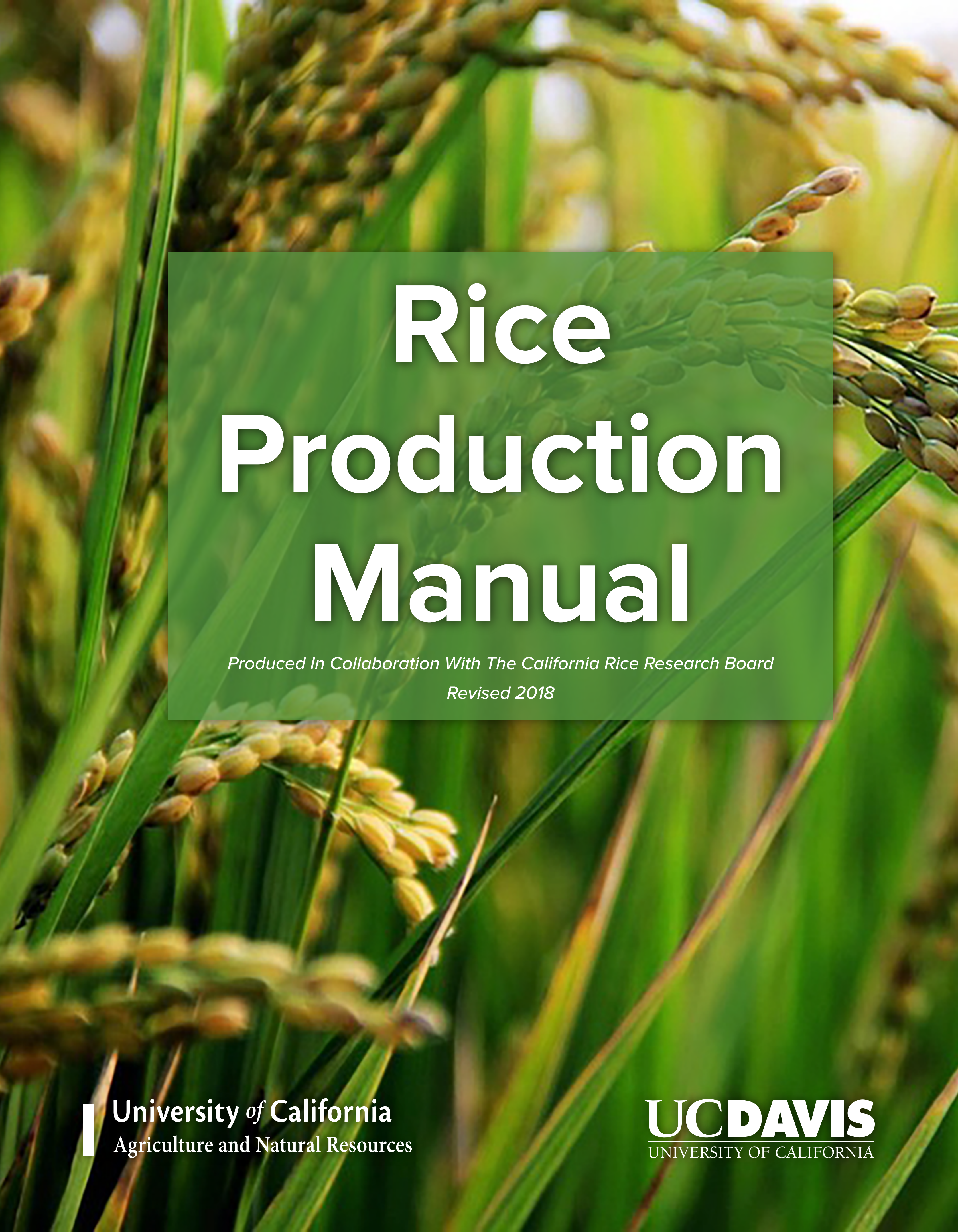

Rice Production Manual

Produced In Collaboration With The California Rice Research Board

Revised 2018

University of California
Agriculture and Natural Resources

UC DAVIS
UNIVERSITY OF CALIFORNIA

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Rice Growth and 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.

Just how is all that grain in the trailer made?

The Yield Components

Generally one thinks of yield as the grand (or maybe not so grand) 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?

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.

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.

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

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

Figure 1. *Rice yield components*

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?

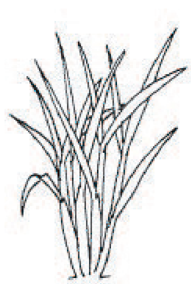
Conversion Factors:
1 lb = 454 grams
1 ac = 43,560 ft2

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

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

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 currently 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 6 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 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,

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

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. Only at the lowest stand density of 12 plants/ft^2 were yields significantly lower and then not by much. Generally, adequate stands require only the development of primary tillers that develop over a relatively short period. However, at densities of 5-7 plants/ft^2, 10-12 tillers/plant would be needed to achieve an adequate panicle density. This would require a longer tiller development period for each plant and usually results in lower yields and lower quality due to a longer maturation period. This is why a field with anything less than 5-7 plants/ft^2 is considered on the borderline for reseeding or over-seeding.

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 can- not 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). When panicle is first visible (about 5 days after green-ring) we call this panicle differentiation.

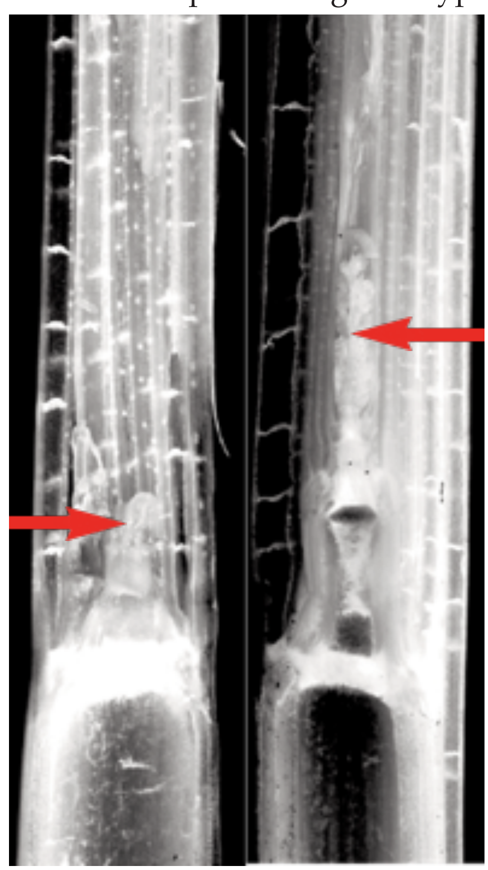
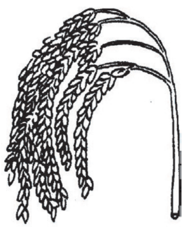


Figure 1. *Young panicle*

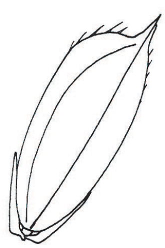
The maximum panicle size of most California calrose types is around 100 spikelets per panicle, but is more on the order of 70 spikelets per panicle with typical densities of 60 to 70 panicles/ft^2. The number of spikelets per panicle, however, can vary genetically from varieties with relatively small panicles to varieties with panicles of over 150 spikelets or more. Some of the Chinese hybrids, for example, have very large panicles. Management 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 between 60^{o} and 55^{o} 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 night-time 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.

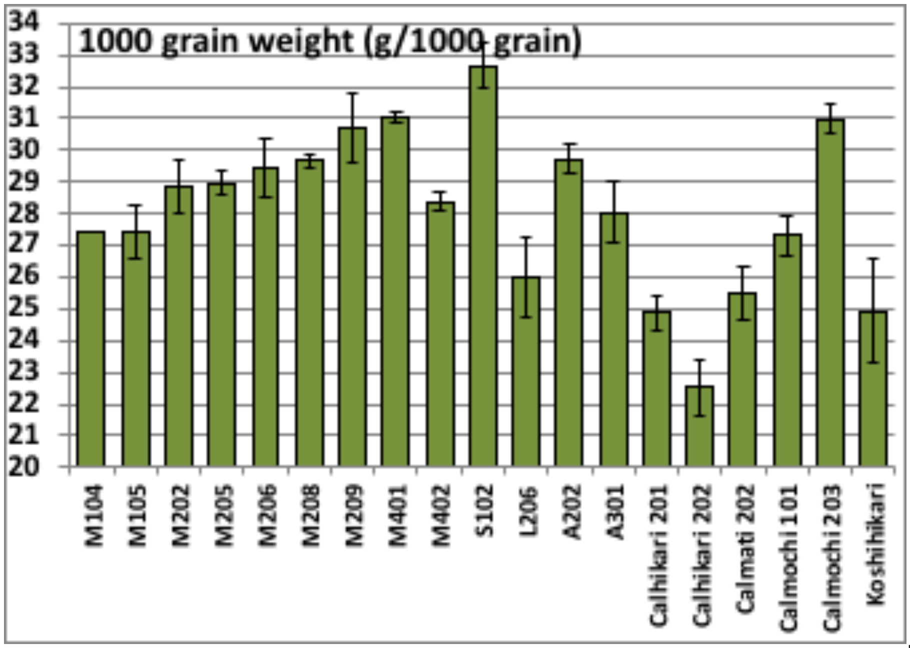


Figure 2. *1000 grain weights for common California rice varieties.*

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. 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 is largely dependent on the stored seed reserves for growth (Figure 4).

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

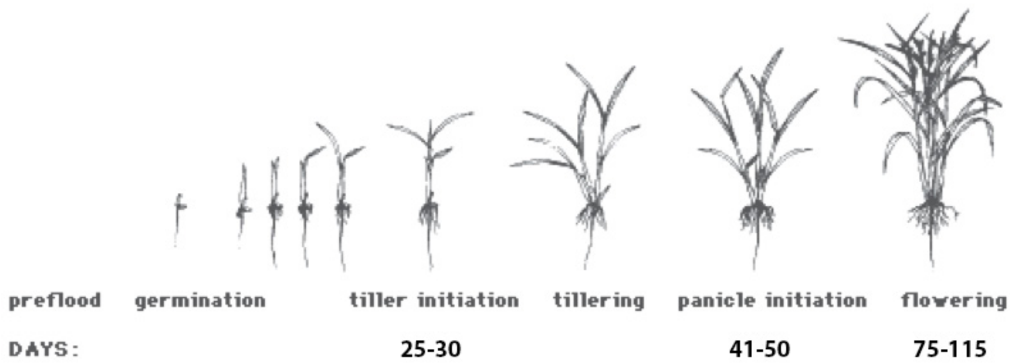


Figure 3. *Growth stages of rice through flowering*

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 (Figure 5).

When the sixth leaf appears, the sec- ond tiller 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 oth-

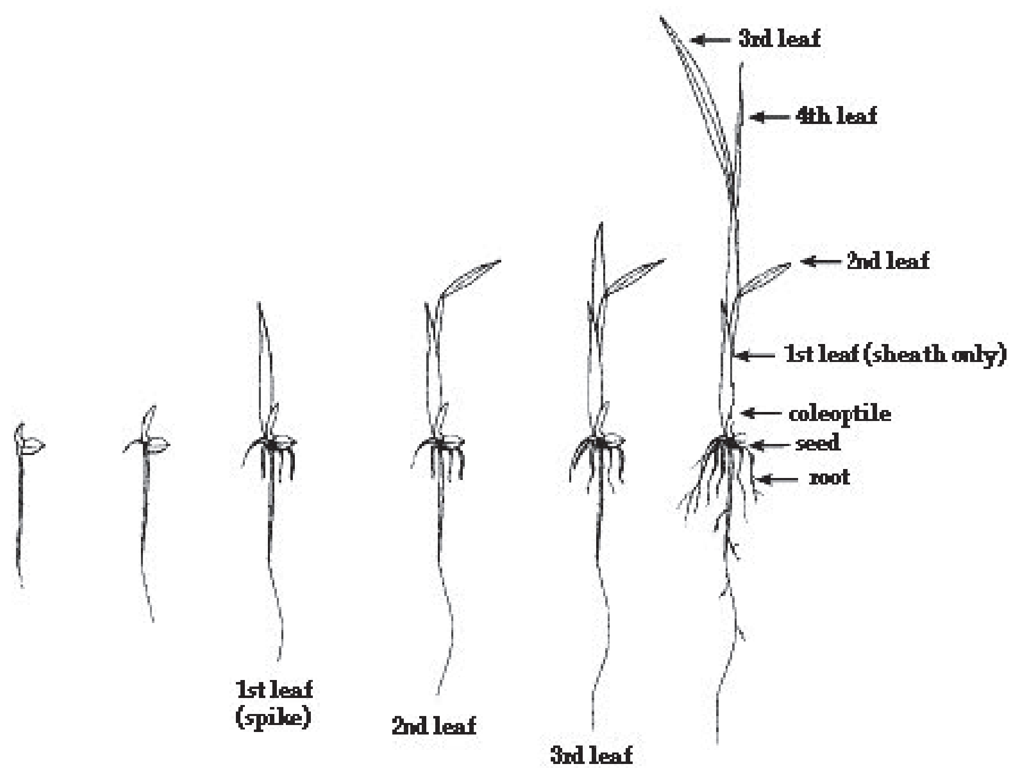


Figure 4. *The stages of seedling development*

er 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 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 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 6 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.

Figure 5. *Tiller initiation at the 5th leaf stage from the axil of the 2nd leaf*

The Reproductive Stage

The reproductive stage begins at PI (Figure 7) 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 3) 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

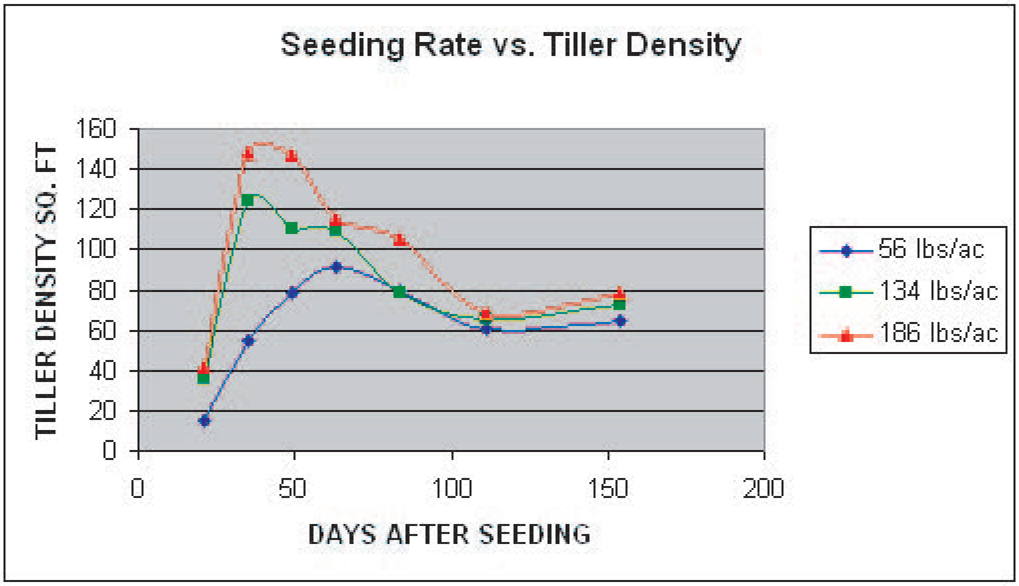


Figure 6. *Tiller development over the season as affected by seeding rate*

(panicle differentation). 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 8 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

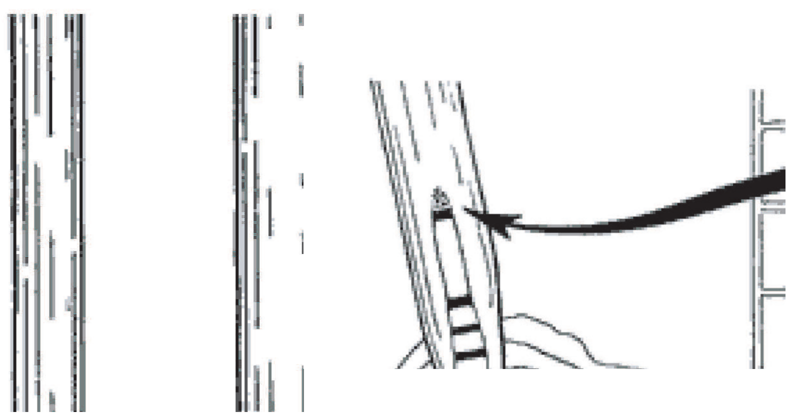


Figure 7. *Initiation of panicle development*

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 topdress as needed if the season is warm. Other management practices such as herbicide treatments at PI may also have an effect on grainfilling.

Table 3 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 3 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.

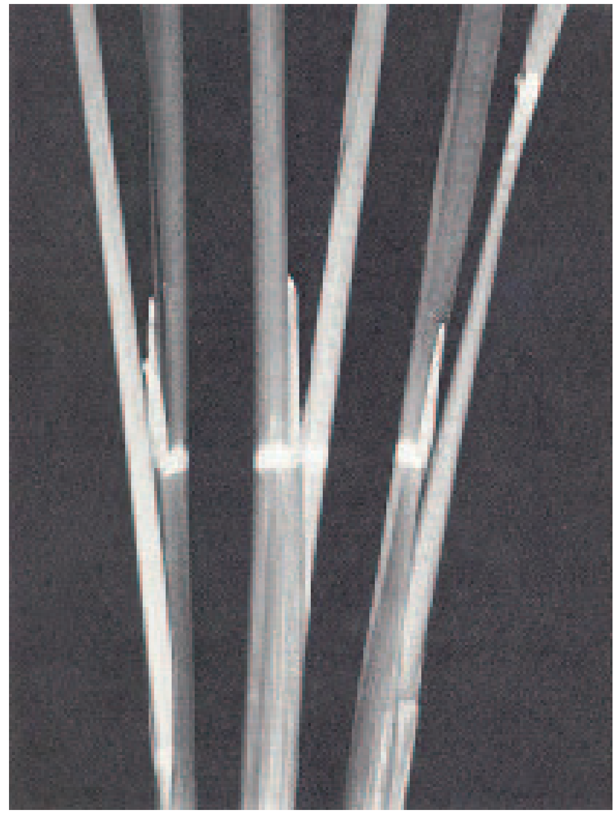


Figure 8. *Pollen formation and cold sensitivity occurs when the collar of the flag leaf is aligned with the collar of the previous leaf (center).*

Flowering, the second part of the reproductive stage, occurs over two to three weeks. The time of flowering varies with the varietal maturity group and location (due to differing temperatures) as shown for average heading date in Tables 4 and 5. Very high temperatures at flowering can dry the germinating pollen tube before fertilization and cause blanking. Generally, these temperatures must be above 104 to 105°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.

__Table 3:__ Days from planting to panicle initiation (green-ring), 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.

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

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 uppermost leaves and developing kernel. The kernel reaches physiological maturity at about 28% 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 4: *Average days to 50% heading for major CA rice varieties grown at the RES. Data are from variety trials conducted at the RES from 2010 to 2014.*

M-104	M-102	M-105	L-206	M-206	M-208	M-202	M-209	M-205	M-402	M-401
Average days to 50% heading										
79	80	80	83	84	86	88	89	90	103	107
Range of days to 50% heading										
75-83	75-84	75-86	77-92	79-88	82-90	84-95	84-93	86-97	93-112	101-115

Table 5: *50% heading dates for several varieties across a range of sites in 2016. Sites are ordered from north (typically warmer) to south.*

		M-105	M-206	M-209	M-205
Location	Date planted	Days to 50% heading			
Glenn	May 11	87	90	94	95
Butte (1)	May 17	85	87	93	94
RES	May 22	79	80	83	85
Butte (2)	May 19	84	85	89	91
Colusa	May 3	93	94	100	101
Yuba	May 23	84	86	92	94
Yolo	May 22	85	90	94	97
Sutter	May 16	86	88	95	97
San Joaquin	May 22	103	106	116	119

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 har- vest? 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 conduct- ed several studies comparing short and tall varieties across dif- ferent 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

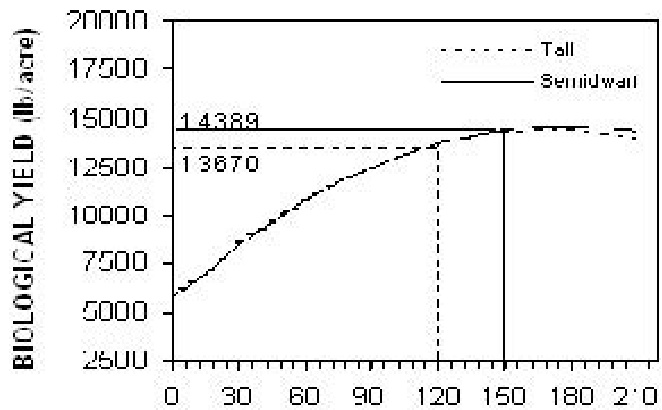


Figure 8. Biological yield (grain + straw) at N rates for tall (120 lb/ac) and short (150 lb/ac) varietiesfrom 2010 to 2014.

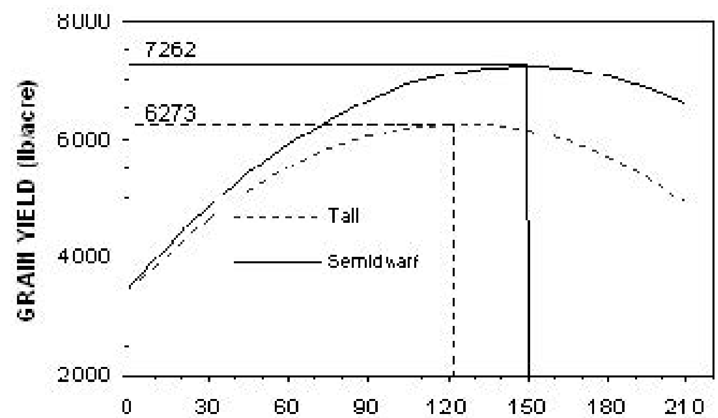


Figure 9. Grain yield at N rates for tall (120 lb/ac) and short (150 lb/ac) varieties.

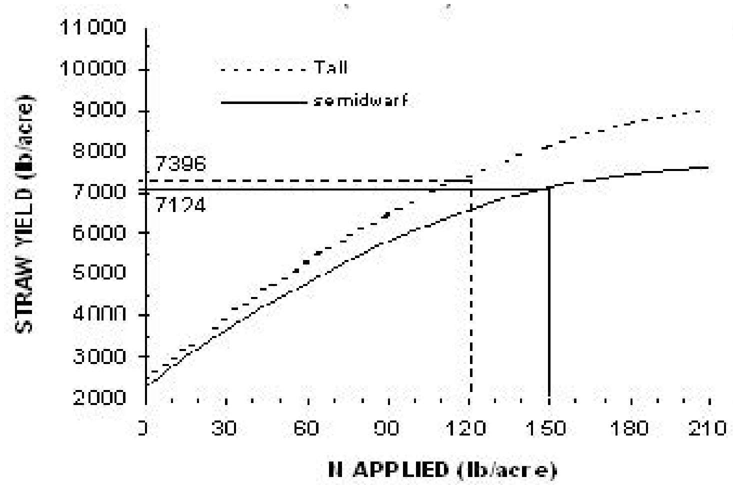


Figure 10 Straw yield at N rates for tall (120 lb/ac) and short (150 lb/ac) varieties.

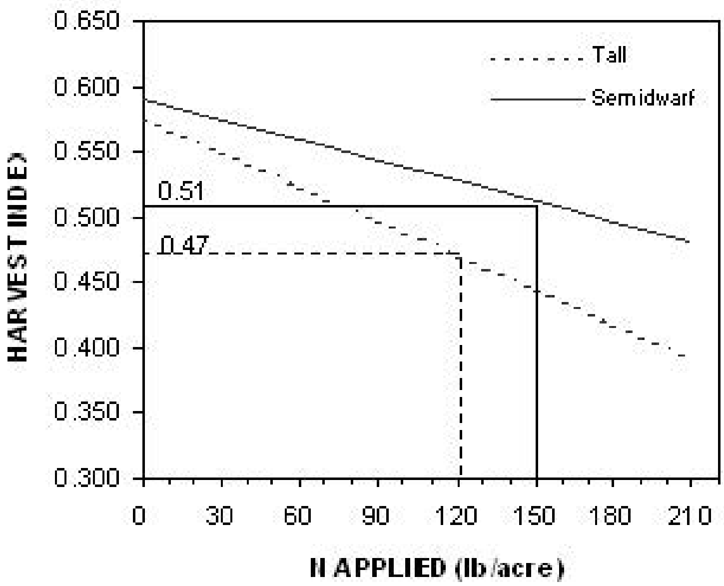


Figure 11. *Harvest index at N rates for tall (120 lb/ac) and short (150 lb/ac) varieties*

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 vari- eties 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 sever- al 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 calculat- ing 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 vari- eties.

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.

Land Formation

Field Development

Field development is the configuration of the field shape and surface slope as well as the installation of water control structures to optimize water management and crop production, conserving resources and improving operational efficiency. Most important to rice is accurate and easy management of water application, depth and drainage so that crop growth is improved and weeds are controlled. Also important is water conservation—through increases in water use efficiency and by minimizing the likelihood of accidental drainage. Another goal is more efficient use of land, tillage and harvest equipment. This can be achieved by reducing the number of levees, straightening the levees making them smaller.

