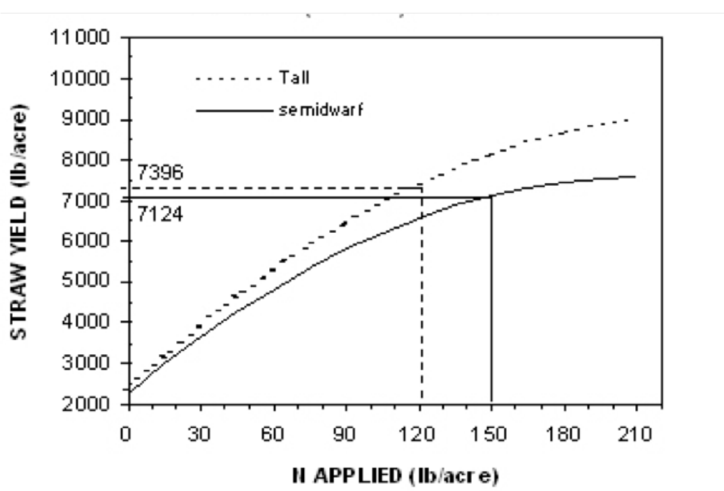


Figure 10. Straw yield at N rates for tall (120 lb/ac) and short (150 lb/ac) varieties

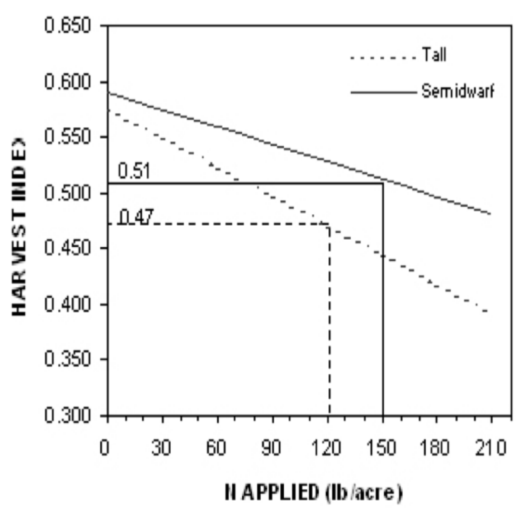


Figure 11. Harvest index at N rates for tall (120 lb/ac) and short (150 lb/ac) varieties