History

Much of the Central Valley is naturally fairly level, ranging from two to five feet fall per mile (Willson 1979), so not much leveling was done in the early days of the rice industry. Consequently, most early efforts towards field improvement were in clearing native vegetation and building irrigation water structures such as canals, drains, weir boxes and levees. The prevailing belief at the time was to leave the soil surface between the levees alone because rice grew poorly in cut areas and rank in fill areas. By the mid-1920's, growers began to see the economic benefits of leveling, although the first heavy earth movers and landplanes capable of major land formation were not available until 1935 (anonymous, 1948). Leveling became widespread after WWII, with a sharp increase in the 1960's. A key concern was whether to maintain the natural contours, which was cheaper, or to make the slope uniform so straight levees could be used, but at higher cost (Figure 1). Wick (1970), estimated an equipment efficiency gain of 12-15%, 10% higher yield, faster initial flooding, more precise depth management, gain in productive land, and increased land value by leveling for parallel levees. The leveling system most commonly used depended on installing a matrix of grade stakes, based on a detailed survey map, which guided the equipment drivers.

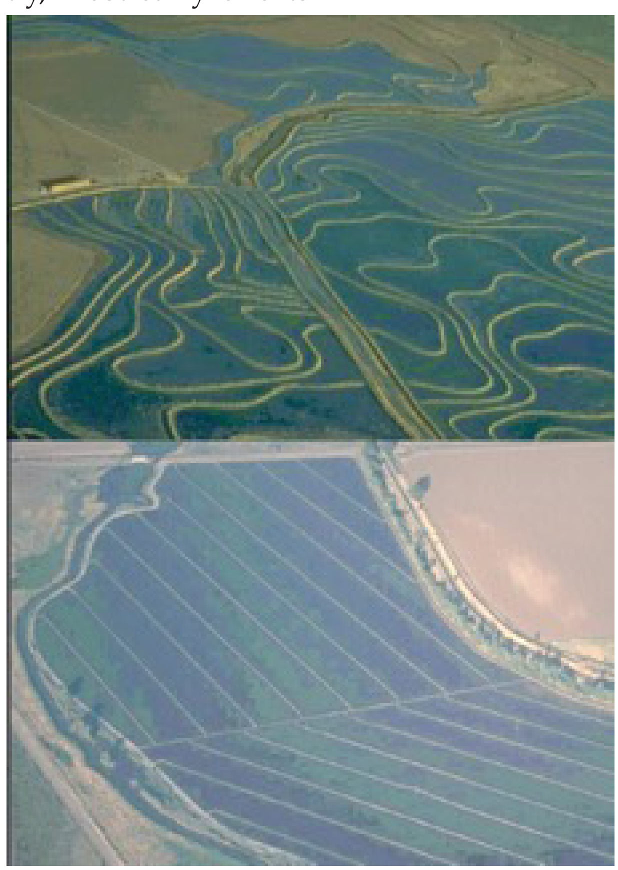


Figure 1. *Typical contour levees required in unleveled land, above. Land leveled to uniform slope with parallel levees, below.*

Figure 2. Typical scraper for leveling equipped with laser receiver that guides position of cutting blade. Signal is received from laser beam on stand in foreground. Scrapers may be equipped with single, dual or satellite guided receivers

Accuracy was dependent on the skill of the operator to match cuts and fills with specifications. In the early 1970's, laser guided equipment (Figure 2) revolutionized land accuracy, automating some equipment operations and eliminating the need to set a complex matrix of grade stakes. With the adoption of the laser and its exceptional accuracy, growers changed their view of how flat fields could be.

Slopes decreased to zero with laser leveling, allowing for wider levee spacing and bigger basins. In addition, in those areas where rice is the only crop, fields were specifically developed for rice using permanent levees and little or no slope. Today, a high percentage of rice fields are laser leveled and have parallel levees. Those which do not are usually in areas where rice is rotated with other crops.

More recently, Global Positioning System (GPS) have been used for precision leveling, because GPS systems can be used to map field elevation in three dimensions, with an accuracy of up to 0.1 inches. This is more accurate than laser leveling, and it is easier to set up, as GPS leveling does not require the laser towers that are required for laser leveling. GPS leveling is less troublesome than the laser leveling, as it is not hampered by dust and wind, whereas laser leveling can be negatively affected by both.

The necessary equipment is a tractor equipped with surveying software, a GPS receiver, and a base reference point. The scraper (which levels the soil) can be adjusted based on the field elevation map, and can be controlled from inside the cab with the software.

Site Selection

Rice fields require the ability to pond water, so soils with low infiltration rates are necessary to prevent excessive water use. Desirable rice soils are those with high clay content (35 to 60%) in the topsoil or subsoil, or which have a cemented layer or hardpan in the subsoil. The most productive rice soils have deeper topsoils although good rice yields may come from shallower soils if crop nutrition needs are adequately met. Fields developed along the edges of the Sacramento Valley and near streams often have more variable soil types across short distances, which should be factored into the development plan. Fields formed from naturally flat topography benefit from less disturbance of topsoils compared to fields developed on steeper land where less fertile subsoils are exposed during leveling. It is especially difficult to farm rice when a calcareous or sodic subsoil is brought to the surface. Such soils often have soil chemistry problems which are difficult to correct.

Leveling

Land leveling allows maintenance of a uniform water depth within the basin (the area between the levees, also called a paddy) and greatly facilitates subsequent management practices for stand establishment, weed control, and field drainage for harvest. When a new field is developed or an old one is improved, an engineering plan is usually developed that includes all the features of the new field such as placement of levees and whether they are straight or contour. It also includes position of roads, landings, irrigation intakes, canals, drains and other necessary structures. Often, several leveling options may be prepared and the producer decides which best fits his situation.

How a field is leveled depends on crops grown, irrigation method, field configuration, soil type, and cost. About two thirds of rice fields in the Sacramento Valley are set up to grow rice only, while the others grow row and field crops in a rice rotation. Fields growing rice only often have little or no slope while those in a crop rotation usually have slopes of 0.05 to 0.1%.

Land leveling allows maintenance of a uniform water depth within the basin

Fields may have a uniform slope across the whole field or the slope will vary because the natural contour of the land varies. Soil type will affect how a field is leveled, primarily as it relates to whether or not a soil can economically support crops other than rice. Although good for rotational crops, inclusions of well-drained soil in a rice field should be avoided if possible to minimize the volume of water needed to maintain a flood.

Cost is frequently the primary determinant of how a field is leveled. Very steep ground is most economically leveled into a series of 'benches,' each separated by a levee. This avoids the need to cut down large hills and fill in deep valleys and it leaves more topsoil in place. The area between the levees in benched fields is essentially a small field with its own uniform slope.

Soil Fertility

Leveled fields frequently have infertile and fertile spots related to the cuts and fills. Since most nutrients in the soil are concentrated in the plow layer, and subsoils are usually alkaline and may have infertile cemented hardpans, the effects of leveling on crop nutrition should be a primary consideration during the planning stage. The leveling plan should consider the depth to infertile subsoil and try to avoid it. The National Resources Conservation Service has irrigation land leveling specifications: "In cut areas, when highly permeable or otherwise unsuitable subsoil conditions are encountered, the cuts shall be overexcavated and the topsoil replaced. In the fill areas, if specified, the topsoil will be stripped, the fills partly made and the topsoil replaced." (NRCS 2000). While more expensive, this method will help reduce the damage from deep cuts and help maintain uniformity of soil fertility.

Levees

Levees can be either permanently installed or taken down annually and reinstalled each spring. Permanent levees predominate in rice-only areas while annually-installed temporary levees are common in mixed cropping areas or where a rotation crop may be grown occasionally. Construction of permanent levees should be integrated with the leveling plan because they are larger and require more soil. Temporary levees are built by pulling a large disk ridger or levee squeeze across the prepared field, gathering soil from a width of 11 to 13'. To prevent seepage, temporary levees often require the construction of two parallel levees with a borrow-pit (indentation) between them. When the levees are knocked down and the field worked, the soil returns to its original position. In some rice-only fields, the individual basins are large (>25 ac) and the levees around them wide enough for roads, which gives complete access for management. The benefits of permanent levees include freedom from annual installation, road access, no borrow-pits, and roll-overs. Roll-overs are flattened areas at the ends of levees for equipment to cross over from basin to basin. The disadvantages of permanent levees are that perennial weeds grow which may contaminate the crop and rodents establish and cause leaks. Some annual repair work is necessary to keep weeds and rodents under control, using herbicides, rodent baits, traps, and discs to repairs holes.

Temporary levees take extra work to build and may require a fresh map or survey of the levee locations each year. Fields in a rotation usually need a fresh levee survey when coming back into rice. Temporary levees are usually free of perennial weeds and rodents. The big advantage to temporary levees is that they can be constructed after soil preparation, making it easier to quickly prepare a large field. Irrigation boxes for temporary levees are usually reinstalled each year, although some growers leave the boxes in from year-to-year and just remove the levee. Temporary levees are built on the prepared field, first marking their location, then pulling the levee. A large rice ridger can work in unplowed soil, but takes several passes to gather sufficient soil for the levee. A squeeze or crowder requires that the ground be loosened first by plowing and drying, then a single pass will create the levee. Both types leave a borrow pit, which means there is unproductive land.

All three levee types, temporary, permanent, and roads, use approximately the same amount of land. A typical leveled field usually has 3-5% of the land in levees. An unleveled field with contour levees may have as much as 10% of the land in levees.

The orientation of levees relative to wind direction can be an important consideration during the planning stages, particularly if the basins are long. Strong winds blowing across the surface of long basins will 'pile' the water on the downwind side, which may cause erosion damage to field sides and levees, and sometimes breaches in levees. In addition, the deeper water may impact rice growth and possibly uproot plants. Levees that are crosswise to the wind help reduce the damaging effects. Larger basins are more susceptible to the effects of wind but are more efficient in many respects, so some compromises are necessary.

Grade

Grade refers to the slope of the land surface. This really means small elevation changes across the field, called either the 'slope' or 'fall'. Because rice needs fairly shallow and uniform water depth large variations in elevation cannot be tolerated. Slope is usually expressed in tenths of a foot per hundred feet of distance or in percent. For example a slope of 0.1′/100′ is the same as 0.1%. A 0.1% fall is equivalent to one foot every thousand feet. One foot is too great a fall for high yield rice production so levees are necessary to break up the field and make sure that water depth will vary no more than 3-4″, and preferably no more than 2.5″. Many fields are leveled to much less than 0.1%, often 0.02 to 0.05%, allowing for wide levee spacing and greater efficiency. Many fields that are used only for rice have no slope at all and are completely flat. Others have compound grades so that levees are set at an angle to the edges of the field. Many fields have more than one grade, so that levee spacing is not uniform across the field. This is usually related to the cost of leveling which may make it impractical to establish a uniform grade.

1. A field has a uniform slope of 0.1′/100′ and the grower wishes to maintain a water level that varies no more than 2.5″ between levees. What is the levee spacing he needs to achieve this, assuming zero slope parallel to the levees?

Convert tenths to inches: 0.1 x 12″ = 1.2″
Determine levee spacing (2.5″/(1.2″/100′) = 208′
The contour interval would be 208′

2. A field has levees spaced 250′ apart and a uniform slope of .1%. What is the difference in elevation between each levee, assuming zero slope parallel to the levees?

Find the fall in 250′: 250′ x .1 = .25′
Convert to inches: 25′ x 12″ = 3″
The fall between levees is 3″

Two goals of leveling and setting levees is to space them far enough apart to minimize their number, but close enough together so that the fall between, which affects water depth, does not exceed what the crop can tolerate. Two examples in the shaded box deal with these primary goals.

The point of the first example is that you choose your levee spacing consistent with the slope of the land and needs of the crop. Usually, when the leveling plan is developed based on criteria discussed above, you can determine levee spacing on the map. If the field falls two directions, the calculation is the same although the levees will not be perpendicular to the side of the field. In practice, levee positions can be done with a laser transit simply by finding those spots in the field that represent the desired fall.

The second example is really the corollary of the first. This may be useful if you know the slope and levee spacing, but the water on the low side is too deep and you want to move the levees.

Irrigation Systems

Water delivery and distribution must be considered in the development of the field. While the levees are the primary means of controlling and containing water, other structures are necessary to regulate and distribute it. The method of water management is also integrated within the field development plan. Several irrigation system design options are discussed in the section on Water Management.

Irrigation boxes

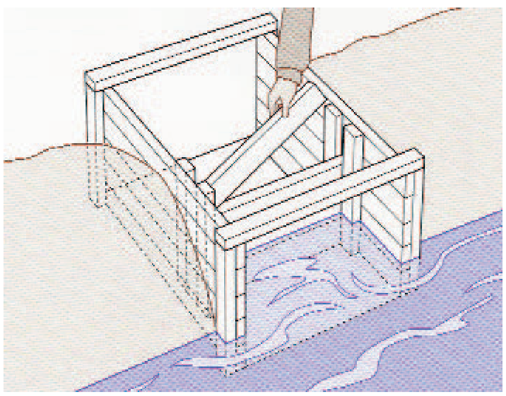


Figure 3. *Typical wooden rice box. From: Hill et.al. 1991.*

Weir boxes in each levee are the primary means of regulating water flow and depth. Several materials have been used to build weir boxes, including wood, steel, cement, plastic and fiberglass. Figure 3 is a typical wooden rice box. Redwood is cheap and easily repaired and is useful in fields where levees and boxes are removed annually. Fields with permanent levees often use more durable materials such as corrugated plastic pipe connected to steel drop boxes. All have common properties including a flume or pipe to move water from one side of a levee to the other, and removable 'flash boards' which hold water back to a given depth and let the excess flow over the top. Water level in the basin above the box is regulated by adding or removing boards. Weir boxes are usually placed near the ends of levees, often in both ends, and sometimes opposite ends in adjacent levees to promote water circula tion. The size and number of rice boxes is dependent on the required capacity to move water from one basin to another. Rice boxes, as in Figure 3, are typically 18″ high, 48″ long and 24-48″ wide. The pipe diameter in permanent rice weirs is usually 12-18″.

Variety Selection and Management

Introduction and History

Since its beginning in 1912, California's rice industry limited its production and marketing largely to a few short and medium grain japonica varieties, developed from stocks originating in Japan and China. These varieties produced good yields of quality rice in the dry, temperate climate of the Sacramento and San Joaquin Valleys. For the grower, the choice of variety to plant was relatively simple because the few varieties available were similar in performance, yield potential and milling quality when properly managed. Included were Colusa, Caloro, and Calrose, all released from the grower owned and funded Rice Experiment Station (RES) at Biggs, CA in 1918, 1921 and 1948, respectively, and Earlirose, a productive, early maturing, proprietary variety, released in 1965 which soon became a popular variety for cold areas and/or late plantings. These were the major rice varieties grown in California until the early 1970's.

Publicly developed and introduced rice varieties are grown annually on about 96% of the planted acres.

Then, the variety picture began to change significantly. A powerful impetus for this was the enactment of the California Rice Research Marketing Order that established the California Rice Research Board in 1969. This grower initiative provided significant and regular funding to hasten development and release of new varieties. The medium grain variety CS-M3 was released in 1970 and the short grain variety CS-S4 in 1971, from rice hybridizations made in 1946 and 1957 at RES. CS-M3 gained wide acceptance and competed with the older Calrose for acreage. But, CS-S4, though an improvement over Caloro, was not widely grown because of its susceptibility to low temperature induced sterility. The last tall stature variety from the RES breeding program, M5, was released in 1975.

In 1976, Calrose 76, the first short stature (semidwarf) California rice, was released. This late maturing medium grain variety was a radiation induced mutant selected by the USDA in Davis in 1971. It was soon followed by the semidwarf M9, developed by hybridizing the tropical "green revolution" variety IR-8 by the RES. Thus began the era of short stature rice in California, which was to have enormous consequences. Subsequently, numerous varieties have been released in a range of maturity groups with different grain shapes and culinary characteristics.

Acreage

Publicly developed and introduced rice varieties are grown annually on over 90% of the planted acreage, and over 40 introduced proprietary varieties are grown on the rest (See Tables 1 & 2). Most of the varieties grown in California are classified as "temperate japonicas", adapted to the cooler rice growing areas and temperate latitudes of the world. This is contrast to "tropical japonicas" (grown in the Southern US) or indicas that constitute the majority of the world's rice production. About 80% of the acreage is planted to 'Calrose' type medium grain varieties destined for a host of purposes including table rice and manufactured uses. California short grains and as well as introduced and proprietary varieties are also temperate japonica. Long grain varieties are tropical japonicas. California short and long grain varieties are also planted on one to two percent of the acres. Premium quality medium and short grain rice is grown on

Table 1. *Outline of the RES rice variety naming system and varieties grown in 2018. Grain type letter(s) are combined with a numeric descriptor. The first digit is the maturity group, the others are the order of release.*

Grain Type	Very Early (100-199)	Early (200-299)	Intermediate (300-399)	Late (400-499)
Short (S)	S-102	-	-	-
Medium (M)	M-104 M-105	M-202* M-205 M-206 M-208* M-209 M-210	-	M-401 M-402
Long (L)	-	L-206 L-207	-	-
Calmochi sweet rice (CM)	CM-101	CM-203	-	-
Aromatic (A)	-	A-201 A-202	A-301*	-
Calhikari short premium (CH)	-	CH-201 CH-202	-	-
Calmati basmati type (CT) Calaroma jasmine type(CJ)	-	CT-201 CT-202 CJ-201	-	-
Calamylow (CA)		CA-201		

**Seed production discontinued.*

about 10% of acres, and is destined for higher priced table rice markets. Additional small acreages of specialty varieties are also planted, such as sweet rice (also called mochi, glutinous or waxy), arborio types (large or bold grain), and aromatic long grains including conventional, basmati, and most recently a jasmine type, and colored bran types.

Table 2. *Acreage estimates for RES rice varieties.*

2016 & 2017 CALIFORNIA RICE ACREAGE BY RES VARIETY SUMMARY

	2016			2017		
Variety	Seed Acres[1]	Percentage	Estimated Acres[2]	Seed Acres[1]	Percentage	Estimated Acres[2]
M-104	250	1.3%	5719	103	0.5%	1967
M-105	1849	9.6%	66403	2336	12.4%	44613
M-202	819	4.2%	18736	0	0.0%	trace
M-205	2086	10.8%	47721	2061	10.9%	39361
M-206	9102	47.2%	235023	8425	44.7%	160902
M-208	299	1.6%	6840	96	0.5%	1833
M-209	3408	17.7%	27065	4467	23.7%	85311
M-401	1316	6.8%	30106	1219	6.5%	23281
M-402	148	0.8%	3386	143	0.8%	2731
Medium Grain	19277	100.0%	441000	18850	100.0%	360000
S-102	758	41.3%	14731	189	14.4%	4664
Calhikari-201	87	4.7%	1691	85	6.5%	2097
Calhikari-202	137	7.5%	2662	95	7.3%	2344
Calmochi-101	755	41.1%	14673	883	67.5%	21788
Calmochi-203	100	5.4%	1943	57	4.4%	1406
Calamylow-201	0	0.0%	75	0	0.0%	trace
Short Grain	1837	100.0%	35700	1309	100.0%	32300
L-206	123	19.8%	1602	67	17.3%	1090
L-207	124	19.9%	1615	9	2.4%	151
A-201	153	24.6%	1992	205	52.9%	3335
A-301	45	7.2%	586	0	0.0%	trace
Calmati-202	49	7.9%	638	0	0.0%	trace
A-202	128	20.6%	1667	106	27.4%	1724
Long Grain	622	100.0%	8100	387	100.0%	6300
NASS CA Acres						
Medium		90.6%	490000		89.9%	400000
Short		7.8%	42000		8.5%	38000
Long		1.7%	9000		1.6%	7000
Total		100.0%	541000		100.0%	445000

[1] California Crop Improvement approved acreage of all classes of certified seed for CCRRF varieties.

[2] Acreage estimated based on seed production of these varieties assuming they account for 90% of the medium and long grains and 85% of the short grain California planted acres reported by NASS.

Subtotals may not match due to new releases that are in the early stages of seed production. The remaining percentage are assumed to be planted to proprietary, Japanese short grains, or older CCRRF varieties not in seed production.

Naming System for Public Varieties in California

In 1979, the California rice industry developed a uniform naming system for new RES developed rice varieties, based on grain type, maturity group and order of release. This was necessary to avoid confusing the large number of varieties to prevent mixing of different type grains and to avoid inappropriate planting dates. Varieties should be referred to by their complete letter, numerical and descriptive name because deleting any component may lead to serious errors.

The name of a new variety contains a prefix letter designating its grain type as long (L), medium (M) or short (S). Specialty rice will carry a descriptive word prefix, such as Calmochi for waxy or sweet rice, Calmati for basmati-like rice, Calhikari for premium quality short grain rice, Calamylow for low amylose (≈7%) type rice, A for aromatic long grains, and Calaroma for jasmine long grains. Immediately following the letter or name descriptor is a three digit number separated by a dash (-) from the letter or name. The first digit in the number designates the maturity group as either 1 (very early), 2 (early), 3 (intermediate) or 4 (late). The last two digits indicate the order of release of this type, from 01 to 99, starting in 1979 when this system began. For example, M-105 indicates a very early maturing medium grain variety which was fifth in order of release.

Proprietary and Introduced Varieties

In addition to the publicly developed varieties, some varieties of Japanese origin are also grown and retain their Japanese name, such as Akitakomachi and Koshihikari. Several companies also introduce or develop varieties for California while others have introduced varieties with unique characteristics such as colored bran, aroma, and special culinary properties. The 2018 list of all rice varieties approved for production in California is provided in Table 3a, 3b and 3c.

Table 3a. *Long Grain Rice varieties approved for production in California and commercial impact and tier designation.*

Variety	CI	Non-CI	Tier
A-201	✓		1
A-202	✓		1
A-301	✓		1
Aromatic Long Grain Red Rice	✓		2
Calaroma-201	✓		1
Calmati-201	✓		1
Calmati-202	✓		1
Donana		✓	
L-202 (not in production)		✓	
L-203 (not in production)		✓	
L-204 (not in production)		✓	
L-205 (not in production)		✓	
L-206		✓	
L-207		✓	
Long Grain Red Rice	✓		2
P-2 Denosa		✓	
P-3 Isla		✓	

Table 3b. *Short Grain Rice varieties approved for production in California and commercial impact and tier designation.*

Variety	CI	Non-CI	Tier
A-17	✓		1
A-20	✓		1
Akita Komachi	✓		1
Asuka (formerly 04-302)			
BL-2 (not in production)	✓		1
Calamylow-201	✓		1
Calhikari 202	✓		1
Calhikari-201	✓		1
Calmochi -101	✓		1
Calmochi -203	✓		1
Calpearl	✓		1
Carnaroli (all subtypes incl MH-1)	✓		1
Himenomochi (formerly PI 504474)	✓		1
Hitomebore	✓		1

Short Grain (cont)

Variety	CI	Non-CI	Tier
Kogane Mochi	✓		1
Koshihikari	✓		1
NFD 108	✓		1
NFD 109	✓		1
S-102		✓	
S-201 (not in seed production)		✓	
S-6		✓	
Sasanishiki	✓		1
SP-2	✓		1
Surpass	✓		1
Vialone Nano	✓		1
WRS-4431	✓		1
Yamada Nishiki	✓		1

Table 3c. *Medium Grain Rice varieties approved for production in California and commercial impact and tier designation.*

Variety	CI	Non-CI	Tier
02-PY-014		✓	
02-PY-021		✓	
85-101-10		✓	
91-130-02		✓	
94-158-01		✓	
Amber (formerly00-117)		✓	
Arborio (incl CA Arborio)	✓		1
Black Japonica (LBJ-489)	✓		2
Black Rice – SWF	✓		2
Black Rice (SunWest)	✓		2
Calriso	✓		1
Carnaroli (all subtypes incl MH-1)	✓		1
Crystal (formerly 04-116)			
Farah (formerly 02-121-03)			
FRC #11		✓	
FRC #22		✓	
Guadiamar		✓	
Hong Kong Black (HKB-102)	✓		2
Jade (formerly 07-122)		✓	

Medium Grain (cont)

Variety	CI	Non-CI	Tier
Kokuho Rose		✓	
LBJ-115	✓		2
LMR-206	✓		2
M-103 (not in seed production)		✓	
M-104		✓	
M-105		✓	
M-201		✓	
M-202		✓	
M-204 (not in seed production)		✓	
M-205		✓	
M-206 (formerly 98-Y-242)		✓	
M-207 (not in seed production)		✓	
M-208		✓	
M-209		✓	
M-210		✓	
M-401		✓	
M-402		✓	
Millrose		✓	
NFD181		✓	
Riz Rouge Camargue	✓		2
Rojito (SunWest)	✓		2
Royce (formerly 95-164-01)		✓	
RRI -226		✓	
RRI-321		✓	
Shasta (formerly 98-102)		✓	
SP-211		✓	
SP-311		✓	
SP-411		✓	
Trisha (formerly KR4)		✓	
Wehani LWE-218 (Lundberg)	✓		2
Winsor (formerly 02-120)		✓	
WRM-3538		✓	
Remy		✓	
Royal		✓	
Jemma		✓	
Imperial		✓	

Grain and Plant Characteristics Important for Management

Successful production and marketing of rice requires knowledge of plant and grain characteristics. Since a rice grower's first concern is usually the market for which the crop is intended, primary consideration must be given to grain shape, appearance and culinary characteristics. Second, yield performance is usually an important criterion for variety selection, although for certain varieties, market quality outweighs yield. Varieties should also be chosen on the basis of their relative maturity so they can fit the cropping schedule of a particular farming operation or are suitable to a particular climatic condition. For example, late maturing varieties fit early planting schedules; cold tolerant varieties are needed for cooler areas. Agronomic characteristics, such as lodging and nitrogen response may also be considered in addition to straw quantity and quality and pubescence (rough or smooth leaf and hull). Currently, no California varieties have insect or herbicide resistance, but will in the future, which may become a primary selection criterion. For those blast prone areas, a blast resistant variety would be consideration (M-210). Rice plant and grain characteristics are discussed below.

Grain Characteristics

Grain Shape

Rice grains are classified as short, medium or long grain. The specific size and shape classification limits of brown rice kernels are shown in Table 4.

Table 4. *Approximate size and shape classifications for California rice varieties, brown basis.*

	Length (mm)	Width (mm)	Length/ width	Kernel wt. (g/1000 kernels)
Premium short	5.2	2.8	1.8	20.2
Short	5.5	3.3	1.7	27.6
Premium medium	6.7	3.0	2.2	23.9
Medium	6.1	2.9	1.9	23.8
Arborio	6.3	3.3	1.9	25.3
Long	7.8	2.2	3.5	21.5
Aromatic	8.2	2.1	3.9	23.1
Basmati type	7.5	2.1	3.6	21.0
Mochi	5.3	3.0	1.8	23.9

Grain Quality

Milling, market and cooking/culinary qualities are mentioned here because they are influenced by varietal selection and management methods. For example, genetic characteristics influence milling quality, which will influence choice of variety. In addition, many quality components of Japanese premium short grain varieties are influenced by production practices.

Grain Starch Content

Amylose is a straight chain glucose molecule, as contrasted to amylopectin, a larger highly branched glucose molecule. In general, the more amylose a variety has, the less sticky. The majority of California rice is Calrose type medium grain and has low amylose content which tends to make it soft when cooked and the grains tend to stick together. "Calrose" is a marketing term that refers to all non-premium quality medium grain rice varieties with cooking/culinary characteristics similar to the original Calrose variety. Demand for Calrose varieties remains strong, and they occupy over 80% of the state's acreage. California non-premium short grain rice also has low amylose and cooks similarly to Calrose and is used as table rice, brown rice, and rice cakes.

Long grain rice in California has higher amylose than medium and short grain which imparts a firm, dry characteristic when cooked. The new Calaroma-201 has a low amylose content similar to medium grains and is softer cooking.

Scent: Aromatic and Basmati Types

A few California varieties, such as A-202, are known as aromatic and have a distinctive scent, similar to popcorn, particularly when cooked. The scent is also discernible in the field. It is from a high 2-acetyl-1-pyrroline content compared to non-aromatic varieties. In addition to aroma, Basmati-type varieties (Calmati-202) also have a cell wall arrangement in the grain that results in grain lengthening during cooking as compared to other varieties which tend to expand uniformly when cooked. Otherwise, they have amylose starch content similar to other long grain varieties. Aromatic and Basmati type rice sells in a unique market. Calaroma-201 is also aromatic but has different cooking properties. The presence of aroma makes it very important to maintain identity preservation of aromatic varieties to avoid mixtures with non-aromatic types.

Arborio/Chalky Types

Arborio is the name of a short grain variety from Italy and a market type for similar varieties grown in California. This type is characterized by having a very large kernel, and an excessive amount of chalkiness which is the presence of white, opaque areas within the milled kernel, as contrasted to the translucent whiteness of most varieties. Chalk is a heritable defect and is one of the first things rice breeders eliminate in most varieties because it results in low milling yields and poor appearance.

Chalk is referred to as white belly and other names, depending on the position of the chalk on or in the milled kernel. But for Arborio, chalk is associated with superior culinary properties for specific dishes, primarily risottos. Other than genetics, chalkiness is caused by high harvest moisture, uneven ripening, and cultural practices that result in uneven ripening and presence of immature kernels at harvest.

Specialty varieties currently grown include aromatic rice (conventional, basmati type), arborio type (large, chalky grain), mochi, (which has no amylose), and colored bran (red or nearly black). The latter has little or no amylose.

Plant Characteristics

Relative Maturity

Maturity of California rice varieties is classified by the number of days from planting to 50% heading in the warmer areas of the state. Four categories are used (Table 5). Maturity differs primarily in the length of the vegetative stage. Beyond the 50% heading point, California short and medium grain varieties normally require another 40 to 55 days for grain maturity in warm areas, and 5 to 15 days more in cool areas. Long grain varieties usually ripen 5 to 10 days faster after 50% heading than medium grain varieties. Maturity is relative and can be advanced or delayed by planting date, nutritional status, temperature and other environmental factors.

Table 5. *Variety maturity group and days to 50% heading at RES*

Maturity Group	Days to 50% heading
Very Early	< 80
Early	81-90
Intermediate	91-99
Late	> 100

Very early varieties are commonly grown in cooler areas and for late planting when later varieties are not well-suited. An increasing practice is to plant them early in warm areas to advance harvest to allow more time for straw management and to shorten the water season. Maintenance of milling quality can be more of an issue when very early varieties are planted early.

Early varieties occupy roughly 70-75% of the acreage. They are predominately Calrose type and are generally higher yielding varieties. Early varieties provide flexibility because they are suited to a wide range of planting dates.

Intermediate maturity varieties were intended to provide a more timely harvest sequence. However, there are few representatives in this category because of the industry preference for earliness.

Late maturity varieties were also intended to provide options for harvest sequencing. However, most late varieties currently grown are used because they have particular characteristics, such as premium quality, rather than for their value in scheduling harvest. They are generally planted before May 1. About 10% of the acres are typically planted to late maturing varieties.

Seedling Vigor

Seedling vigor refers to early growth and includes rapid leaf emergence through the water, stand density, growth rate after emergence, leaf droopiness, and leafiness. Vigor is an important component in variety evaluation because it helps improve stand establishment. For the grower, vigorous varieties make water management easier and may improve competition against weeds. California varieties vary in their vigor over a fairly narrow range, with the long grains having less vigor than medium and short grains.

Plant Height

Plant height is the distance between the soil surface and the tip of the erect panicle. Height is important because of its relationship to plant physiological processes and lodging which affects harvestability and yield. Height classifications include short, intermediate and tall. Short stature varieties at average soil fertility are less than 95 cm; intermediate stature varieties are 95-105 cm; and tall varieties are taller than 105 cm. Prior to 1976, all California varieties were tall and tended to lodge, particularly under high nitrogen fertility. Beginning with the release of Calrose 76, all varieties from the public program have been short stature. Since full adoption of short stature varieties from 1976 to about 1980, statewide average yields rose dramatically.

Pubescence of Hulls and Leaves

The predominant hull trait important to producers is the presence or absence of hairs. Pubescent/hairy/rough varieties have numerous hairs called trichomes distributed over the flower, seed covers and leaf surfaces. Glabrous/smooth varieties have a few hairs on the keel of the hull and the margin of the leaves, but are otherwise smooth. Before heading, smooth and rough varieties can be distinguished by running a leaf blade between thumb and finger and noting whether its surface (not edge) is rough. Of importance to producers is the fact that smooth varieties have a higher bulk density (test weight) than hairy varieties and result in heavier trucks which can be easily overloaded; and tighter packing in bin driers requires more pressure to move air compared to rough varieties. Smooth varieties are also less dusty during harvest and drying, resulting in less discomfort for harvest and drier personnel. With the exception of CM-101, CH-201, CH-202, CT-202, CJ-201, and S-102, all public California varieties are smooth. Both Koshihikari and Akitakomachi are rough hulled.

Awns

Varieties may have long, medium, or short awns, or be awnless. The characteristic is under genetic, and to some extent, environmental control. The importance of awns for producers is in harvesting. Awns on some varieties may be difficult to remove resulting in lower bulk density and difficulty in unloading harvesters due to bridging, especially pubescent varieties.

Photoperiod Response

Some rice varieties respond to the length of the day, the time between sunrise and sunset. This is the photoperiod. The transition from vegetative to reproductive growth is triggered by day length in photoperiod sensitive varieties which are mostly grown in the tropics. However, with the exception of M-401, most rice grown in temperate zones, including California, is generally insensitive to photoperiod, and responds primarily to temperature.

Tolerance to Low Temperature Sterility

Low temperatures during formation of the pollen mother cell (microsporogenesis) is a primary cause of panicle sterility (blanking). This physiological stage coincides with the time when the collar of the flag leaf is adjacent to the penultimate leaf (next to the last leaf), and when the panicle is still entirely inside the boot. The cause is low temperature for a sufficient duration, particularly if it occurs for several successive nights. While many combinations of time and temperature can cause blanking, an overnight low of 55°-60° or lower can be used as an alert that temperatures may be low enough to cause damage. All varieties are screened for tolerance to blanking. Table 6 gives approximate ranking of varieties by their general level of low temperature sterility tolerance.

Table 6. *Relative ranking of RES rice varieties for cold temperature sterility tolerance. The + sign indicates better tolerance for the group.*

Low	Fair	Good	Excellent
Calmati 201	M-205	S-102	M-104
Calmati 202	L-206+	M-206+	CM-101
Calarma-201+	L-207+	M-105+	
M-401	M-209+	Calmochi-203	
A-202+	Calhikari-201	Akitakomachi	
	Calhikari-202	M-209	
	Koshihikari		
	M-402		

Pest Resistance

Resistance to diseases is a long term goal of rice plant breeding. To date M-208 is the only blast resistant variety in California. Relative levels of stem rot resistance are given in the Agronomy Fact Sheets, and all fall within a fairly narrow range. Efforts are continuing to try improve resistance to stem rot and blast. Resistant lines are being used but the problem continues to be in recovering good agronomic characteristics.

Characteristics of Varieties

UC Cooperative Extension produces Agronomy Fact Sheets annually. The brochure “Characteristics of Public California Rice Varieties” gives a comparison of RES varieties in production. There are individual brochures for varieties that are prepared when they are released as well.

Management of Rice Varieties

Planting Date

Suggested planting dates for public varieties are given in Table 7. These suggestions assume average weather conditions will prevail. Within the preferred planting date range the variety should perform well if other conditions are optimum. Planting outside these ranges increases risk of weather related damage. Planting dates are not rigid and many growers accept the risk and successfully plant outside these ranges. They are meant as a guideline. Warm areas in Table 6 refer to the Sacramento Valley north of Highway 20 and west of Highway 99. Cool areas include

Table 7. *Suggested planting date ranges for public varieties.*

Variety by Maturity Group	Preferred Date Range	Optimum	Comments
Very Early	May 1 - May 25	May 10	Avoid early planting in warm areas
S-102	May 1 - May 25	May 10	with all very early varieties.
M-104	May 1 - May 20	May 5	Advance all dates 5-10 days in cool
CM-101	May 1 - May 20	May 5	areas. CM-203is slow grain filling
CM-203			
Early			For warm areas
M-205	April 25 - May 20	May 5	Adapted to most ar-
M-206	April 20 - May 25	May 5 - 10	eas Avoid cold areas
M-208	April 20 - May 25	May 5 - 10	Avoid cool areas
M-209	April 20 - May 25	May 5 - 10	Suited to all but cold areas
L-205	April 20 - May 20	May 5 - 10	Avoid cool areas
L-206	April 20 - May 20	May 5 - 10	Avoid cool areas
Calhikari-201	April 25 - May 20	May 5	Avoid cool areas and excess nitrogen
Calhikari-202	April 25 - May 20	May 5	For warm areas
A-201	April 25 - May 20	May 5	Avoid cool ar-
A-202	April 25 - May 20	May 5	eas Avoid cool
Calmati-202	April 25 - May 20	May 5	areas Avoid
Akitakomachi	April 25 - May 20	May 5	cool areas For
Koshihikari	April 20 - May 20	May 5	most areas
	April 20 - May 20	May 5	Avoid cool
			areas
Late	April 20 - May 10	May 1	For warm ar-
M-401	April 20 - May 5	May 1	eas For warm
M-402			areas

south of Highway 20 and east of Highway 99. Cold areas include south Natomas and Escalon areas.

Seeding Rate

Short stature rice varieties perform well at uniform densities of 10 to 20 vigorous plants per square foot. However, many rice fields have plant populations over 30 plants. Plant density can be quite variable and still produce optimum yield. For example, approximately 40 productive tillers per square foot, each giving 100 grains, will produce about 10,000 lbs/ac. The rice plant responds to different populations. Low density planting increases tillering, whereas high density reduces tillering so that the number of panicles per square foot remain fairly constant across a wide range of planting rates. In addition, the number of kernels per panicle also increases or decreases, depending on the density of the panicles. Modern rice fields are usually sown heavily to provide quick cover, weed competition and insurance against catastrophic stand loss. Research has shown that seeding rate, within a wide range, does not dramatically affect yield, assuming normal growing conditions. At all sowing rates, the number of seeds is much higher than needed for healthy stands if all the seeds made strong seedlings. However, the consequence of too dense planting is primarily cost although some data suggests that stem rot severity may increase in dense stands. While seed cost remains low in California, growers may continue to use high seed rates without great penalty.

Nitrogen Rates for Different Varieties

Varieties differ in their nitrogen (N) requirements, particularly when comparing short stature Calrose and short grain types to taller premium short and medium grain types, and certain proprietary tall varieties, such as Kokuhorose. The yield of grain + straw (biological yield) is similar for tall and short varieties. However, with short varieties, more of the biological yield is grain, due to more efficient partitioning of plant energy (photosynthates). In addition, they do not lodge as easily under high N fertility. Both higher efficiency and less lodging result in higher yield than tall varieties. Recent field trials have demonstrated small differences in N requirements among common short stature varieties. Nitrogen rate fertilization testing of new releases has not been a research priority in the decades since the shift to semidwarfing varieties. Over fertilization increases the risk of lodging, disease, low temperature sterility, and is inefficient economically. Lower rates of N are used in the premium quality short grains or specialty varieties because of lodging is characteristic of these types. Varieties with good lodging resistance (M-205 and M-209) may receive slightly a higher application of N.

Variety and Harvest Considerations

Short and medium grain rice typically produce higher head rice yields (HRY) than does long grain rice. This is due to the more rounded, thicker, and harder kernels of medium grains. Additionally, earlier-maturing varieties may yield less head rice than later-maturing varieties, which is thought to be a result of grain filling processes.

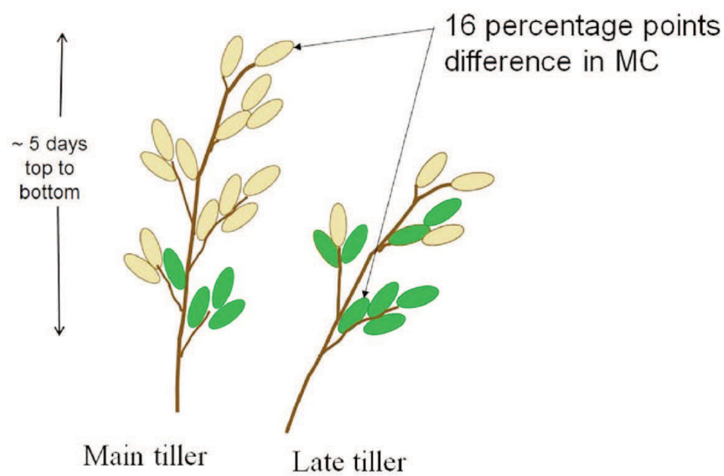


Figure 1. *The moisture content of individual kernels varies due to the pattern of flowering within a panicle.*

Flowering patterns with the panicle vary somewhat between varieties. Anthesis (flower opening) begins at the top of the panicle and proceeds downward, a characteristic present in all California varieties and referred to as nonsynchronous flowering. The number of days required for flower opening ranges from 4 to 8 depending on the variety (Figure 1). The delay in anthesis from the top to the bottom also means that all flowers do not reach the stage of development that is sensitive to low temperature induced pollen sterility at the same time. Brief periods of low temperature result in sections of the panicle being "blank".

Correspondingly, the range of moisture content of individual kernels within a panicle can vary from 15 to 30 percent moisture content even though the aver- age may be around 24 percent (Figure 2). Research has shown that the kernels at 15 percent moisture or less are likely to fissure when exposed to several hours of dew. Rice harvested at a moisture content of 18 percent may contain a large portion of individual kernels with moisture contents as low as 10 percent. There is inherent risk if standard harvesting procedures are adopted that uses an average moisture content of 18 percent as the time to harvest a given field.

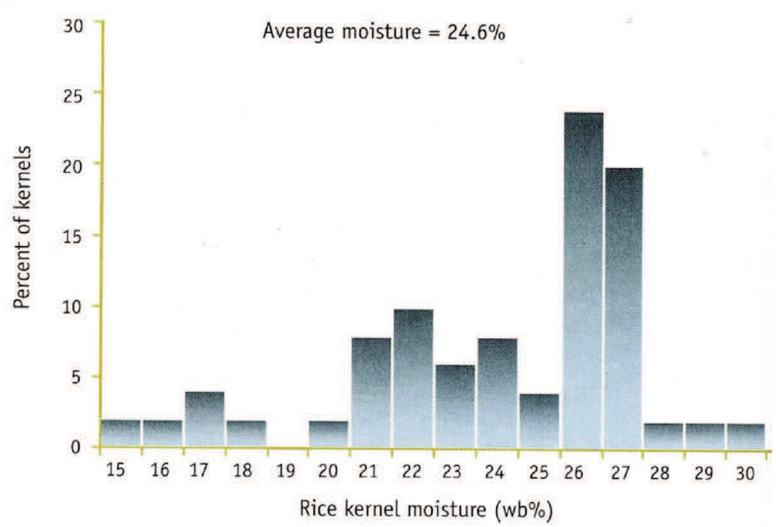


Figure 2. *The range of kernel moisture content in a sample may be 15 perecnt or more.*

The range of maturity (i.e. harvestable moisture content) can be further accentuated by within-field variability in plant growth and development. Such variation is attributable to such things as variable water depth, the uneven application of nitro- gen fertilizer, water temperature, or soil type. Research showed that the moisture content in a California rice field can range from 10 to 22 percent

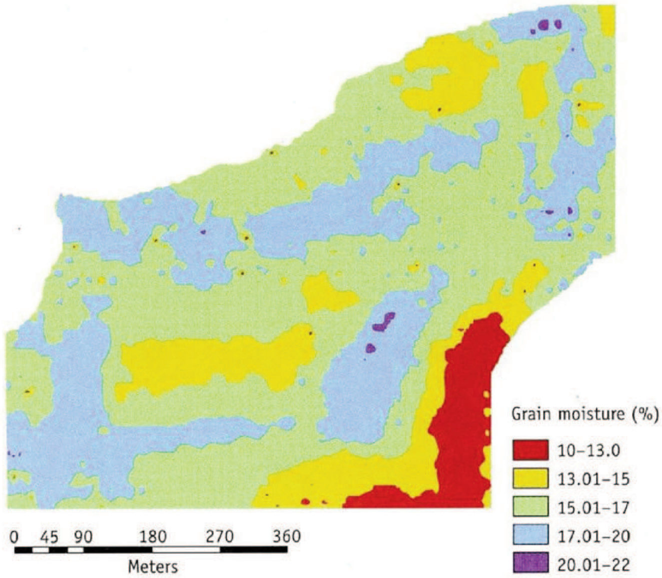


Figure3. *Moisture content at harvest can vary widely due to management and soil type.*

under routine farm management practices (Figure 3). Without prior knowledge of specific field, a simple "nosing in" of the combine to check moisture content can be misleading.

Environmental Effects on Head Rice Yield

Rice harvested at low moisture content often does not produce low head rice quality if it has not been exposed to rehydrating conditions. During the dry north wind periods that commonly occur during harvest, rice can dry to quite low moisture contents and still produce good milling quality because dry conditions prevent dew formation.

However when the north wind ceases and dew forming conditions return, head rice yield drops. In weather conditions with high dew point temperatures, rice can rehydrate to fairly high moisture contents, levels that normally associated with high head rice yield (Figure 4).

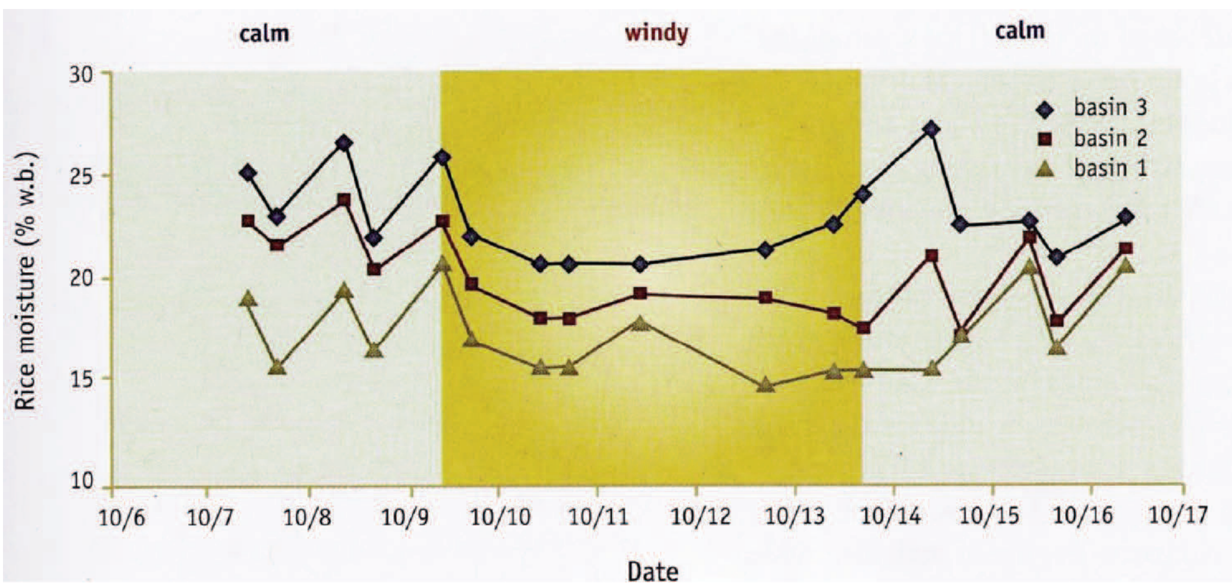


Figure 4 . *Diurnal fluctuation in rice grain moisture before, during, and after a north wind period.*

Rice that rehydrates after a north wind can produce poor head rice quality even though it is harvested at the recommended moisture content. The history of rice moisture content is an important aspect of understanding the head rice yield produced in a particular field. Soil type also influences the time course of head rice loss. For example, a more rapid decline in head rice yield would be expected on light-textured soils exposed to dry, windy conditions.

In 2003 and 2004 at RES, harvest moisture content dropped 6.2 and 8.2 percentages points by the end of the windy period (Figure 5). During the north wind head rice yield declined by over 8 points in both years. Interestingly, growers' return per acre decreased by only $0.08 and $0.17

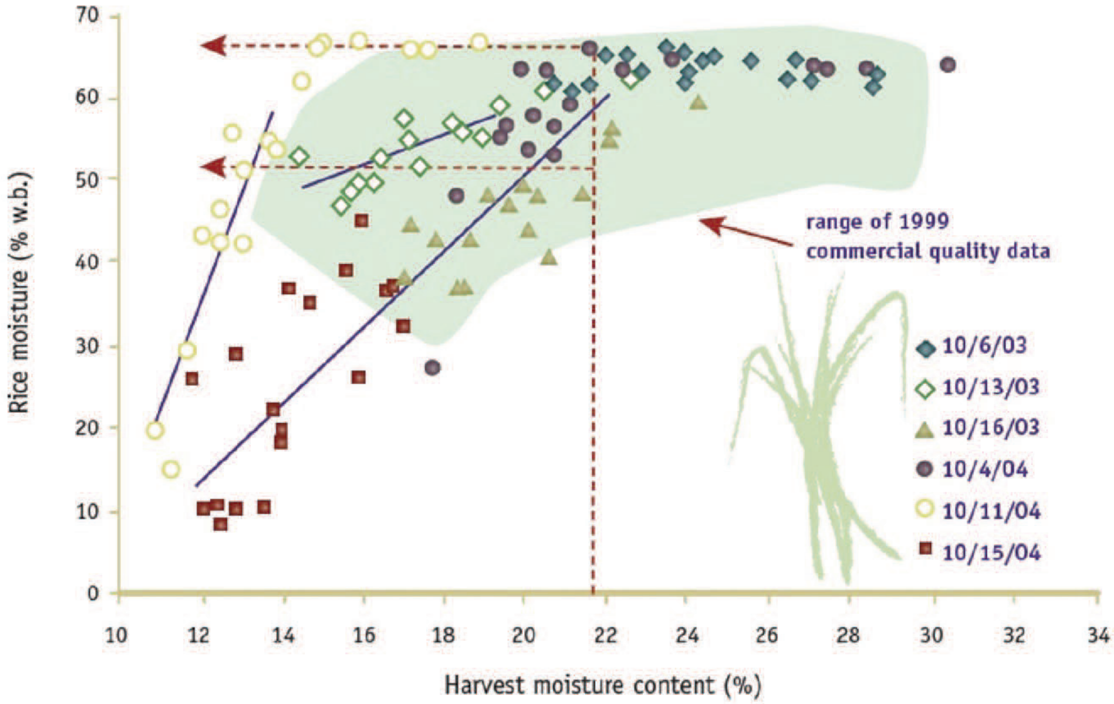


Figure 5 . *Head rice yield as related to harvest moisture content before, during, and after a dry north wind period in 2003 and 2004, Biggs, CA.*

per cwt in 2003 and 2004, respectively (Table 9). During the dry weather, reduced drying costs off- set most of the head rice yield loss.

Table 9 . *Rice quality and value before, during, and after a dry north wind period in 2003 and 2004 for M-202, Biggs, CA.*

Harvest date		Moisture content (%)	Head Rice yield (%)	Grower Return ($/cwt)
2003	Oct. 6	24.3	63.8	5.63
	Oct. 13	18.1	55.6	5.55
	Oct.16	19.6	45.8	5.01
2004	Oct. 4	22.8	58.2	5.46
	Oct. 11	14.6	49.7	5.29
	Oct. 15	14.3	25.3	4.04

Typically, the west side of the Sacramento Valley experiences more north wind days than areas on the east side (Figure 6). The number of windy days during harvest ranges from a low of 1.0 around Nicolaus to around 4 near Orland.

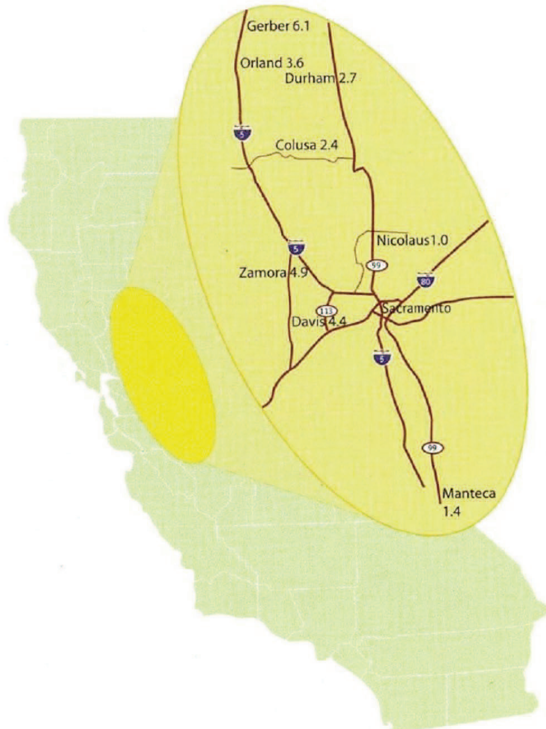


Figure 6 . *Average number of north wind days at select- ed locations in the Sacramento Valley. Data based on 10-year averages.*

Sampling for Harvest Moisture Content

Rice moisture content may fluctuate by 5 or more percentage points during a 24 hour period before and after a north wind period. When evaluating a field in preparation for harvest, it is important to sample at a consistent time of day, such as around noon. By doing so the moisture samples are comparable between days and provide a clearer picture of the dry down rate of the rice. Rice will generally dry down at a rate of about 0.5 percent per day, north wind and high temperatures notwithstanding. For best accuracy, use a harvester to cut the sample to provide the best representation of the true moisture content. Alternatively, one can hand strip heads from random locations. Be sure to to take some the sample from the lower, less-mature panicles. Avoid taking just the ripe grains from the topmost panicles; this will produce a sample with a higher moisture reading than would a combine cut.

Harvest Moisture Range by Variety

As a general rule the newer Calrose varieties (i.e. M-105, M-205, and M-206) can be harvested at lower moisture contents than the older varieties (i.e. M-104, M-202, and M-401). Head rice yield is fairly stable in the newer varieties down to harvest moisture contents of around 18 to 19%. M-209 with its larger kernel is not as stable as the other new varieties and harvest at low moisture should be avoided. Good milling returns below this moisture content are weather dependent. Consequently harvesting low moisture rice should be an annual management decision based on the likelihood of long periods of dew. Harvesting low moisture rice should not be standard practice across years. High head and total yields observed in recent years are in part due to weather. Seven of the last ten years had relatively few dew events of eight hours or longer (Figure 7). For example in 2011 there were only two in nights were extended periods of dew and none in 2012. However in 2007 there were 7 continuous days of heavy dew during peak harvest (Table 10). This adversely affected head rice yields resulting in 15 and 30 percentage point loss in M-206 and M-202, respectively.

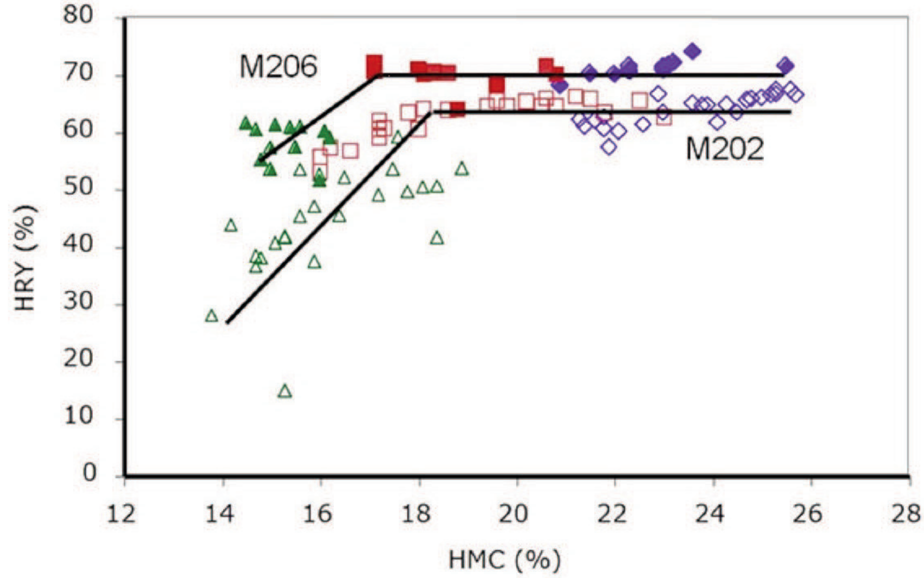


Figure 7. *The percent head rice yield (HRY) of M-206 and M-202 across a range of moisture contents when exposed to repeated dew events..*

Table 10. *Total number of hours of dew at the Rice Experiment Station during harvest season , 2003 – 2012.*

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Sept 21	16	14	2							
22	16	14	4		11	2		2		
23	14	14			12					
24	11	14		2	8					
25	16	15			5				11	
26	16	11								
27	16	14	5	2	2					
28	11	12		5	13					
29	17	11			8					
30	16	14		3	6					
Oct.1	17	14		5	1					
2	16	14	3	6	2	9				
3	14	14	6	7	4	18			16	
4	13	12	2		6	10		4	4	
5	16	10			4	12				3
6	16	14		13	2	11		3		5
7	15	8		11	4	4				
8	16	10							1	
9	14				10		1		6	
10	1				13				4	
11	12			2	16		2			4
12	15			1	16		3			2
13	3	5		4	12		14			
14	15	8	2	8	12		7			3
15	16		8	10	17	2	12			
16	16			5	16	3			3	
17					5	2	10	8		
18				1	5		9	9		
19			8		13	6	9	8	6	
20			8			4			4	4
21							8	1		6
22					7		11	3		
23					7	1		4		

Reducing Variability in Quality Appraisal Samples

Variability and error in appraisal samples can be minimized by:

- collecting a representative sample; do not use a single catch can sample,
- drying samples with room temperature air to maximize head rice quality,
- drying samples to the same moisture contents, because lower moisture samples have slightly, higher head rice quality than samples at 14 percent moisture content,
- using a standard multi-sample vacuum probe and a splitter to obtain the needed amount.

Analysis of replicated head rice samples appraisals by the CDFA showed that results fall within a range of 4.8 percent (± 2.4 percentage points). Variability was greater when the samples were appraised with- in a few days of drying, but did not change after longer periods of storage (Figure 8).

Sample Drying

Air temperature used for sample drying can affect head rice quality. Maximum quality is achieved by using air at a constant room temperature of 75° F or lower (Figure 8). If the air is heated, the rice should be exposed to warm air only periodically and allowed to temper between exposures. For example, the California Warehouse Association recommends heated air at 100° F followed by a 4-hour tempering before the next 30 minute exposure. This procedure produces head rice yields about 2.5 percentage points lower than the room temperature air method.

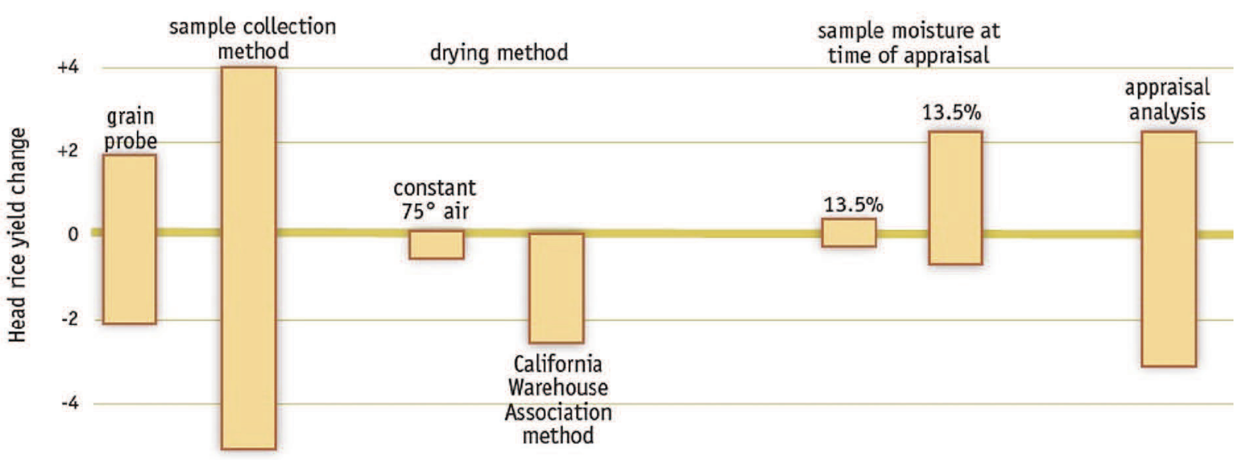


Figure 8. *Variability and error in head rice yield results associated with appraisal sample collection, sample drying method, and sample analysis.*

Sample Moisture

Sample moisture content at milling appraisal affects head rice yield. For example, medium grain rice gains about 2 percentage points of head rice when the sample moisture drops from 13.5 to 12 percent. Short grain rice is less affected by sample moisture. In contrast, long grain rice may have a 6-point spread over this range of grain moisture content.

Rice Certification Law

California's complex market and variety situation requires procedures to ensure that different types of rice do not get mixed. In addition, transgenic varieties with unique production and quality traits are on the horizon, although none are currently grown commercially in California. While biotechnology has enormous potential to create rices with a wide variety of nutritional, medicinal and industrial uses, it is important to prevent mixtures with other, similar-looking rices that are not transgenic. Processors are demanding assurances of purity in response to the consumer reaction to transgenic crops, particularly in export markets. Hence, the California rice industry sponsored the California Rice Certification Act of 2000 to ensure consistently high quality of California rice, maintain consumer confidence, and enhance and protect California's reputation as a provider of high quality rice.

The Rice Certification Act of 2000 (Assembly Bulletin 2622) was signed into law on September 22, 2000 and its provisions went to effect in the 2003 crop year. This legislation contains both mandatory and voluntary identity preservation (IP) components allowing for the certification of any verifiable attribute of rice. The California Rice Commission (CRC) recognized that "There is a growing need to maintain the identity of various types of rice to satisfy increasing consumer demand for specialty rice varieties. This demand requires providing the industry with the ability to establish the terms and conditions for the production and handling of rice in order to minimize the potential for the commingling of various types of rice, and in order to prevent commingling where reconditioning is infeasible or impossible." All rice varieties for commercial production in California possessing "traits of commercial significance" will be required by statute to be produced within an IP certification system. The cost of the mandatory program will be borne by the growers of the specialty rice seed and grain. The CRC is empowered to collect fees, receive and investigate complaints, provide notice of action regarding alleged violations, and seek injunctive relief and other legal means to prevent violation of the Act. The Rice Certification Act is an example of a product-based IP system.

Any characteristics that may adversely affect the marketability of rice if mixtures occur are defined as having “commercial impact.” Included are those that can be visually identified (e.g., bran color, grain shape, grain size, etc.) or that require specialized equipment to determine their identity or composition (e.g., lab cooking tests, taste panels, DNA or specific protein tests). For example, if rice with red bran were mixed with Calrose type medium grain, the mixture would have lower value, and hence be commercially impacted. All rice grown, sold or processed in California will be evaluated for characteristics of commercial impact, including rice brought into California for processing or sale, and IP protocols can be required for production, handling, transportation and storage of a given variety to prevent contamination of other rice. Several specialty rices currently being grown and successfully segregated in California (e.g., sweet, scented, basmati, arborio, and colored bran rices) may eventually be identified as having commercial impact. IP procedures for these varieties are already in place. However, traits that are not visible, such as herbicide tolerance, especially if the varieties are grown widely, will require extra vigilance to keep them separate from other similar varieties.

An advisory committee will recommend regulations to the Secretary of the California Department of Food and Agriculture pertaining to rice identified as having characteristics of commercial impact. The advisory committee will consider each variety separately and render a judgment, using science, economics and market experience, as to whether a given attribute has the potential for commercial impact. If it does, the committee will then establish terms and conditions of production, transportation, drying and storage to segregate the commodity from other rice types. These may include the method of seed application to prevent contamination of neighboring fields, buffer zones between fields, handling requirements to prevent mixtures, and other IP requirements.

An expressed intent of the Act is to encourage research and development of new types of rice. However, to prevent contamination and introduction of exotic pests, the committee must approve research protocols to ensure that the research will not have negative commercial impact. Researchers will be required to submit their research protocols, location of the research and acreage to the advisory committee and follow required procedures. Specific attributes of the rice for research do not have to be revealed. “Research” is limited to 50 or fewer acres of a single type of rice or rice that is intended for commercial use. The advisory committee also reviews procedures for rice brought into the state from other states or countries for research purposes. Current state or federal regulations for bringing such rice into California will apply unless the committee can justify that they are not acceptable. This Act does not apply to rice research conducted by the University of California except when such rice enters the channels of trade.

Separate from the work of the advisory committee, the Act allows the

CRC to establish a voluntary program to certify any verifiable attribute of rice although it has not been used to any extent to date. Certified rice may be labeled with the words "This lot of rice certified (specified attribute) in accordance with the California Rice Certification Act of 2000." Certifiable attributes include any of those characteristics that can be verified, such as origin, scent, herbicide tolerance, colored bran, mochi quality, variety, etc. One may certify, with the appropriate documentation and procedures, that a given lot of rice has or does not have a particular attribute. Hence, rice could be certified as non-transgenic or free of colored bran. Rices with and without commercial impact and seed, rough, and milled rice can all be certified. The Act does not certify rice as organic, although specific attributes of organic rice could be certified.

Regulations on Varieties and Rice Seed

Rice seed can only be introduced into the US through a USDA APHIS approved quarantine permitted greenhouse protocol.

A similar quarantine protocol is also required to bring seed rice into California from the rice producing states in the southern US.

All rice varieties grown in California must be reviewed by Rice Certification Committee of the California Rice Commission for determination of commercial impact (CI) and approved for commercial production. Varieties are classified as;

1. No commercial impact (standard medium, short and long grains).

2. Tier 1 premium short grains, waxy or mochi, bold grains, or aromatics
.

3. Tier 2 colored bran, or genetically modified (currently none in the US).

4. Tier 1&2 have requirement for identification, handling, planting and harvest to prevent contamination.

5. Testing for the presence of the transgenic "Liberty Link" event that contaminated southern US long grains will only continue on "foundation" seed for all commercial varieties.

6. Beginning in 2019 all commercial rice planting in California must use a class of certified seed, (see California Crop Improvement Association) or an approved seed program for varieties not able to be certified or proprietary (e.g. Quality Assurance (QA) seed).

Intellectual Property Protection

Since the unauthorized export of RES rice varieties to Spain in 1989, rice varieties released by the California Cooperative Rice Research Foundation's (CCRRF) Rice Experiment Station have been protected under the US Plant Variety Protection Act (Title 5 to be sold as a class of certified seed only and not for export) and since 2000 all releases have been protected with US Utility Patent. Use of these varieties for breeding or genetic research requires a material transfer agreement. Beginning in 2018 all seed produces of RES rice varieties will be licensed by CCRRF that includes registering with complying with the requirement of the California Crop Improvement Association and the California Department of Food Agriculture.

Appendix A - History of California Rice Varieties

The short grain varieties, predominantly Caloro and Colusa, occupied essentially all of California's production until the late 1950's. The state's production shifted to Calrose following its release in 1948. California's short grain acreage continued to decline due to the success of Calrose and its progeny that currently occupy more than 80 percent of the rice acreage. Long grain, waxy short grains, aromatic long grains have been developed but have never occupied a large percentage of California's rice production. A detailed review of California's rice history from it's beginnings to 1980 had been prepared by J. H. Willson (Willson 1979).

The accelerated rice breeding program initiated in 1969 began delivering new rice varieties to growers beginning in 1976. The successful development of semidwarf Calrose mediums grains was accomplished by Rugter et al. (1977) through induced breeding and Carnahan et al. (1978) through backcrossing. These founding semidwarfs formed the germplasm pools that have allowed the development and release of 19 improved medium and short grain California varieties. The medium grain decedents of Calrose were selected to have Calrose cooking and processing characteristics and are predominantly commercially commingled in drying, storage, and utilization.

The California breeding program began to develop adapted long grains from different parentage for California. Tseng et al. (1984) released the well adapted and productive L-202. L-202 has been a successful parent in the development of recent long grain varieties Cypress and Cocodrie developed in Louisiana. L-202 seed was also exported to Spain and renamed "Thaibonnet" and it has become the major long grain variety grown in that region. Additional long grains were released by Tseng et al with improvements in agronomic, milling, and cooking quality; however, long grain production still occupies <5% of California's rice acreage.

California's traditional short grain acreage has remained small in recent years after losing a major market in Puerto Rico. Premium quality short grains, primarily the Japanese varieties Koshihikari and Akitakomachi, developed in the late 1990s in response to the opening of the Japanese market to rice. Satisfying the quality requirement for the Japanese market has proven to be a significant challenge at the commercial level with the Japanese varieties. Developing high yielding adapted varieties with premium quality characteristics has proven to be an even more difficult task. Premium short grain production seems to have become established in California but the acreage is fluctuating being subject to trade and marketing issues.

California has an established premium quality medium grain production. These types cook similar to the Japanese premium short grains with a similar texture appear very shiny and remain soft after cooling. They trace their ancestry back to the proprietary tall late maturing medium grain varieties Terso and Kokuhorose. M-401 and induced semidwarf of Terso is the predominant variety.

Specialty rice varieties occupy a small acreage. They include Calmochi-101, waxy short grain, aromatic long grains, Mediterranean bold grains, and colored bran. They are grown under contract and include proprietary lines and introductions.

The Calrose market type grown in California may include several medium grain varieties. M-202 (Johnson et al. 1986) has been the predominant variety produced in the state with new releases M-205 and M-104 (Johnson 2002; 2002a) the next most widely grown Calrose medium grains. Table I contains a summary some of the major physicochemical characteristics of several Calrose medium grains. They have a low apparent amylose content and low gelatinization temperature. The kernel size and shape are identifiable features of these varieties. Cooking and processing characteristics including desirability for breakfast cereals are recognized in the market place but not well characterized in standard laboratory testing methods. Environmental factors like climate and temperature in the California rice production region also contribute to grain quality.

Traditional California short grains have low amylose and low gelatinization temperature. The kernels are relatively large and may have some chalkiness. This chalky spot or region being whiter than the surrounding endosperm and these short grain types were referred to as “pearl” rice. In addition to table rice these short grains like S-102 are often used in production puffed rice cakes. Table A-II also contains the physicochemical characteristics for premium quality short grains grown in California. These short grains have a smaller very translucent kernel and produce very high whole kernel milling yields. Koshihikari, a Japanese short grain variety released in the 1950's, is the established standard for Japanese premium quality. The breeding, production, and quality of Koshihikari have been recently reviewed by Iwate (2001). Other premium short grains grown in California include Akitakomachi, a very early maturing variety developed in Japan, and Calhikari-201 is a semidwarf variety developed in California. Eating quality is considered one of the most important traits of rice in Japan and has been the focus of extensive research as well as evaluation of rice for use and sale in the marketplace. Near infra-red based “Japanese taste machines” that measure components like amylose, protein, moisture, K and Mg, and fatty acid content correlated with taste panel results are used to analyze samples and issue a taste score for commerce in Japan. A review of rice grain quality from a Japanese perspective is available from Matsuo et al. (1997).

Development of long grains for production in California faces both the agronomic challenge of cold tolerance and the need to achieve the milling, cooking, and processing properties found in long grains grown in the southern US. Breeding efforts have been directed toward developing adapted long grains that cooked firmer and less sticky because of the soft cooking tendency of California grown conventional long-grain rice. As part of this approach, L-205 was developed with the Newrex quality that is characterized by having 2 to 3% higher amylose content and a stronger viscogram profile than conventional long grains. Because of these characteristics, Newrex types cook dry and exhibit minimal solids loss during the cooking process, and are regarded as a superior type for canned soups, parboiling, and noodle making. Considerable improvement in whole kernel milling yields have also been achieved in the more recent California long grains. Table A-III contain quality characteristics for California long grains.

Specialty types include the waxy short grain Calmochi-101; the long grain aromatic A-201; and the aromatic basmati type Calmati-201. These special purpose varieties are usually grown under contract and some of their physicochemical characteristics can be found in Table A-I, A-II, A-III. There has been a significant increase in interest in these and other specialty types including the Jasmine, basmati, Mediterranean varieties like Arborio, and colored bran types in recent years in both the public and private sector. Some common features of these types are that they are generally ethnic foods, have low agronomic productivity, may present milling or handling challenges, and a lack of established quality evaluation criteria that make them a particularly challenging target for rice breeding or marketing.

Table A-I. *Characteristics of California medium grain varieties.*

Variety	Type	AC[1]	% Protein[2]		KOH Score[3]	Brown Rice Kernels[5]			
		%	Brown	Milled	1.7%	Length	Width	L/W	Weight
M-104	Calrose	17.8	7.8	7.0	6.4	6.3	2.8	2.3	24.1
M-202	Calrose	16.5	7.5	6.6	6.9	6.1	2.9	2.1	23.9
M-205	Calrose	17.8	7.1	6.3	6.9	6.4	2.7	2.3	24.4
M-206	Calrose	17.7	6.7	5.9	6.4	6.2	2.8	2.2	24.6
M-208	Calrose	17.3	6.2	5.6	6.8	6.6	2.9	2.3	24.9
M-401	Premium	18.1	5.9	5.2	7.0	6.4	2.8	2.3	25.6
M-402	Premium	17.5	6.5	5.8	7.0	6.2	2.7	2.3	22.5

[1]Apparent amylose content.

[2]N%x 5.95 dry basis.

[3]Alkali Spreading Value (1.7% KOH)

[4]Kernel dimensions in mm, L/W, length width ratio, and 1000 kernel weight in g.

Table A-II. *Characteristics of California Short Grain Varieties*

Variety	Type	AC[1]	% Protein[2]		KOH Score[3]	Brown Rice Kernels[5]			
		%	Brown	Milled	1.7%	Length	Width	L/W	Weight
Akitakomachi	Premium	17.0	7.2	6.4	6.9	5.3	2.9	1.9	21.3
Koshihikari	Premium	17.6	6.5	5.5	7.0	5.1	2.9	1.8	20.0
Calhikari-201	Premium	18.2	6.7	5.7	6.8	5.1	3.0	1.7	20.3
S-102	Short	18.6	7.0	6.4	6.5	5.8	3.2	1.8	27.5
Calmochi-101	Glutinous	0.1	6.8	6.1	6.2	5.3	2.9	1.8	22.7
Calamylow-201	Low amylose	6.3	6.5	5.7	6.3	4.8	2.9	1.6	18.5

[1]Apparent amylose content.
[2]N%x 5.95 dry basis.
[3]Alkai Spreading Value (1,7% KOH)
[4]Kernel dimensions in mm, L/W, length width ratio, and 1000 kernel weight in g.

Table A-III. *Characteristics of California Long Grain Varieties*

Variety	Type	AC[1]	% Protein[2]		KOH Score[3]	Brown Rice Kernels[5]			
		%	Brown	Milled	1.7%	Length	Width	L/W	Weight
L-205	Newrex	24.1	8.0	7.7	5.0	7.3	2.3	3.2	21.7
L-206	Long	23.1	6.9	6.2	4.5	8.0	2.2	3.6	23.2
Calmati-201	Basmati	23.3	9.1	8.6	4.8	7.3	2.2	3.4	20.8
Calmati-202	Basmati	24.8	8.0	7.5	4.4	8.0	2.1	3.9	22.2

[1]Apparent amylose content.
[2]N%x 5.95 dry basis.
[3]Alkai Spreading Value (1,7% KOH)
[4]Kernel dimensions in mm, L/W, length width ratio, and 1000 kernel weight in g.

California's medium-grain market was developed using the variety Calrose released in 1948. The name "rose" indicates medium-grain shape and "Cal" to indicate California origin and production. Specific processing and cooking properties were associated with Calrose. Over the years new varieties with the same cooking properties as Calrose were released. These medium- grains were commingled with Calrose in storage and later replaced the variety in commercial production. Calrose, as a market class, was established and is still used to identify California medium-grain quality. Physicochemical and cooking tests are used to screen experimental entries and verify that new medium-grain variety releases have acceptable Calrose cooking and processing characteristics.

Newrex is special quality rice that has 2 to 3% higher amylose content and a stronger viscogram profile than conventional long grains. Because of these characteristics, Newrex types cook dry, exhibit minimal solids loss during the cooking, and are a superior type for canned soups, parboiling, and noodle making. The dry cooking characteristics of a Newrex type variety may help address the soft cooking tendency of California grown conventional long-grain rice.

"Premium quality" is a term used to identify the California medium-grain varieties like M-401 that have unique cooking characteristics preferred by certain ethnic groups (e.g., Japanese and Korean). Premium quality medium grains are very glossy after cooking, sticky with a smooth texture, and remain soft after cooling. Aroma and taste are also cited as important features. These types are similar to the high quality short-grain Japanese varieties like Koshihikari. Premium quality is a complex rice quality characteristic and developing improved high yielding premium quality varieties adapted to California continues to be a challenge.

Table A-IV. *Grain shape, year of release, maturity category and parentage of California public rice varieties.**

Cultivar	Grain	Year	Maturity	Parents
Caloro	S	1917	L	Early Wateribune
Colusa	S	1921	L	Chinese
Calrose	M	1948	L	Caloro/Calady*2
CS-M3	M	1971	L	C6 Smooth/Calrose
CS-S4	S	1972	L	Caloro/Smooth No. 3//Caloro/3/Caloro
M5	M	1975	L	CS-M3 natural mutation selections
S6	S	1975	E	Colusa/CS-M3
Calrose 76	M	1976	L	Induced mutant of Calrose
M7	M	1978	L	Calrose 76/CS-M3
M9	M	1978	E	IR-8/CS-M3*2//10-7*2
Calmochi-201	S	1979	E	Induced mutant of S6
L-201	L	1979	E	CI 9701/3/R134-1/R48-257//R50-11
M-101	M	1979	VE	CS-M3/Calrose 76//D31
M-301	M	1980	M	Calrose 76/CS-M3//M5
S-201	S	1980	E	Calrose 76/CS-M3//S6
Calmochi-202	S	1981	E	R57-362-4/D51//Calmochi-201
M-302	M	1981	M	Calrose 76/CM-M3//M5
M-401	M	1981	L	Induced mutant of Terso
M-201	M	1982	E	Terso/3/IR-8/CS-M3*2//Kokuhorose
L-202	L	1984	E	723761/ 7232278//L-201
Calmochi-101	S	1985	VE	Tatsumi mochi//M7/S6
M-202	M	1985	E	IR-8/CS-M3*2//10-7*2/3/M-101
A-301	L	1987	M	IR-22/R48-257//5915C35-8/3/Della
M-102	M	1987	VE	M-201/M-101
M-203	M	1988	E	Induced mutant of M-401
S-101	S	1988	VE	0-6526//R26/Toyohikari/3/M7/74-Y-89//SD7/73-221
M-103	M	1989	VE	SD7//Earlirose/Reimei/3/M-302
S-301	S	1990	M	SD7/73-221/M7P-1/3/M7P-5
L-203	L	1991	E	L-202/83-Y-45
M-204	M	1994	E	M-201/M7/3/M7//ESD7-3/Kokuhorose
A-201	L	1996	E	L-202/PI 457920//L-202
L-204	L	1996	E	Lemont//Tainung-sen-yu 2414/L-201
S-102	S	1996	VE	Calpearl/Calmochi-101//Calpearl
Calhikari-201	S	1999	E	Koshihikari/(Koshihikari/S-101)*2
Calmati-201	L	1999	E	82-Y-51/83-Y-45//L202/PI373938/3/83-Y-45/PI457918
L-205	L	1999	E	M7/R660//M7/R1588/3/82-Y-52/4/Rexmont/83-Y-45
M-402	M	1999	L	Kokuhorose/4/M7*2/M9//M7/3/M-401/Kokuhorose
M-104	M	2000	VE	M-103/6/F1(M-102/4/M-201/3/M7/M9//M7/5/M-103)
M-205	M	2000	E	M-201/M7//M-201/3/M-202
M-206	M	2000	E	S-301/M204
M-208	M	2006	E	M-401/3/Mercury//Mercury/Koshihikari/4/M-204
Calmati-202	B	2006	E	A-201/9543483 (Calmati-201 sib)
L-206	L	2006	E	L-203/4/Lemont/3/R1588/L-201//R1588/Labelle

*Parts taken from Rice Origin, History, Technology, and Production Smith and Dilday Wiley & sons 2002

Planting and Stand Establishment

Tillage

Tillage contributes significantly to rice production costs, time, and effort, including approximately 50% of equipment investment and 15% of operating costs (Espino et al., 2015). So, it is important to have a good grasp of the objectives of tillage, which include,

- Drying of soil
- Loosening of the soil to allow for subsequent land smoothing operations and application of preplant fertilizer
- Forming a uniform seedbed free of large clods
- Destruction of growing weeds
- Aeration to hasten decomposition of residue
- Release of nutrients in organic matter
- Burial of crop residue to reduce disease inoculum and keep floating residue from accumulating and suppressing crop growth

A great deal of rice production costs, time and effort are related to tillage

Typical tillage involves one or two passes with a chisel plow, one pass with a stubble disc, and two more passes with a finish disc. Sometimes soil will be very cloddy and require extra work to break down large clods. Fields should be laser leveled with a dual GPS scraper, as necessary. On non-leveling years, a triplane is used to maintain the ground level. After discing and leveling, a corrugated roller is used prior to flooding and planting. The final seedbed in a rice field does not have to be as fine as for direct seeding of row crops, and by comparison is quite coarse. More important is the uniformity of the surface so that there are no off-grade high and low spots and large clods do not protrude from the water after flooding.

Figure 1. Fall chisel plow operation incorporating rice straw (left), and typical chisel shank (right).

Chiselplow. Many growers rely on heavy chisel-plows as the first ground breaking operation in the spring. The chisels are usually mounted on a spring or have a coil configuration which helps lift the soil. Some are rigid chisels and penetrate slightly deeper and produce a more cloddy surface. Chisels have a lifting action and the objective is to loosen, aerate and dry the ground. Drying is important to facilitate subsequent ground work, to allow air to get in pore spaces, and to avoid destruction of soil structure which may be damaged by heavy equipment working on wet soils. Subsequent operations depend on dry soil, so it is important to allow adequate time for drying before proceeding. A chisel shank and chiselplow operation are shown in Figure 1.

Discs. Heavy single offset discs are usually used after chiseling to work deeper and mix crop residue with the soil. Such discs have a rigid mainframe that supports two gangs of disc blades that operate at an angle to the direction of travel so that they penetrate the soil and roll it (Figure 2).

Figure 2. Heavy-duty single offset disc, called a stubble disc, for use in fall straw incorporation (left). Lighter versions with smaller blades are used for spring tillage. On the right, a schematic overview of a typical single offset disc.

The front gang is set to cut in the opposite direction of the rear gang. The round blades may vary from 28″ to 32,″ and may have smooth or scalloped edges. This operation is important to continue drying the soil, facilitate soil contact for residue decomposition and to prevent residue from rising to the surface where it may be a problem.

One or two passes with each implement is usually necessary. These operations also destroy growing weeds to prevent them from getting a head start on the crop. As air enters the pore spaces, organic matter begins to decay more rapidly, which results in conversion of nutrients from their organic forms to mineral forms, called mineralization. Greater availability of nutrients, particularly nitrogen, is an important benefit of tillage. Rice soils which never dry and aerate are generally less fertile.

Plowing

Figure 3. Typical two-way moldboard plow.

Deep tillage with a moldboard plow (Figure 3) or disc plow is less commonly used because of higher cost and disturbance of the smoothness of the field. However, plows may be useful because they invert the soil and can completely bury residues and weed seeds. They also, however, leave the ground very rough and possibly out of level. Since they cut deeply, plows are not appropriate in fields with shallow surface layers or cacareous subsoils, where they may bring soil chemistry problems to the surface. Plowing is more common in row crop areas, but some growers may plow about every third year in rice-only areas. Over the long term, deeper tillage will deepen the plow layer and should benefit soil fertility and root growth.

Depth of Tillage

Tillage depth should be consistent with the overall objectives of land preparation, drying and loosening the soil, and burying residue. Typically, 6″ to 8″ is sufficient. Some shallow soils limit tillage depth while others have deeper topsoil. Rice roots are shallow and do not respond to deep tillage as some deep-root-ed crops do. The supply of nutrients is more important than depth. Deeper soils tend to have a thicker layer of nutrient rich soil, so rice on such soils often performs better compared to performance on shallow soils.

Spring Residue Management

Most straw management work is done in the fall, but despite best efforts, there is often abundant straw in the typical spring seedbed, which must be managed. Good practices in the fall will help spring operations, particularly chopping, which assists with incorporation and decomposition. Uncovered straw will float and drift into corners, edges or high spots, reduce stand, and increase disease, so a goal of spring work is to cover as much straw as possible. Chisels and discs will partially cover straw but have the tendency to also bring some back up again. The only remedy is to do extra ground work if there is abundant straw still on the surface. It is probably not economical to continue to work the ground past one or two extra operations.

Figure 4. Typical three wheel land plane.

Land Planing

A land plane is simply a long, rigid rectangular (four wheels) or 'A' frame (three wheels) in the center of which a scrapper blade or bucket is set (Figure 4). As the operator pulls the plane across the field, soil fills the bucket and simultaneously spills forward out of the bucket, creating a churning action that breaks up the clods, improves their uniformity and fills in ruts from previous groundwork. The depth of cut of the scraper blade can be adjusted, but it typically cuts no more than an inch deep into the tilled soil. The smooth surface is ideal for fertilizer application because it facilitates uniform depth of placement. Typically, one pass with a plane is sufficient; although, some growers make a second pass at an angle to the first. Landplaning is a relatively slow and expensive operation. Planing only smooths the surface; it is not a substitute for leveling. However, land planing is important for maintaining integrity of the leveling job and to fine tune it for the current season. With prevailing shallow water management, off grade spots and large clods represent potential weedy sites. Planes do not work well in wet soil since the soil must flow freely in and out of the bucket. Land planing packs the soil, and if it is moist, will stimulate early weed growth. Therefore, once the field is planed, subsequent operations must be done promptly. Preplant fertilizer is usually applied to the smoothed soil; although, some growers plane after fertilizer application.

Figure 5. Corrugated roller (left) and closeup of roller surface showing ridges that form corrugations (right).

Corrugated Rollers

Heavy corrugated rollers are commonly used as a final field operation to eliminate large clods and pack the soil, providing a more uniform surface compared to a disced seedbed (Figure 5). To some extent, the corrugations help keep seed evenly distributed. Seed planted in corrugated fields often settles into the bottom of the grooves, resembling drill seeded rice. Corrugated rollers are 15′ to 24′ wide and have ridges at 6″ to 7″ spacing around their circumference. This tool is consistent with shallow water management because large clods are either broken or pressed down in the seedbed. Liquid and dry fertilizer and herbicide applicators may be attached to the roller frame and allow growers to perform simultaneous operations. Rollers require dry soil for good operation. Moist soil will cake on the surface, and clean corrugations will not form.

Corrugated rollers are fairly cheap to operate unless additional operations are combined with them. These combined operations require additional controls in the tractor cab, and a skilled operator is important.

Alternative Systems

Examples of alternative systems include dry seeding, stale seedbed, and no-till. Dry seeding involves sowing unsoaked seed on the soil surface and shallowly covering it with soil using a corrugated roller or light harrow, or drill seeding as one would plant wheat. The seedbed in a drill seeded field is prepared as for water seeding, except the goal is a finer, well-packed seedbed to precisely control seed depth. A smooth roller may benefit this operation. See page 4.9 for more information on drill seeding. The stale seedbed method involves limited tillage in the fall or spring to help germinate weeds and provide alternative weed control strategies. See pages 4.10-4.12 for more information on stale seedbed systems. Rarely, growers may drill directly into the field without otherwise tilling the soil, called ‘no-till.’ Growers use no-till to reduce tillage costs, get an earlier start and discourage weeds, which tend to be less severe when the soil is not disturbed. A heavier, specialized drill is usually needed to cut through residue and packed soil. This is rarely done because there is often some damage to the soil surface from harvesting or spraying equipment that must be repaired.

Seed Soaking

Most California rice fields are sown with soaked, pregerminated rice seeds. Soaking accomplishes two purposes. First, water replaces air inside the seed coat so that the seed is less buoyant and sinks more readily, helping to keep the seed from drifting and ‘bunching.’ Second, germination processes are started so that the seed will have a headstart when it is planted compared to dry sown seed. A flooded rice field is an inhospitable environment, habitat for numerous pests and competitors of rice seed. During soaking, vital physiological processes begin which are precursors to growth. Allowing the most vulnerable period of a seed’s first hours of growth to take place in the relatively benign environment of a soaking tank helps assure its success in the field. Dry seeds sown into water tend to be more susceptible to midge, shrimp and disease attack. Research has shown that the duration of soaking is roughly equivalent, in terms of plant growth, to sowing earlier by the same amount of time as the soaking (Grigarick et al. 1984).

Pregerminated seeds sprout quicker and anchor their roots into the soil, reducing the time of exposure to the different pest and environmental problems that affect early seedling development.

Water absorption and growth.

A rice seed absorbs moisture rapidly once it is placed in water, and continues to increase its water content well beyond the time when it is ready for sowing (Figure 6). Early growth processes were observed at a steady 68ºF, somewhat cooler than the typical environment of a rice soaking tank (Williams, unpublished data). Water was absorbed rapidly during the first three hours, and then the rate of absorption declined to a relatively steady rate thereafter. At 12 hours after imbibition, the seeds had a 'hydrated' look and moisture content over 25%, about doubling water content. The first visual sign of growth was swelling of the embryo and a change to a translucent character at 42 hours and moisture content of 36.5%. By 48 hours, the embryo was just beginning to split the hull, and by 60 hours the first shoots were breaking through.

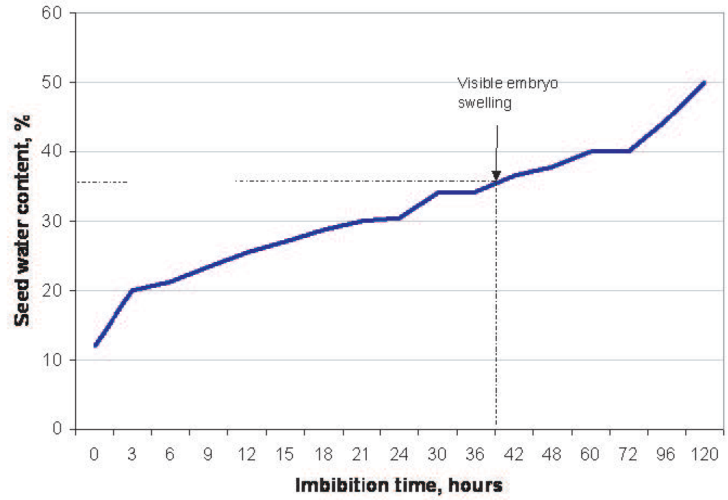


Figure 6. Rice seed water uptake at 68ºF. Visible embryo swelling first seen at 42 hours at seed water content of 36.5%, dry weight basis. (Williams unpublished data)

Soaking

Soaking is typically done in steel bins (Figure 7), with dimensions of approximately 48" wide, 48" deep, and 51" high, and a volume of 62 to 64 cubic feet. Sodium hypochlorite or a similar disinfectant is usually added to the soaking water to help control bakanae, a fungal disease that causes seedling elongation and yellowing. (For more information on bakanae control measures, including soaking, see the Diseases chapter.) The bins have indentations at the bottom for forklifts to lift, invert and dump the seed into trucks. A full bin will hold up to about 2300 lbs of dry seed, and contains about 230 gallons of water (seed just covered). In other words, ten gallons of water is required for every hundredweight (cwt) seed, plus an additional gallon/cwt as the seed absorbs water. The exact amount of water for initial filling depends on the grain type, with medium grains requiring slightly more water than long grains. The bins are usually fitted with drains so that water can be drained.

Figure 7. Typical rice seed soaking bins

Some seed soaking is also done in the same trucks that deliver the seed to the airstrip before planting. The advantage is reduced handling, no need for bins or forklifts and less labor. The disadvantage is that the large volume will generate more heat than small bins if seeding is delayed, and it is difficult to refill and cool the seed. Sprinklers are sometimes put on the trucks for cooling if seeding is delayed.

The metabolic activity of growth creates heat which will accumulate in the enclosed soaking bin. High outside air temperature will increase the rate of heat accumulation. As temperature rises, respiration rate increases, up to about 90ºF, and then starts to drop off. Oxygen levels also decline as the seed oxygen demand increases. If soaking proceeds too long, the combination of high, sub-lethal temperature and low oxygen will cause poor seedling vigor and delay in stand establishment. Loss of seedling vigor may lead to stand loss from pests and weather damage. Lethal temperatures for wet rice seeds have been reported from 104 to 113ºF.

Damaging temperatures can easily be reached if soaking is not done properly, and is regulated mainly by time of soaking and drainage. Recommended soaking guidelines are 24 hours in the soak water and 24 hours of draining, for a total pregermination time of 48 hours. Seed does not have to remain in the water for the entire duration of pregermination for early growth to begin. The seed should be sown promptly after 48 hours to avoid heat accumulation and oxygen depletion; however, some growers' practices vary significantly from these guidelines. There is some safety built into the guidelines, but problems with heat begin when 48 hours is greatly exceeded. When sowing is delayed by north wind or flooding delays, growers should attempt to cool the seed by refilling the soak tanks with fresh, cool water. Trucks with seed in them should be taken to a shady area, tarps removed and sprinklers put on top.

Adequate drainage is necessary to prepare the seed for sowing. During drainage, while pregermination continues, excess moisture drains away so the seed will more easily flow from the trucks and the aircraft spreaders. Poorly drained seed will stick together and resist flowing, resulting in poor seed distribution in the field.

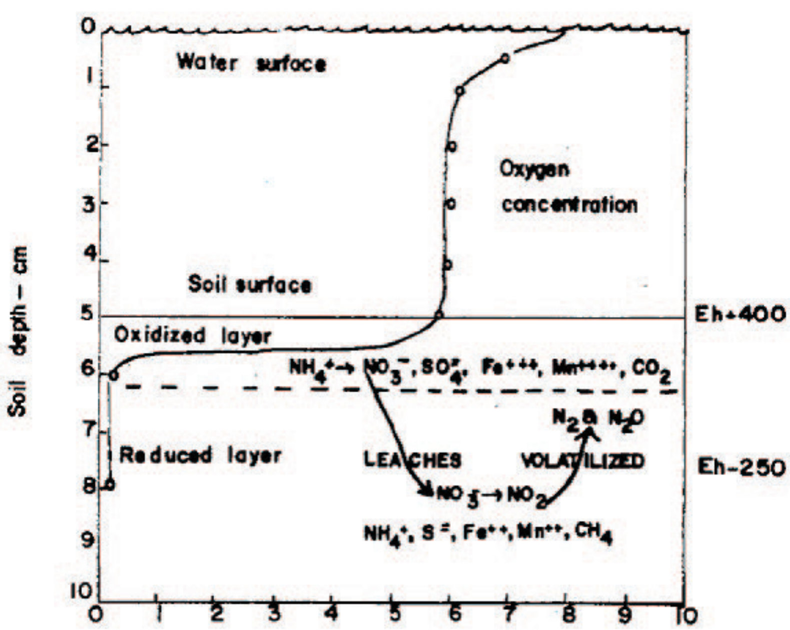


Figure 8. Oxygen levels in soil and water of a typical rice field. From: Plant Nutrient Behavior in Flooded Soils. (Patrick & Mikkelsen 1971)

Planting

Direct sowing requires soaked seed be flown directly into the flooded field so that it comes to rest on the soil surface. It is important that the seed remain on the soil surface. Seed that is buried more than a centimeter in the soil will have low vigor or won't germinate because of inadequate oxygen. Rice seed needs a ready oxygen supply to sprout. Flood water replaces air in the soil and greatly reduces diffusion. Figure 8 shows how oxygen levels in the water and soil differ. Research by UC scientists and others showed that the oxygen level in a rice field drops to near zero within 6 to 10 hours of when a dry soil is flooded. In addition, the flood water reduces oxygen diffusion into the soil by a factor of over 10,000 times. (Patrick and Mikkelsen 1971).

The top centimeter of soil contains some oxygen which declines rapidly with depth. Burying seed severely reduces germination and emergence.

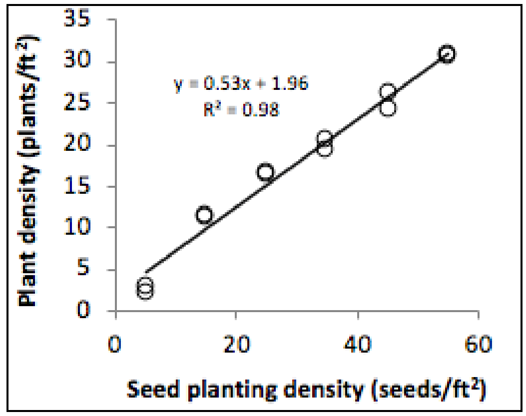


Figure 9. The relationship between seed density and plant density. Results are combined for the two planting dates, May 25 and June 1, and are for variety M.206.

Stand assessment

Minimum seedling population for maximum yield is dependent on many factors--sowing method, water management, planting date, variety, soil type and others. In 2015, a trial was conducted to determine optimal seed and plant density for maximum yield, using variety M.206 (Linquist, 2016). The results showed that plant density (plants/ft^2) was about half of the seed density (Figure 9). In other words, only about half of the planted seeds germinated. Furthermore, maximum yields were achieved with about 25 plants/ft^2 (Figure 10). At half of that plant population (12.5 plants/ft^2), yield potential declined to approximately 90%. While optimum seed and plant density may vary with different varieties and across years, these results provide guidance for stand assessment. UC Cooperative Extension has developed an online seeding rate calculator to assist with determining seeding rate based on variety and the desired stand density. The calculator is located at http://rice.ucanr.edu/Rice_Calculator/.

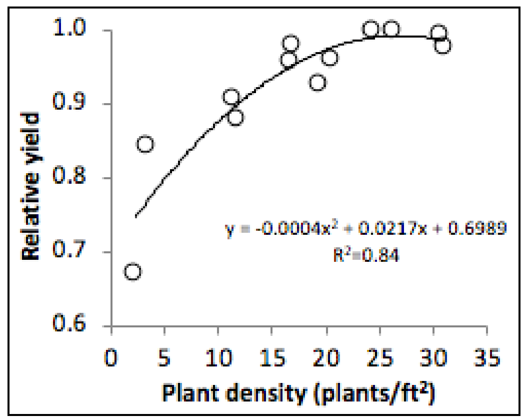


Figure 10. Relative yield versus plant density. Results are combined for the two planting dates, May 25 and June 1, and are for variety M.206.

Assessment of the stand soon after sowing is very important to ensure that pests (diseases, midges, shrimp) and burial have not reduced the stand to an unacceptable level. In cool weather, rice will germinate and grow slowly and less uniformly, and as temperatures warm the reverse is true. Optimum temperatures for germination and early seedling growth are in the range of 77 - 94ºF. Minimum temperature for germination is 54 - 56ºF, and maximum temperature is 104ºF. Seedling pests also respond to temperature, with diseases tending to be more damaging in cool weather, partially a result of poor growth and prolonged exposure of the rice. Shrimp and midges, on the other hand, tend to be more severe during warm periods.

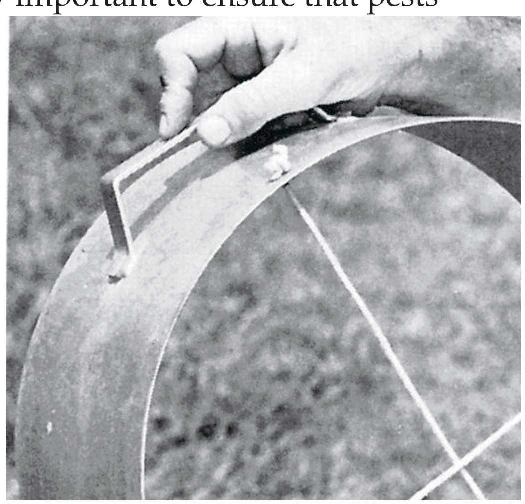


Figure 11. Sampling cylinder.

Early identification of insufficient stand is essential to successful reseeding. The longer the delay, the lower the success of replanting. Stand evaluation must be made within the field. A useful tool for looking at small plants is a sampling cylinder (Figure 11). Carefully push it slightly into the soil to avoid stirring up sediment, and observe the condition of seeds within the cylinder. By making it a known size, such as one square foot, one can make a count of healthy seedlings. Another version is a box fitted with a Plexiglas bottom. By pressing the box to the soil surface, seeds can be easily seen without mud obscuring them. Close examination of individual seedlings is necessary, so it is very helpful to have a hand lens. More information on stand establishment pests can be found in the sections on diseases and invertebrates.

Wind burial can reduce plant population, and bunching can leave large open areas, both of which may necessitate reseeding. Assessing a buried or bunched stand is difficult. Buried seeds may eventually succeed but finding them is difficult. A coarse screen with mesh just smaller than the seed can be fitted in a frame and pulled across the surface. Sluicing with water will reveal the seed, although it does take some work. A bunched stand leaves many areas under populated, while other areas having too thick a stand.

Reseeding

The decision to replant if stand density is less than optimal is an economic decision that growers will have to make based on their planting costs and expected lost revenues from reduced yield. If the decision to reseed has been made, identify and manage the possible impediments to success. Over the first few days of flooding many organisms establish in the field - algae, crustaceans, insects, microorganisms - some of which are potentially damaging to the rice. In addition, a layer of detritus composed of dead algae and diatoms may form on the soil surface which can deter root growth. To the extent possible, one should manage these problems with appropriate measures. As stated above, early diagnosis is important and the most important component of successful reseeding. Depending on the density of the stand, the reseeding rate can be from 50 to 100% of the original rate. Normal soaking procedures should be used so the new seed will start quickly. Depending on the time difference between first and second seeding, one may consider using an earlier maturing variety of the same market category to help with uniform maturity. Soaking of the new seed should be done according to standard guidelines (24 hours soak, 24 hours drain). The new seed will perform better if the field is drained. However, drainage must be balanced against the potential loss of weed control.

Rice seed has dormancy inhibitors in the hull when it is first harvested. Currently-used varieties naturally lose their dormancy with time, and it is not necessary to do any special treatments prior to planting at normal dates. In the past, seed treatments had been beneficial to increasing uniformity and rate of germination, both of which are affected by dormancy. Dormancy has been associated with chemical germination inhibitors in the hull and impermeability of the hull and seed coat to water. Sodium hypochlorite has been used in the soak water, at the rate of one gallon of 5.25% sodium hypochlorite per hundred gallons of water, a 1% solution, to alter the chemical germination inhibitors in the hull to improve speed of germination and early growth. Percent germination is not affected.

Wet seedbeds and delayed planting

Late spring rain may make it impossible to adequately dry the seedbed for optimum stand conditions. The result can be lower soil fertility, difficulty in land planing and rolling, precocious weed growth, difficulty in placement of aqua fertilizer, more algae, and delayed planting. If time permits, rework the ground, using a chisel-plow, to speed drying. If the ground has not been worked, and there is a stand of vetch or other vegetation, let it grow as long as possible, and it will help dry the soil. If the ground is worked wet, expect some of the problems cited above and manage accordingly.

Drill Seeding

Drill seeding is used by some to reduce costs and manage herbicide resistant weeds. It is also the typical planting practice in the Sacramento-San Joaquin Delta region where dry seed is drilled into moist soil (as one might do with wheat). The light-weight, high organic matter soils of the region make water seeding less successful because the soil can bury the seed and prevent germination. High winds in the region may also impact seedling root anchoring under water seeding.

The primary issues in drill seeding are depth of seed placement and management of moisture for germination. Rice seedlings may not emerge well from deep planting. Studies in 1985 (Gunnell et al.) demonstrated reduced emergence as planting depth increased from ½ to 3″. Emergence percentage for M.202 was 100%, 100%, 92.5% and 20%, at ½″, 1″, 2″, and 3″, respectively. Deeply planted seeds took much longer to emerge and often came up twisted and bent. For current varieties, plant no deeper than 1 ½″ to 2″. Growers who drill seed can plant to moisture or plant dry and irrigate the field to bring up the plants. The former is better to reduce weeds in the rice, but there is the risk of missing the moisture. Drill seeding into a dry seedbed and flush irrigating reduces that risk if done properly, but weeds are usually more of a problem. Either way, the permanent flood is established about a month later when the rice is at the 3 to 4 leaf stage.

Alternative Stand Establishment Methods

Continuously farmed rice affords few options for breaking weed population cycles. Consequently, the number of aggressive herbicide resistant weeds has built up over time. In heavily infested rice fields, conventional weed control strategies are ineffective and costly. The weed seed bank in the soil becomes increasingly dominated by resistant biotypes in these fields. Alternative stand establishment methods can reduce the resistant weed seed bank in the absence of traditional crop rotation.

These methods do pose some risk. However, with careful management, good yields are possible. Keep in mind that the primary objective is to reduce the population of resistant weeds and then return the field to a conventional water seeded system where weed control is once again cost effective. UC studies concluded that integrating cultural and chemical weed control practices is effective without significant reductions in yield (Figure 12). Integrating reduced tillage and a stale seedbed in rice systems will reduce herbicide resistant weed populations, delay the evolution of herbicide resistance, and reduce weed seed banks. Establishment techniques such as reduced tillage, stale seedbed or dry seeding may be used to manipulate weed species recruitment and expand herbicide options.

Planting into a Stale Seedbed

A stale seedbed is one where rice is planted into undisturbed soil. A stale seedbed approach encourages weeds to germinate by using irrigation prior to planting. Once the weeds are established, they are killed with non-selective herbicides, such as glyphosate (Roundup). In dry seeded rice, pendimethalin (Prowl) may be used for soil residual control of many grass species. These herbicides provide alternative mechanisms of action to control resistant species.

Fall Tillage versus Spring Tillage

A stale seedbed can be established with either fall or spring tillage. The pre-plant irrigation and weed control with a non-selective herbicide is the same for both circumstances. Fall seedbed preparation requires that the straw is well incorporated; an additional pass with a disc may be necessary. Flood the field for decomposition as usual. A prolonged winter flood should "melt" the clods to a relatively smooth soil surface by spring. If the field is cultivated in spring, apply P and K fertilizer during the cultivation operations prior to irrigation, weed germination, and herbicide application. Phosphorus left on the soil surface promotes algae growth. If it is inopportune to apply them during cultivation, they can be applied into the water 20-30 days after seeding.

Key points to remember for stale seedbed method

- Cultivate the field in the fall in the usual fashion.
- In the spring, flood the field to germinate weed seeds, preferably during warmer periods to encourage rice weed germination.
    a. Water grass and other grass seeds: maintain flood or saturated soil for 4 to 5 days.
    b. Sedge and broadleaf seeds: maintain flood or saturated soil for about 10 days.
- Dry-up the ground. Apply glyphosate to kill germinated weeds approximately 10 to 14 days after drain.
- Do not apply the herbicide until the rice weeds are vigorously growing. Applying too early will compromise control. Be patient.
- Do not disturb the soil after glyphosate treatment to avoid bringing more weed seeds to the surface.

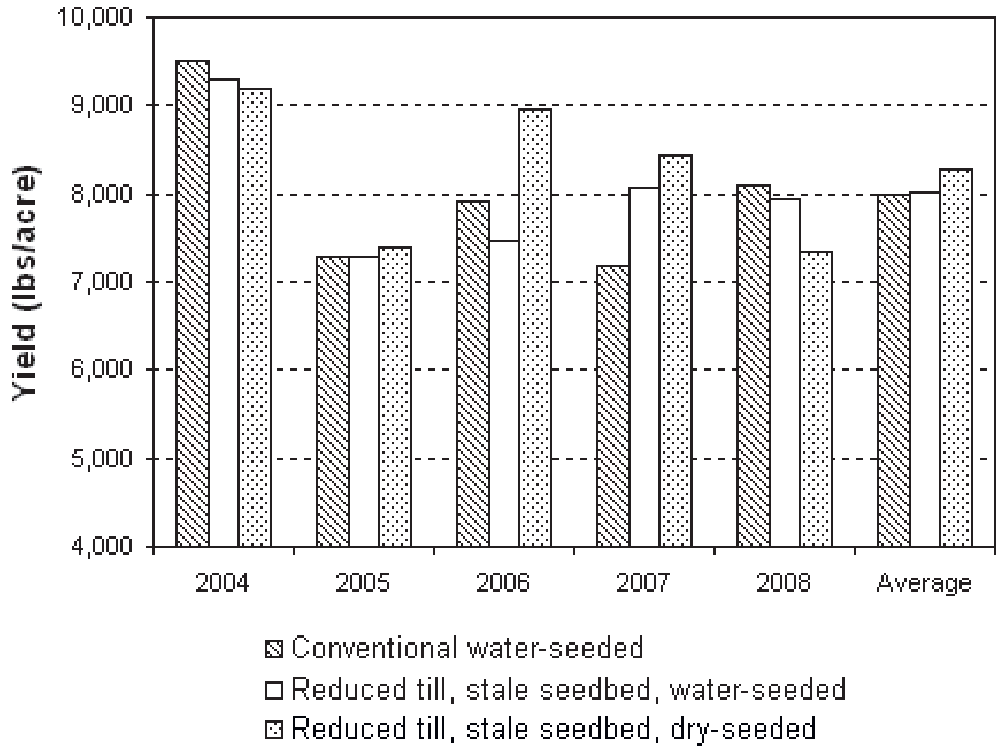


Figure 12. Grain rice yields under conventional and reduced till, stale seedbed water- and dry-seeded systems, 2004-2008, Biggs, CA

Table 1. Example operations for planting rice using water seeded or dry seeded stale seedbed alternative stand establishment methods.

REDUCED TILL, STALE SEEDBED, WATER SEEDED	REDUCED TILL, STALE SEEDBED, DRY SEEDED
Preplant Weed Control • Flood the field to germinate weed seeds • Drain, then apply non-selective herbicide after the weeds are vigorously growing • Introduce flood for planting 2 days after herbicide application.	**Preplant Weed Control** • Flood the field to germinate weed seeds • Drain, then apply non-selective herbicide after the weeds are vigorously growing
Seeding, fertility and water management Apply N at 20-60 lb/ac to soil surface (optional). a. Use ammonium sulfate if you typically see a benefit from sulfur. b. Use urea if you can flood quickly. c. Consider applying P and K in the fall. Flood field. Seed with pre-germinated seed at a heavier rate than usual (~200 lb/ac). There are two options following seeding 1. Drain field for stand establishment (especially if ground was not dried and soil oxygen concentration may be low) Apply bulk of N (150 lb/ac) as urea immediately prior to permanent reflood Top 1″ of soil must be dry so that flood water will drive urea into soil and prevent N volatilization losses. 2. Maintain a continuous flood and raise water depth as seedlings develop. • Apply bulk of N (150 lb/ac) as ammonium sulfate at the 3-4 leaf stage of rice or when rice roots are well- developed.	**Seeding, fertility and water management** • Pre-plant application of 1/3 total N. a. ~30-50 lb N/ac as ammonium sulfate. b. N may be applied with drill. c. Total N requirement may be a little higher than in a conventional water seeded system. • Seed at a rate of about 100 lb/ac. a. 5-7″ spacing. b. Depth < 1″ • Flush/drain to promote rice germination. a. Rice seed may not germinate in low spots with standing water. b. Rapid water movement in fields with lighter textured soils may bury the seeds in some areas and thin the stand. • May need to flush again prior to permanent flood, depending on the weather. Hot, windy weather can cause the soil to crust before the seedlings emerge. • Apply remaining 2/3 total N just prior to permanent flood. a. 100 to 120 lb N/ac as urea. b. Top 1″ of soil must be dry so that flood water will drive urea into soil and prevent N volatilization losses. • Apply permanent flood when rice plants are large enough to be above water; typically between the 4 leaf and tillering stage.
Weed management Weed management options when draining for stand establishment: 1. Pre-plant glyphosate (Roundup). 2. Foliar herbicide application at 3 leaf stage of rice. 3. Into the water application after reflooding, or foliar application with rice 3-4 leaf stage to tillering and water lowered for 70% exposure of weed foliage. Weed management options with continuous flooded system 1. Pre-plant glyphosate (Roundup). 2. Into the water herbicides. 3. Foliar herbicide options at 1-3 tiller rice with water lowered if needed for 70% exposure of weed foliage	**Weed management** 1. Pre-plant glyphosate (Roundup). 2. Herbicide options: • A pre-emergent herbicide application after the first flush of irrigation followed by a foliar application prior to permanent flooding. • A foliar herbicide in tank mixture with a soil residual herbicide applied when rice is the 2-4 leaf stage. 3. Come back with a foliar herbicide application after permanent flood if needed to control a new flush of weed emergence. Water should be lowered for 70% weed foliage exposure to the herbicide.

Water Management

Most California rice is produced by direct seeding into standing water with permanent flood for most of the season. Limited acreage is drill seeded which also uses a permanent flood after stand establishment. The origins of this system have much to do with weed control, nitrogen management and productivity, discussed in other sections.

Typically, a shallow flood is established over the field and pre-germinated seed is sown by airplane into the water. The seed comes to rest on the soil surface and establishes in that spot. The water is kept on the field throughout the season except for short term drainage, permanently removing it only at the end of the growing season to prepare the field for harvest. Rice growers spend much of their time managing the water and there are numerous variations on this simple theme which makes water management more complicated than it first appears. A previous section dealt with leveling and water management structures. This section deals with water management during the season.

The origins of this system have much to do with weed control, nitrogen nutrition and productivity, discussed in other sections

Purposes of Water Management

The general goals of water management are:

- Supply water to the crop
- Establish an optimum plant population
- Suppress weeds
- Provide for pesticide applications
- Conserve nutrients
- Protect against cold weather
- Protect water quality
- Manage salinity

Each will be discussed later in the chapter.

Seasonal Water Use

Seasonal water delivery for California rice varies a great deal depending on soil type, management and seasonal length (Table 1). The average delivered use is approximately 4.5 to 5. af/a, but varies from about 4 to 8

Table 1. *Approximate seasonal water use by use component for rice in California. Note, this table does not account for leaks in levees and outlets.*

Seasonal Water Use	Acre feet per acre
Evapotraspiration (Et)	2.75
Percolation/seepage	0.5 – 1.0
Drainage	0 - 2.0
Total	3.25 – 5.75

af/a, or more, depending on soil properties and water management.

Evapotranspiration (Et, crop use, consumptive use) is the amount the crop itself takes up through the roots and transpires from leaf surfaces into the atmosphere. Et varies with seasonal length, so an easy way to save water in rice is to grow shorter season varieties. There is also some seasonal variation in Et due to annual weather fluctuations and differences due to planting date. The climatic factors important to crop use are solar radiation, wind and temperature.

Percolation is controlled by soil texture and impervious subsoils. Most rice soils have clay and/or hardpan in the subsoil, so water does not percolate rapidly compared to deep loamy or sandy soils. In general, percolation losses over the course of a growing season in California clay soils are less than 4" per growing season. If deep percolation is excessive, rice may be a poor crop choice. In New South Wales, Australia, where water shortage is chronic, rice soils are tested for infiltration rate, and if excessive, rice cannot be grown.

out of the, usually through levees. Seepage course Seepage rates are also determined by the height of water on the other side of the levee. Seepage is lower (or even reversed) when there is a water supply canal or another flooded rice field on the other side of the levee. Studies have shown that seasonal water losses due to seepage are less than 2" per growing season.

Drainage during and at the end of the season accounts for the balance of delivered use. This number has gone down with widespread use of laser leveling, which allows for less spillage, and mandated water holding required for pesticide use.

Water Management Systems

Different water management system designs are used for ease of management, water conservation and maintenance of tailwater quality. Each are discussed below. For a more complete discussion, see "Rice Irrigation Systems for Tailwater Management", UC DANR Publication 21490, available at UC Cooperative Extension Offices in the Sacramento Valley.

Flow Through System

The most common system is the flow through system, also called the conventional system. Water supplied to the top- most basin sequentially floods each successive basin as it makes its way to the lowermost basin. The water is regulated by weirs or rice boxes. Excess water is allowed to spill over the last box into a drain. By continually supplying water to the top, and allowing a small amount to spill out the bottom, with the boxes adjusted properly, the water level is automatically maintained, hence the name "flow through system." The advantages of this system include low installation cost, ability to flush salts from the field, easy installation and removal, and adaptation to irregular slopes. The disadvantages include substantial management, difficulty in preventing excess water in lower basins, and slow response to adjustments. This system is not well adapted to holding water as required by regulations (discussed later in this section). Holding water is really contrary to the intended purpose of the system. Figure 1 is a schematic of a conventional flow through system.

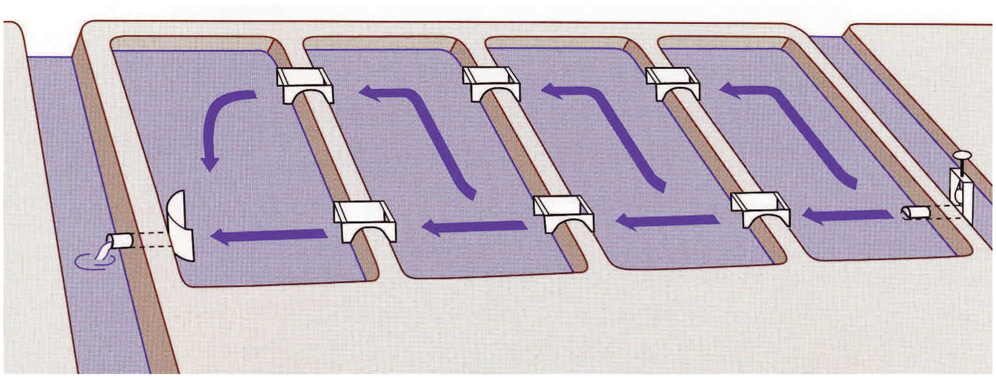


Figure 1. *Conventional flow through system showing serial application of water from top (right) to the bottom of the field (left). Double box system reduces restrictions on water flow and may improve circulation. From: Hill et al. 1991.*

Recirculating Tailwater Recovery System.

These systems capture tailwater in a sump and pump it back to an inlet for reuse in the same or other field. They are useful for water conservation and keeping pesticide residues out of public waterways. Numerous recirculation systems have been installed although many have fallen into disuse because of maintenance and operation cost. These systems are adaptable to single fields, whole farms and whole irrigation districts. Only a few single field systems are in use. Figure 2 is a schematic of a single field with a recirculation system. The concept is applicable to various scales. All systems in use help stretch the limited supply of expensive water and allow growers to comply with less restrictive holding requirements. In-field water management is the same as for the flow through system. The major management challenge is balancing intake of fresh water with recirculated water, which is more difficult as the system increases in size. The advantages of this system are ability to keep pesticide residues out of public waterways, good flexibility of management relative to regulations, reduction of cold water effects, conservation of water, and lower water expense. Disadvantages are cost of

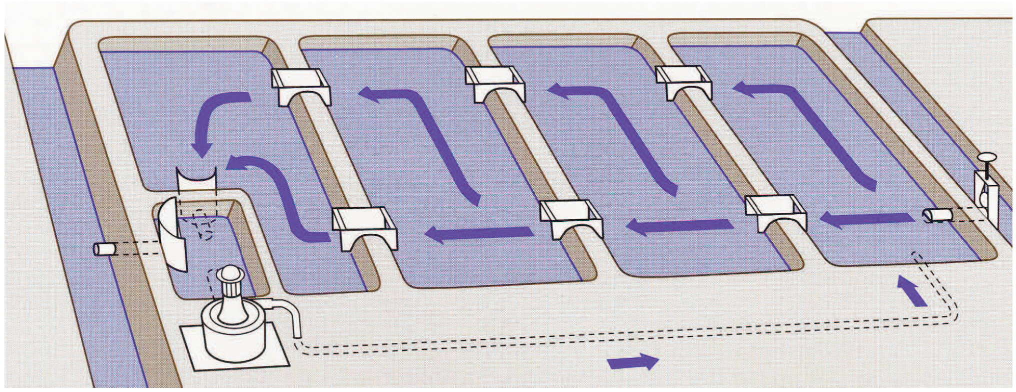


Figure 2. *Single field recirculation system. This concept can be scaled up to multiple fields, multiple farms or whole irrigation districts. From: Hill et al. 1991*

installation and maintenance, extra land out of production, and a higher level of management.

Static Water Irrigation System

This system was developed specifically to keep pesticide residues out of public water. The key features include multiple water inlets from a canal along the side of the field, so that each basin is irrigated in parallel but separate from the others (Figure 3). The inlet acts as the drain at the end of the season and the goal is for zero drainage. Some saline fields have conventional drains at the end opposite the intakes which allow for flushing of salts at the start of the season. Once water goes into the field it stays until the end of the season, with additional water added as needed. To accomplish this, inlet pipes are installed below grade at the low side of each basin. Each pipe has a flap valve that is opened by the pressure of inflowing water, and closes as the inflow declines, keeping water in the field. Water levels are managed by changing the levels in the supply ditch. Opposite each inlet pipe is an in-ditch weir to adjust water levels. To drain the basins, water in the supply ditch must be drained and the flaps opened. Advantages include an excellent capability for water holding, water conservation, independent control of levels in each basin, easier management and no need for a return pump. Disadvantages include higher cost of installation and maintenance of the system, land out of production, reduced flushing of salts, and unsuitability of perma-

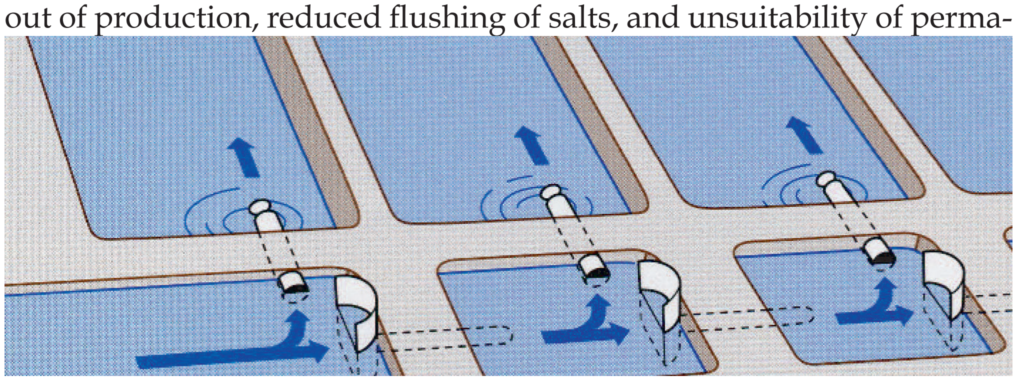


Figure 3. *Static water irrigation system. From: Hill et. al.,1991*

nent installations for rotation crops (although temporary static systems have been used in row crop areas).

Cold Water Effects

It is common knowledge that yields are low near a cold water intake. Recent research has shown that the cold water and the associated reduction in rice productivity extend well beyond the area where the effects are readily visible. The distribution of cold water can extend throughout the intake check and bleed into the adjacent check (Figure 4). The infrared image taken in early June showed that the water temperature warmed by only about 5 degrees as it passed through the 15 acre check. The intake water temperature was 56° F when it entered the field. Plant development throughout the growing season was delayed as a result (Table 2). Interestingly, the gradient in developmental delay was accentuated with time. For example, there was an 11 day difference in the time to first tiller between the cold and warmer parts of the check. The differential increased to 21 days by panicle initiation and to 32 days at boot. The cold water effects are accumulative. Similar relationships were observed in the yield components (Table 3). Head size and seeds per panicle decreased from the warm to the cold areas of the check. There was a corresponding increase in blanking and reduction in yield. Notice that the yield loss is not restricted to a just the area surrounding the intake box. It appears that the potential yield reduction

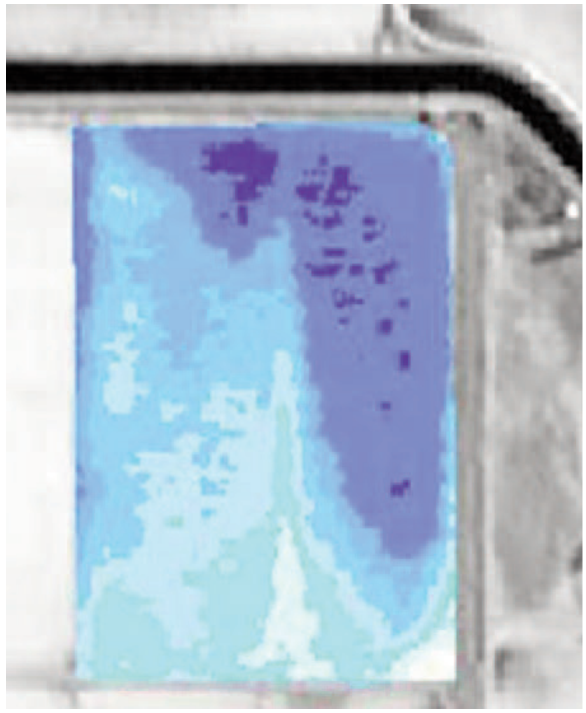


Figure 4. *An infrared image showing the water temperature gradient in an intake check in early June 2001. In coming water = 56° F. There a temperature gradient of about 5° F across the check.*

Table 2. *Days after planting (DAP) to reach different stage of development in a cold water intake check.*

	1st Tiller	PI	Boot	50% Heading
	-------------------------------- DAP --------------------------------			
North	43	85	120	---
(inlet)	34	69	104	114
	31	64	90	104
South	32	64	88	96

Table 3. *Yield components as effected by water temperature gradient across an intake check.*

	Head (cm)	Seeds per panicle	% Blanks	Yield (lb) @ 14% MC
North	14	0	98	402 (green)
(inlet)	13	10	53	2288
	16	45	29	5924
South	17	53	12	9138

due to cold temperature is comparable to a dose-response function.

In that, the longer the crop is exposed to cold water the more pronounced the impact. Figure 5 uses a threshold water temperature of 65° to illustrate the concept. The longer the plants were exposed to water temperature of less than 65° during the day for the first six weeks the greater the yield loss. For example, only 20 percent of the yield potential was observed in the areas of the field that experienced water temperature under 65° for 250 hours (i.e. 80 percent reduction). In contrast, at 150 hours of exposure 60 percent of the yield potential was realized. If you farm ground with cold water, you may want to consider modifying the water delivery channel when laying out your irrigation system to

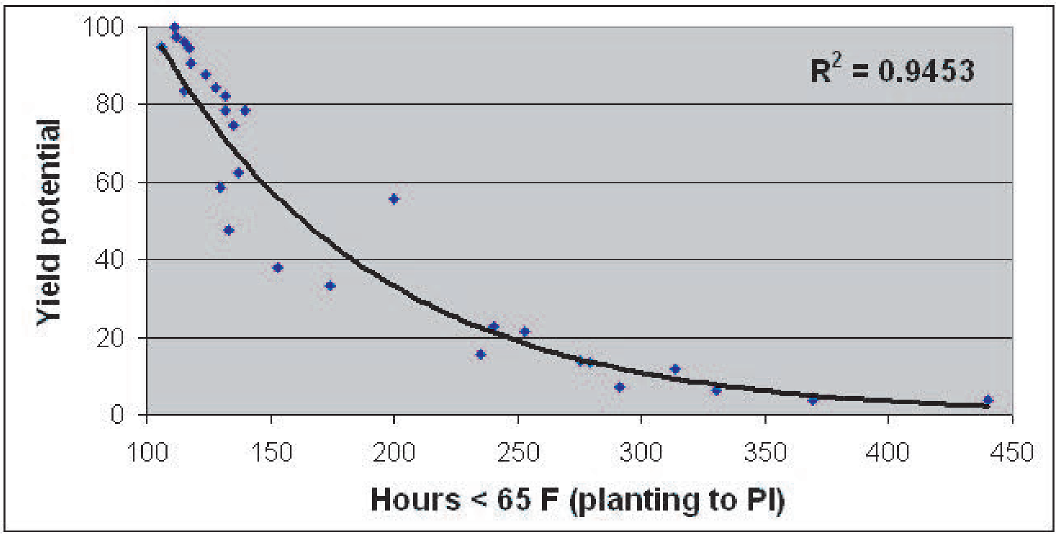


Figure 5. *The potential yield reduction in rice when exposed to water temperatures < 65° F for different periods of time.*

minimize this effect.

Flow Rates

Flow rates determine the speed of initial flooding and, if necessary, reflooding. Speedy flooding is desirable for earlier planting and to prevent weeds and other pests, such as seedling disease, shrimp and midge, from getting ahead of the rice. Precision leveling, flat fields and corrugated rollers have made initial flooding quicker compared to earlier years, given similar flow rates. Increasing competition for water and greater reliance on pumps may reduce flow rates in the future, so it is important to have an appreciation for what is needed for the various stages of crop production.

Flow rate guidelines appear in Table 4, and can be used to estimate time to flood with a given quantity of water or the desired flow rate for a given size field. The calculations in Table 4 are for a delivery of four acre inches per acre, which assumes that this is sufficient to just cover the field for seeding, but not to establish a depth of flood water. About two inches are assumed to go into the soil and the balance will be on top. The amount required for initial flooding is really quite variable and depends on the amount of water already stored in the soil, the slope of the field and how the grower floods. 'Acceptable' flooding times are in the shaded area and are selected to help avoid problems that develop with increasing time. During cool spells a longer flooding period may be acceptable because growth of pests is slower. Acceptable time is arbitrarily set at 96 hours in Table 4, although it is not a disaster if the field takes a day or two longer to flood. When fields take longer than a week to flood, pest problems start to increase.

Putting it in simple terms, quick flooding requires roughly 28 gpm/a. Once a flood is established, the amount needed for maintenance is much less, a continuous flow of 5 gpm/a over the course of a season is usually adequate. For design purposes, one should plan on a minimum of 10 gpm/a. The extra capacity allows electric pumps to operate during off-peak periods. Extremely low flow rates may require special management, such as sowing rice in sections of the field as they are flooded, or dividing fields into small units.

Table 4. *Approximate hours for initial flood for various field sizes with different flow rates. Shaded area represents acceptable time. Based on delivering 4 acre inches/a.*

	Size of Field in Acres			
GPM	**50**	**100**	**150**	**200**
500	181	361	542	722
1000	90	181	271	361
2000	45	90	135	181
3000	30	60	90	120
4000	23	45	68	90
5000	18	36	54	72
6000	15	30	45	60
7000	13	26	39	52
8000	11	23	34	45
9000	10	20	30	40
10000	9	18	27	36

Water Management Methods

Initial Flood

When field preparation is completed, boxes installed, and levee ends closed, water is introduced into the top of the field. Additional inlet sites may be used in large fields to speed the process if sufficient water is available. Flow rates determine the rate of flooding. The objective in the initial flood is to get the entire field wet as quickly as possible. In a flow-through system, this may be accomplished by blocking back water in the top basin until it is nearly covered by setting the board in the first box to hold the minimum amount and allowing the rest of the water to spill over. Repeat this basin by basin until the last one is covered. It is not necessary to establish final depth at this time, only to get the soil wet to receive the seed. It may take several days to establish the desired depth, but it is not necessary to delay seeding. Flooding from the top of the field helps flood the field faster. If the boxes are all wide open during initial flooding, the water will tend to run straight to the lowest basin, and one must work from the bottom of the field to the top. This is called back flooding and takes much more time because the tendency is to get more water than needed in the lower basins. Increasingly growers are establishing shallow ditches between rice check boxes which allows the checks to flood more uniformly.

Establishing a Stand

Following seeding, the goal of early season water management is to establish a vigorous, healthy, weed-free stand. The management of water during this period is integrated with herbicide use and greatly affected by water supply. For example, early applied foliar materials, such as Clincher, require a drained field. Rapid reapplication of water is important for good weed control and may affect success in some areas because of low flow rate. For materials applied into the water, such as Ordram and Bolero, the goal of water management is to quickly establish a continuous flood of 4 to 5” which provides a good compromise between rice growth and weed suppression. Shallow water (1-3”) promotes rice growth and root anchorage, but also favors weed growth. Deep water (7-8”) delays early rice growth and tillering, but also greatly inhibits grasses and smallflower umbrellaplant, the most competitive weed species. Water management for specific herbicides is discussed in the section on weed management.

Drainage for stand establishment

Many growers use a planned drain period after sowing to help improve stand establishment. This practice is known as the ‘Leathers method,’ after the grower who popularized it. This is a useful practice where rice has difficulty in anchoring to the soil or is easily covered or moved during windy weather. When properly used, stand density and uniformity of distribution is usually improved and concerns about the effects of wind are less. Generally, fields are completely drained immediately after sowing and the water left off until the radicle penetrates the soil and anchors the seedling. In this aerated situation, roots are stimulated to grow more than they are in a flooded, less well-aerated environment. Seedling rice responds to a surplus of air by increasing root growth, while shoot growth is less stimulated. The sequence of events is,

- Sow rice into shallow flood;
- Drain field rapidly and completely, immediately after sowing up to two days after sowing;
- Maintain drained condition for 3 to 5 days, depending on temperature and growth of roots
- Reflood when radicle penetrates soil

It is very important this practice be used only where there are enough outlets for quick drainage and there is adequate water supply for quick reflooding. Furthermore, the field should be well leveled so that it will flood and drain quickly. If the field takes too long to drain and reflood, drought stress may kill some of the seedlings and result in a poor stand in portions of the field. Internal drains, either across the basins or around their circumference, help speed water removal and application. Timing of drainage relative to planting is also important. Waiting more than a day or two reduces the beneficial effects and may jeopardize weed control operations and timing.

Early season water management and weed control: Delayed Pinpoint Flood

While it may be desirable to maintain a 4-5" of water on the field early in the growing season to control weeds, some herbicides (particularly foliar herbicides) require lowering the water in the field to expose weeds and maximize herbicide contact with weeds. This is discussed in more detail in the weed control chapter. The main point for this chapter is that during the first month and a half of the growing season, water management is often driven by herbicide (and other pesticide) use. The usage of these chemicals affect water height in the field, when water is flowing into the field as well as imposing strict limits on when water is flowing out of fields due to water holding periods (discussed in more detail later). When possible, quick removal of water and replacement after spray application is desirable for good weed control. A prolonged drain period promotes weed growth and delayed reflooding may reduce herbicide efficacy.

Permanent flood, water depth effects

A permanent flood should be established as soon as possible after sowing. The sooner it is done, the more beneficial impact it will have on weed management. Once established, permanent flood is maintained throughout the rest of the season. Maintain a steady depth of 4″-5″ through maximum tillering and avoid taking water off the field.

The goal of the permanent flood is to maintain steady pressure on weeds and optimize rice growth. Rice growth response to various depths is demonstrated in Figure 6. Rice growing in shallow water (1-2″) begins tillering faster, and reaches a higher maximum tiller number earlier than rice growing in medium (4-5″) or deep water (7-8″). Rapid establishment of plant cover is the main reason many growers prefer shallow water early in the season. Ultimately, the final tiller number is similar at all depths within this range because excess tillers developed in shallow water die off to a level that the plant can support. Leaf development and plant size (biomass) follow a trend similar to tillering. However, rice plants in deep water tend to be taller and mature earlier compared to rice growing in shallow water. Growth of rice in deep water suggests it is under stress which slows growth for the first half of the season, even though final growth parameters, except height and maturity, are similar at all three depths. Yield in field scale trials comparing different depths within the range of 2″ to 8″ was the same across all depths.

Most growers are reluctant to accept slower crop development and increased management required for deeper water and prefer lower water to ensure that plants perform at their optimum, particularly when environmental conditions are adverse. Some soils, such as alkaline and saline soils, are already stressful to the crop, and deep water is not advisable. In addition, levees holding deep water are more subject to wind damage. Use of some herbicides in deep water is also not advisable. However, some growers have found value in deeper water, 5-7″ through tillering, for better weed control where soil conditions permit it. One should avoid very shallow water, 1-3″, because weed control will be difficult.

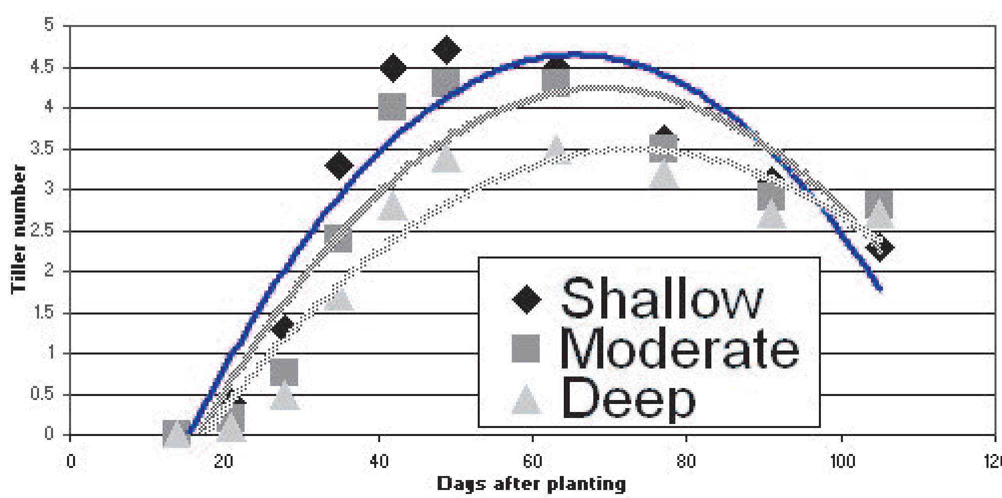


Figure 6. *Tillering of M-202 rice at three water depths held season long, 1986. (Williams et al. 1994)*

Blanking Protection

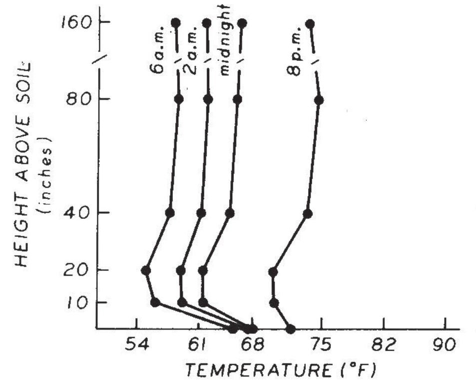


Figure 7. *Temperature profile of a rice canopy. Water depth is 6". From: Board and Peterson 1980.*

Blanking occurs when pollen is damaged by cool temperature (55-60°F, depends on variety). It is the major temperature related factor reducing yields in California. It is a potential problem in all areas of the valley but the problem increases as one moves south due to cooler night-time temperatures. Since rice florets are primarily self-fertilized, the loss of pollen is not usually replaced from other nearby florets, so a kernel does not develop. UC research in the early 1970's showed that the position of the panicle when it is sensitive to cool temperature is low in the stem, partially underwater. This is usually 10-14 days before the panicle emerges, and when the collars of the flag leaf and the penultimate leaf are aligned. The sensitive period lasts for about a week for any individual panicle, and for about three weeks for a field. As air cools during the night, the air temperature within the canopy also drops. However, the water resists change and its temperature takes longer to drop. The higher water temperature can provide a critical source of heat to protect the rice heads from cool temperature damage. The change in air and water temperature at different heights above the soil is shown in Figure 7. At 8 pm, the air and water temperature are similar, but by 6 am, there is a large difference. The amount of difference increases with depth of water and lower temperature. Growers can take advan- tage of this natural heater by increasing the water 7 to 21 days before heading. The water should be as deep as the levee system in the field will allow, but at least 8". This depth will partially cover the developing panicles and help protect them from the cooler air above. Since tillering is complete, water depth will not affect growth.

Pre-harvest Water Management

Preharvest drainage requires a com- promise between the conflicting needs of harvesting equipment and crop ripening, although certain risk factors can be identified to guide the process. As with many other management practices, the grower's task is to optimize drain timing.

Typically, water is removed two to four weeks before anticipated harvest date. Heavy harvesting equipment requires a firm soil so it won't cause deep ruts and/or get stuck in mud. Mud during harvest not only decreases efficiency, it may cause serious damage to valuable equipment and rut the field. The exact timing, to ensure a firm soil, depends on,

- surface drainage-accurately leveled fields drain more completely than those with low spots;
- internal drainage of the soil-soils with deep profiles usually drain quicker although soils with very high clay, such as Willows clay, are slow to drain;
- physiological activity of the rice-plants that remain greener will use more moisture than senescent plants; Quadris sprayed fields tend to hang on longer and affect drain time;
- and climate during the drain period--high temperatures and north wind increase evapotranspiration.

Integrating these factors is more art than science and there is no substitute for experience with a particular field. In the end, you want a firm, but not dry, soil surface on which to run harvest equipment. In recent years, many growers have switched from half track and full track equipment to rubber tires, increasing the importance of a firm soil at harvest.

As important as making sure the ground is dry enough to support equipment is to make sure it is moist enough to finish the crop. Premature drainage will impede ripening and result in more chalk and light kernels. In addition, research has shown that milling quality is improved if the water is left on longer, including up to the time of har- vest! Since harvesting in the water is not a practical option, the grower has to decide when to drain to optimize ripening. Rice does not ripen uniformly, especially in different parts of the field, so assessing the entire field is important. The same factors that govern how fast the soil drains pertain to the moisture supply for ripening. Some rough guidelines for determining when the crop is sufficiently ripe to tolerate drainage are,

- grains have filled from the top to the bottom of the panicle;
- color has changed from green to golden;
- tip kernels have become hard;
- lower kernels will have soft dough but not milk.

Water Stress

Drought stress sometimes occurs when a pump shuts off or on the high side of a poorly leveled field. Some organic growers also use mid-season drainage for weed control which induces drought. Rice grows well under flooded conditions and most varieties that have been breed for flooded conditions are not very tolerant of water stress and yields will be reduced when subjected to water stress. That said, a number of recent studies on-farm and at the RES (specifically to look at effects of drying a field briefly to lower arsenic uptake and reduce methane emissions) have demonstrated that yields are not reduced when soil water content is lowered below saturation between 45 and 55 days (just before PI) after sowing. In these cases, water has been off the surface of the soil for up to eight days.

Signs of water stress include leaf-rolling, leaf-scorching, impaired tillering, stunting, delayed flowering, spikelet sterility, and incomplete grain filling (Yoshida 1981). Drought avoidance is important during expansive growth beginning in the early vegetative stage, the degree of injury from which is related to the intensity and duration of the water deficit (Hsiao 1982). However, if not severe, addition of water usually leads to complete recovery. The most drought sensitive growth stage is floral development, starting with microsporogenesis through heading (Boyer and McPherson 1976). Drought stress during this stage leads to blanking and the crop cannot recover from it. During ripening, premature removal of water may lead to incompletely filled kernels and lower test weight.

Managing Salinity

Rice is particularly sensitive to salinity during the seedling and pollination stages. While most irrigation water used on rice in California has low salt (<0.7 dS/m), some water sources that include drain and well water can go much higher (Scardaci et al. 2002). Sacramento River wa-

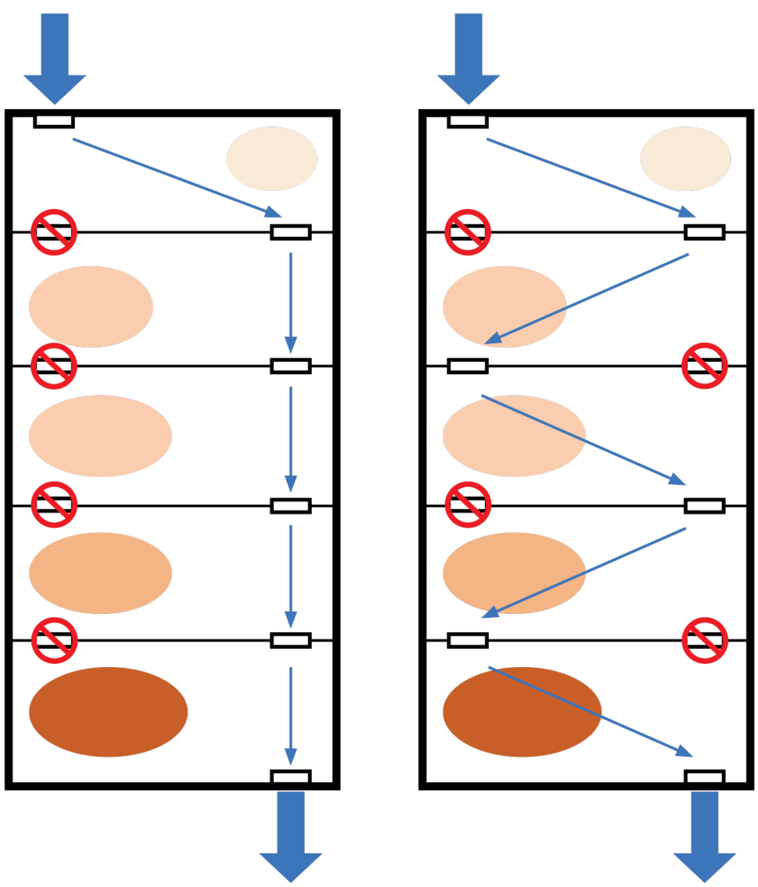


Figure 8. *In the diagram above, the left shows a field with water running down one side of the field and how flood water salinity is concentrated on one side of the field (darker colors indicate higher salinity). By changing the water flow path in this field (shown on right) the water flow path is forced through the high salinity areas and helps flush them out.*

ter is low in salt being between 0.13 and 0.37 dS/m.

The type of irrigation system and pattern of flow also affects salinity. In static and conventional systems, salinity increased with distance from the inlet and in areas where water stagnates (Figure 8). Water with much lower salinity will result in higher salinity as salt accumulates and moves through the field so that lower basins typically have higher salinity, which peaks during holding periods. Yield reductions were associated with salinity of >0.9 dS/m .

Below are some steps to consider in order to control salinity.

- **Irrigation water should have an EC below 0.6 dS/m** – For an averaged sized field this will help ensure that the field water salinity does not increase beyond the 0.9 dS/m yield threshold at the bottom of a field.

- **Change water flow path** – Salinity builds-up in stagnant parts of the field. Changing water flow path will reduce salinity hot spots from developing (Figure 8).

- **Early in the season when salinity is highest, allow for spillage and maintain higher water levels** – This may not be possible in drought years or with certain herbicide programs.

- **Smaller fields and multiple side inlets** – The distance water travels in a field largely determines the build-up of water salinity. Larger fields will have greater water salinity build-up in the bottom of the field. Smaller fields and multiple inlets should be considered in fields with saline soil or receiving irrigation water high in salinity.

- **Herbicide selection** - Growers using saline water should avoid using herbicides that require long term holding so they can flush the field during the early part of the season.

Maintaining Water Quality

How one manages water not only impacts the growth of rice but also water quality. Since rice tailwater ultimately flows back to public waterways, growers must maintain its quality by using appropriate practices. Chapter 11 on water quality discusses these issues.

References:

1. Scardaci, S.C., Shannon, M.C., Grattan, S.R., Eke, A.U., Roberts, S.R., Goldman-Smith, S., Hill, J.E., 2002. Water Management Practices Can Affect Salinity in Rice Fields. Calif. Agric. 56, 184-88.

Fertility and Crop Nutrition

Introduction

When considering profitable agriculture from a practical perspective, the factors affecting plant growth and harvestable productivity are of the utmost importance. A myriad of factors, such as genetics, environment, and irrigation management, impact yields independently and through interactions. Knowledge of these factors, the interactions, and how to manipulate them make it possible for the farm operation to maximize the return. Of course, all are not under the control of the grower. However, crop nutrition and soil fertility can be managed for good yields and production efficiency.

There are 17 elements that are essential to the growth of plants in general. Not all are required for all plants. Carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur are the elements required for proteins and cell walls. The other thirteen elements include calcium, magnesium, potassium, iron, manganese, molybdenum, copper, boron, zinc, chlorine, and silicon. A few plants require sodium, cobalt, and vanadium. Among the essential nutrients, nitrogen, phosphorus, potassium, zinc, and to a lesser extent sulfur and iron are the nutrients of concern in the California rice cropping system. The behavior of these elements and their management is somewhat unique in rice as compared to other cropping systems because of the anaerobic soil conditions due to flooding.

The major characteristic of a submerged soil is the depletion of oxygen (O_2). Microorganisms deplete the free O_2 throughout most of the root zone within a few days of flooding.

Soil under rice cultivation

The major characteristic of a submerged soil is the depletion of oxygen (O_2). Microorganisms deplete the free O_2 throughout most of the root zone within a few days of flooding. The water contains dissolved O_2, which can diffuse a short distance into the soil. The deeper the water, the less O_2 can move from the air to the soil. The thickness of the oxidized layer at the soil/water interface ranges up to about 1 inch thick depend- ing on the microbial activity. For example, in a soil with a large supply of decomposable organic matter (i.e. incorporated straw) the oxidized layer is very thin. Once the soil O_2 supply becomes depleted, the soil bacteria are forced to extract O_2 from other compounds. These compounds in the order of utilization are nitrate, manganese oxide, iron hydroxide, and sulfate-sulfur. Once this pool of compounds is exhausted, the soil bacteria will use the energy stored in organic compounds by fermenting organic matter to carbon dioxide and methane. Another unique property of flooded soil is that upon flooding the soil, pH regardless of the starting pH approaches neutrality (pH 6.5 to 7.5). This occurs in about two weeks. As a result, the chemistry of an anaerobic soil alters the level and forms of some plant nutrients and results in the production of compounds which are sometimes toxic to rice.

Approaches to nutrient management

The goal in nutrient management is to match nutrient supply with crop requirements and to minimize nutrient losses from fields. Properly managed fertilizers support cropping systems that provide economic, social and environmental benefits. On the other hand, poorly managed nutrient applications can decrease profitability and increase nutrient losses, potentially degrading water and air quality.

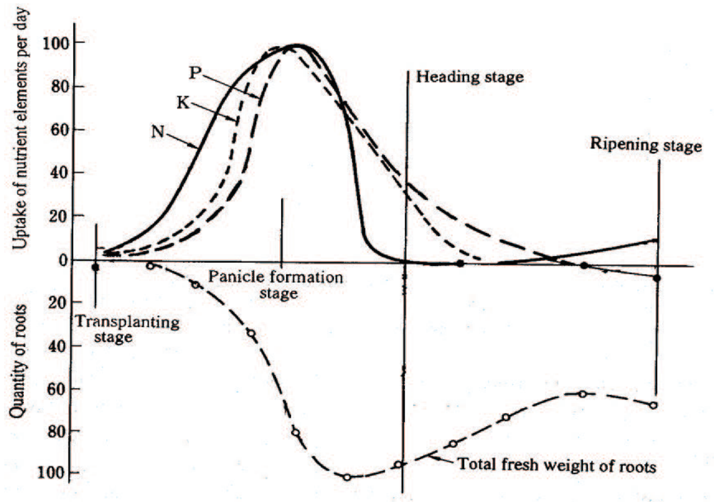


Figure 1. Seasonal uptake rate of selected nutrients and rootgrowth by a rice plant.

The 4R approach is one that offers enhanced environmental protection, increased production, increased farmer profitability, and improved sustainability. The concept is to use the **right fertilizer source**, at the **right rate**, at the **right time**, with the **right placement**.

In order to implement the 4R approach it is necessary to understand some fundamentals about when the crop needs nutrients and how much it needs. In general, maximum nutrient uptake occurs from tillering and goes through to the onset of the reproductive stage (Fig. 1). The peak nutrient uptake rate coincides with the maximum root biomass accumulation. As the grain ripens nutrients and carbohydrates are transported from the vegetative parts of the plant into the panicle. Therefore, the critical time frame for careful nutrient management is between planting and panicle initiation. In the case of some specialty varieties, there may some fertility management decisions based on grain quality that would justify later applications of nitrogen.

The plant gets nutrients from the soil, irrigation water and atmospheric deposition. What is not provided from these sources needs to be made up from other nutrient inputs (fertilizer, manure, cover crops, etc). Nutrients have different roles within the plant and thus are needed in different quantities by the plant. Of the three main nutrients that are typically applied the rice plant demands similar amounts of N and K (33-34 lb N or K / ton) and less of P (6 lb P/ ton grain yield) (Table 1). To put this in fertilizer equivalents where P is expressed as P_2O_5 and K as K_2O the crop takes up 14 lb P_2O_5/ ton and 40 lb K_2O/ ton grain yield (Table 1).

Soil and tissue sampling

Nutrient deficiencies can be determined from both soil and tissue tests. Soil samples are usually taken before planting and before any fertilizers have been applied. Soil samples are useful in that you may be able to determine deficiencies before the season and take corrective measures. Tissue samples are taken during the season. The exact tissue (usually leaf

Table 1. *Concentration and uptake of N, P and K in rice at time of harvest. (Data com- piled from Do- bermann and Fairhurst, 2000)*

Plant part	Nitrogen	Phosphorus	Potassium
	lb nutrient/ton grain yield		
	N	P	K
Grain	21.2	4.2	5.4
Straw	12.6	2.0	27.8
Grain+Straw	33.8	6.2	33.2
	lb nutrient/ton grain yield (in fertilizer equivalents)1		
		P_2O_5	K_2O
Grain		9.6	6.5
Straw		4.6	33.4
Grain+Straw		14.2	39.8
	Concentration of nutrients		
	%N	%P	%K
Grain	1.06	0.21	0.27
Straw	0.63	0.10	1.39
1 - $\%P_2O_5$ = %P x 2.29; $\%K_2O$ = %K x 1.2			

or whole plant) and time of sampling will vary depending on nutrient of interest. While such tests can be helpful, lab results will often come back too late to be able to correct the deficiency in the current season. However, they do provide valuable information for the following season. Leaf color charts of chlorophyll meters are able to provide instant readings of leaf "greenness" and are a good indicator of N deficiencies (discussed in Nitrogen section).

For soil samples using a soil auger or shovel (shovel is best in tilled field) to a depth of 6 inches (roughly the plow layer). Take about 20 samples in a 20 to 40 acre field by walking randomly through the field (Fig. 2). Be sure to collect samples from all quadrants of the field to achieve a representative sample. Mix the soil sample in a non-metallic container and let the soil air dry. Transfer the mixed sample into a labeled paper or plastic bag, and send to a qualified laboratory for analysis. Sample prob- lem areas separately every year and non-prob- lem areas every two to three years.

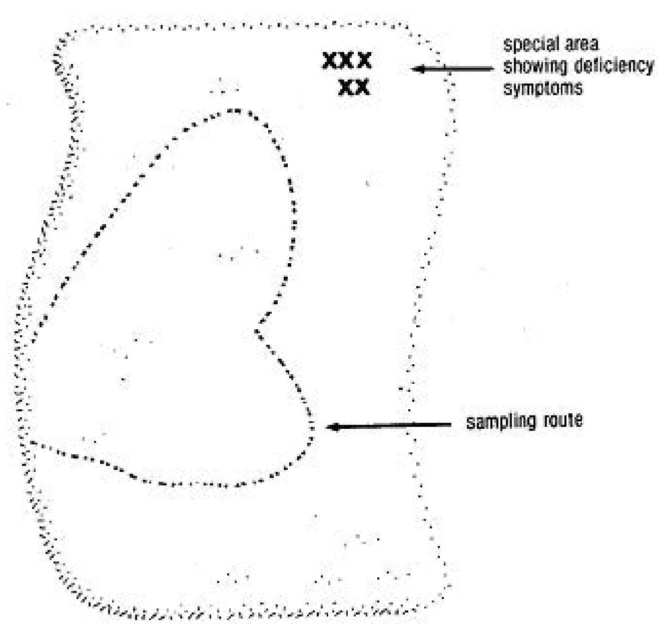


Figure 2. Sampling pattern for taking soil or leaf samples to test for nutrient deficiencies.

Nitrogen

Plant function

Nitrogen is an essential part of all amino acids, proteins, enzymes, chlorophyll molecules, and nucleotides (e.g. DNA). Because nitrogen is present in so many essential compounds even slight deficiencies can result in reduced growth and productivity.

Deficiency symptoms

Nitrogen deficiency is the most common nutrient deficiency in rice. Older leaves (and sometime all leaves) are light green (or even yellow) and may be chlorotic at the tip. Under severe N stress older leaves will die and young leaves will be narrow, short and yellowish green. Visually, N deficiencies can look like S deficiencies (which are not very common); however in an S deficiency all leaves turn light green/yellow.

Nitrogen cycle/soil nitrogen

The diagram (Fig. 3) depicts the major pathways, transformations, and chemical species in nitrogen cycling. Thickness of the arrow depicts relative abundance. Nitrogen can be lost from the soil thereby reducing the efficiency of fertilizer applications because of these conversions. Nitrogen losses in the soil occur mainly from denitrification, ammonia volatilization, leaching, and surface runoff. Of these, ammonia volatilization and dentrification are the main N loss pathways. Additionally, immobilization and ammonium fixation make nitrogen temporarily unavailable to the rice crop. Nitrogen conversion processes are defined in Table 2.

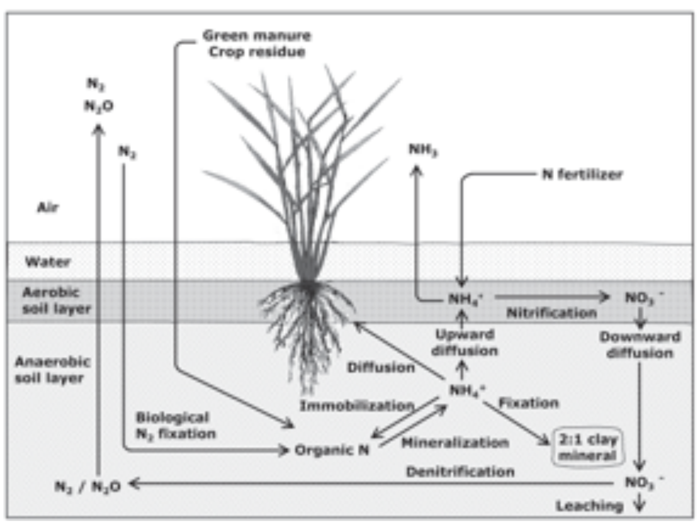


Figure 3. The nitrogen cycle in rice systems (Source: Food & Fertilizer Technology Center)

Denitrification of nitrogen fertilizer and subsequent loss as nitrogen gas, can result in high losse s of the applied nitrogen, particularly when applied in a nitrate form (nitrate fertilizers should not be applied to rice systems) or when there has been significant nitrification of N fertilizers

Table 2. *Definition of terms describing major processes in the nitrogren cycle.*

Nitrogen fixation	The process by which atmospheric nitrogen is converted to biologically usable forms of nitrogen by microorganisms.
Mineralization	The breakdown of organic matter resulting in the release of ammonium (NH_4) and other nutrients which can be used by plants.
Nitrification	The conversion of ammonium (NH_4) to nitrate (NO_3).
Denitrification	The conversion of nitrate (NO_3) to nitrogen gas (N_2), resulting in a loss of plant available N.
Immobilization	The assimilation (tying up) of inorganic N (NH_4 and NO_3) by microorganisms resulting in the nitrogen being unavailable for plant uptake.
Ammonia volatilization	The loss of ammonia gas to the atmosphere, following the conversion of ammonium (NH_4) to ammonia (NH_3).

(aqua ammonia, urea or ammonium sulfate). The conversion occurs in the anaerobic zone of the soil. Manageable factors contributing to denitrification include wet/dry cycles and fertilizer management. Severe nitrogen losses occur in soils subjected to alternate draining (aerobic) and flooding (anaerobic) which occur after N fertilizer has been applied. Lowering water following planting for a short time period to ensure good crop establishment (Leather's Method) does not lead to significant denitrification losses provided the soils a reflooded relatively quickly.

Another important mechanism of nitrogen loss is the volatilization of ammonium formed as a result of mineralization. Among the factors affecting the process are moisture content, pH, cation exchange capacity, lime content, temperature, flood depth, and the type of fertilizer. Again maintaining a constant flood is one method by which growers can minimize the loss. Surface applied urea volatilizes more readily than incorporated aqua-ammonia. Regardless of the form, however, the longer the time between application and the establishment of the permanent flood the greater the loss.

Another critical process of particular relevance to California is immobi- lization. The incorporation of straw (carbon) stimulates microbial activity. Consequently, nitrogen becomes unavailable for plant uptake because the nitrogen is incorporated into the microbial biomass.

Determining a deficiency

Standard soil tests are not reliable for determining the amount of nitrogen available for a rice crop. The dynamic nature of the various forms of nitrogen in a flooded soil makes it difficult to sample and analyze the soil in a condition that is representative of actual growing conditions. For example if sampled in a dry aerobic state, nitrate-nitrogen may be the dominant form available to the plant, but once flooded the soil becomes anaerobic, nitrate-nitrogen is lost via denitrification.

Latter in the season leaf tissue tests, leaf color charts, or chlorophyll meters may be used to identify deficiencies. These will be discussed later.

4R Management

—Right rate—

Despite the fact that N is required in greater quantities than any other nutrient and is usually the most expensive nutrient input, there are no good soil tests to determine the correct nutrient rate to use in rice systems. Therefore, many growers use historical experience to decide on their N rate. However, with changing practices over time (i.e. straw management, fertilizer N management, water management, and varieties) the optimal N rate can change. With the increased use of yield monitors, an effective way to identify the correct N rate for a particular field is to do test strips using different N rates. To do this we recommend

1. Identifying a representative field and check.
2. Within a check apply a test strip (full length of field) at an N rate of 25 lb N/ac above and below the N rate being applied to the rest of the field using aqua rig (Fig. 4).
   a. the aqua rig used to apply the N strips needs to be at least as wide as the combine header. If not apply two strips of each N rate. After applying N to test strips flag each strip.
   b. test strips should not be directly adjacent to the levee.
3. Monitor strips throughout the season.
4. At harvest, using a yield monitor, determine the yield from each test strip. Make sure to adjust for moisture since higher N rates are likely to be slightly delayed in maturity.
5. Comparing yields from test strips will let you know if you under or over applied.
6. By doing this over different fields and years (along with keeping good records), growers can confidently make adjustments to their N rate.

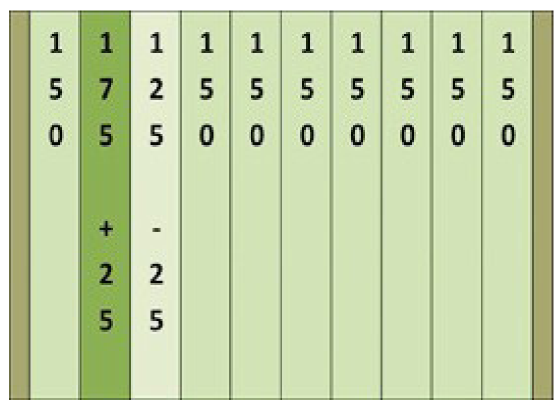


Figure 4. Example of a field with test strips of different N rates

—Right source—

There are a number of N-fertilizer choices available for rice growers. However, N sources containing nitrate-N should not be used due to potential for high N loss. The N source applied in largest quantities to water-seeded rice systems is aqua-ammonia or "aqua". Aqua contains 20% N. Other common N sources used in California rice systems are urea (45-46% N), ammonium sulfate (21% N) and various starter blends starters which are usually blended from ammonium phosphates and ammonium sulfate.

Growers typically apply the majority of their N rate as aqua (60-75%) and apply the rest of the N rate in the starter blend and sometimes as a topdress later in the season. The rational for applying starter N is to provide young emerging seedlings with a readily available N until the rice roots grow into the aqua that is injected 3-4" below the soil sur- face. On-farm research address- ing the need for starter N shows that starter N is not necessary. In fact, at equivalent N rates higher yields and N uptake were achieved when all of the N was applied as aqua (Fig. 5). The reason for this is that the N injected below the soil surface is better protected from both ammonia volatilization and denitrification losses.

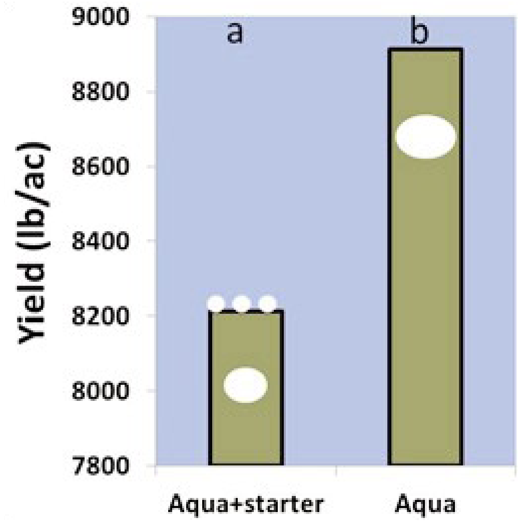


Figure 5. Effect of N source and placement on yields. The N rate shown here is 100 lb N/ac and the date represent the average response across 7 different fields.

While applying starter did increase plant size early in the season in some of the trials, this never translated into increased yields at the end of the season. Results of this research suggest that overall N rates to achieve optimal yields could be reduced by 10 lb/ac if all the N was applied as aqua.

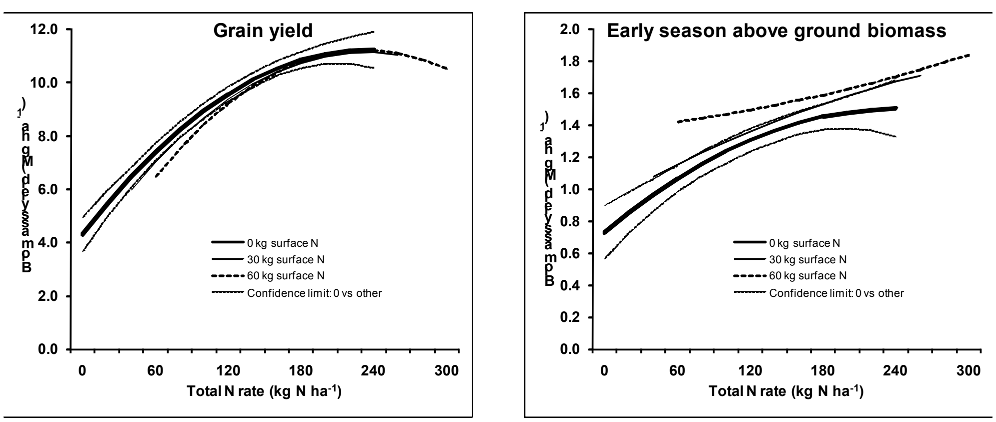


Figure 6. CaThe effect of early season N placement on early season biomass (about 35 days after sowing) and yield. Shows that at same total N rates, applying the effect of applying 30 or 60 kg N/ha (34 and 78 lb N/ac) as a surface applied starter increases early sason biomass but has no effect on yield potential; while at the lower N rates, yields are reduced. Note: lb/ac = Mg/ha * 890.

While starter N may not be necessary, P fertilizer is often required and P is usually only available as ammonium phosphates (i.e. a fertilizer that contains N). Thus, applying P fertilizer usually requires that some N fertilizer is also applied. Applying P is usually applied as a starter fertilizer before planting. Therefore, if a starter fertilizer is necessary (due to need for P), we recommend using a starter blend with the lowest amount of N possible. The N in the starter should be considered as part of the total N rate.

If a top dress is necessary, ammonium sulfate is often used as it has a lower N content and is easier to apply uniformly by air. However, urea could also be used and is generally a cheaper source of N.

—Right time—

Numerous research trials have shown that the most efficient time to apply N to water seeded rice systems is to apply it all before planting. These trials have shown no benefit to splitting the N rate between planting and a topdress application. In drill seeded systems or when water is drained from the field for an extended period of time it may be necessary to apply fertilizer at different times. We have found no benefit to planning a topdress application of nitrogen.

Figure6. The UC leaf color chart determines leaf nitrogen based on leaf color

All the nitrogen should be applied before planting. However, there may be cases where a topdress is necessary. For example, if the growing season is particularly favorable resulting in greater growth and yield potential, or an unplanned water drainage event may necessitate a topdress due to N losses associated with draining the field. Topdress N fertilizer should be applied around PI.

In these cases a decision on whether or not to topdress can be made with a leaf color chart, chlorophyll meter or Green Seeker.

Chlorophyll Meter (SPAD meter). The meter is a hand held device that estimates leaf nitrogen based on leaf color and transmitted light. The meter is quick. However, the meter displays numbers which are not directly related to leaf nitrogen. Consequently, considerable effort is required to establish a calibration curve. Moreover, leaf thickness can influence the readings because the chlorophyll meter relies on transmitted light. Thus, a single curve may not accurately describe leaf nitrogen for all varieties. Table 3 presents the relationship between the SPAD meter reading and leaf N (%) at panicle initiation for ten rice varieties. It is based on currently available information which does not include newer varieties such as M-206. In this case, M-202 calibration would provide a reasonable estimation of leaf N for M-206. Using the %N value from Table 3, one can determine if crop N is sufficient using Table 4.

Table 3. *Leaf N content (%) at panicle initiation of select rice varieties and the corre- sponding chlorophyll meter (SPAD, Minolta) readings*

% Nitrogen at Panicle Initiation										
SPAD	S-102	Cal-hikari	M-202	M-204	M-205	L-204	L-205	Calmati	Akita	Koshi
25	2.3	2.6	2.4	2.4	2.5	2.4	2.2	2.2	1.8	1.8
26	2.4	2.7	2.5	2.5	2.7	2.5	2.4	2.4	1.9	1.9
27	2.5	2.8	2.6	2.7	2.8	2.6	2.5	2.5	2.0	2.0
28	2.6	2.9	2.8	2.8	2.9	2.8	2.6	2.7	2.1	2.1
29	2.7	3.0	2.9	2.9	3.1	2.9	2.8	2.8	2.2	2.2
30	2.8	3.1	3.0	3.0	3.2	3.0	2.9	3.0	2.3	2.3
31	2.9	3.3	3.2	3.1	3.3	3.2	3.0	3.1	2.4	2.4
32	3.0	3.4	3.3	3.2	3.5	3.3	3.2	3.3	2.5	2.5
33	3.1	3.5	3.4	3.4	3.6	3.4	3.3	3.5	2.6	2.6
34	3.2	3.6	3.5	3.5	3.7	3.5	3.4	3.6	2.7	2.7
35	3.3	3.7	3.7	3.6	3.8	3.7	3.6	3.8	2.8	2.8
36	3.4	3.8	3.8	3.7	4.0	3.8	3.7	3.9	2.9	2.9
37	3.5	4.0	3.9	3.8	4.1	3.9	3.9	4.1	3.0	3.0
38	3.6	4.1	4.1	3.9	4.2	4.1	4.0	4.2	3.1	3.1
39	3.7	4.2	4.2	4.1	4.4	4.2	4.1	4.4	3.2	3.2
40	3.8	4.3	4.3	4.2	4.5	4.3	4.3	4.6	3.3	3.3
41	3.9	4.4	4.5	4.3	4.6	4.5	4.4	4.7	3.3	3.4
42	4.0	4.5	4.6	4.4	4.8	4.6	4.5	4.9	3.4	3.5
43	4.1	4.6	4.7	4.5	4.9	4.7	4.7	5.0	3.5	3.6
44	4.2	4.8	4.9	4.6	5.0	4.8	4.8	5.2	3.6	3.7
45	4.3	4.9	5.0	4.8	5.1	5.0	4.9	5.3	3.7	3.7

Leaf color chart: The UC leaf color chart is a series of color panels against which leaves are compared (Fig. 7). With some practice, leaf nitrogen can be predicted with a high degree of accuracy using the LCC. Furthermore, it does not take a lot of practice to get good results. On the back of the chart there is table relating panel color to leaf nitrogen. Refer to Table 4 to determine if the leaf N concentration is adequate.

Table 4. *Interpretive guide for leaf nitrogen percentage. Total leaf N concentrations are for California short, medium and long grain varieties.*

Plant growth stage	*Critical*	*Adequate*
mid-tillering	4.0	4.0 - 4.6
maximum tillering	3.6	3.6 - 4.2
panicle initiation	3.2	3.2 - 3.6
flag leaf	2.8	2.8 - 3.2

Green Seeker. The Green Seeker is a new tool that we have been testing for this purpose. It measures the NDVI (Normalized Difference Vegetation Index) of the canopy. Based on preliminary data, we have developed a response index to help growers decide when a top-dress N application is necessary. We have found that an index of 1.1 or greater indicates the need for top-dress N application. The response index is the NDVI reading of an enriched N strip (representing a crop with unlimited N) divided by the NDVI reading from the field test area. The N enriched strip is an area where extra N was added to the field (could be done by overlapping an area with an aqua rig). For example if the N enriched strip gave an NDVI value of 78 and the field test area gave an NDVI value of 68, the response index would be 1.14 (78/68=1.15) and this would indicate the need for a top-dress N application. Further research is being done on the use of drones to capture similar NDVI measurements, which would allow growers to access a larger portion of the field more rapidly.

We would like to emphasize that this is based on preliminary data and further testing may change the response index. However, for now it does provide a useful guide. Some limitations to the Green Seeker are that it is still relatively limited in area that can be tested; although it is much faster to take readings and therefore get a better assessment of the field. You can also not use the Green Seeker when leaves have dew or rainfall on them. The Green Seeker also does not work well where there is poor stand establishment or a high amount of weeds.

—Right place—

In water-seeded rice systems, the objective needs to be to get as much of the fertilizer N as possible below the soil surface. In a flooded system the top 0.5″ of soil is oxidized and fertilizer N in this area can be nitrified which can then lead to N losses via denitrification. Many stud- ies both in California and in other parts of the world have shown that N placed deep into the soil results in greater N use efficiency.

Given that the majority of N applied to water-seeded rice systems is aqua-ammonia the issue of fertilizer placement is not so relevant as aqua is always injected into the soil. The main issue then becomes how deep should aqua be injected. This has not been a topic of research; however most growers apply aqua at 3-4 inches deed which is adequate to get good soil coverage following application. N applied at this depth will ensure that the fertilizer is in the zone of soil that is reduced following flooding which will help minimize N losses. At this time there does not seem to be a good rational for placing the aqua any deeper than the 3-4 inches currently being practiced.

Starter and topdress fertilizers are usually applied to the surface. To redcue N losses from N in the starter fertilizer, growers should seek to limit the amount of N in the starter blend by using a blend containing the lowest amount of N possible. Also, lightly harrowing fertilizer into the soil can help prevent N losses. For the topdress N, this N is usually applied later in the season (i.e. between maximum tillering and panicle initiation) when the crop is growing rapidly and the demand for N is high. Therefore, much of the N is taken up by the crop rapidly after application which helps to minimize losses.

Effect of straw management on N management

California rice growers annually incorporate about 8000 lb/ac of straw across most of the Sacramento Valley. This straw contains approximately 50 lb of N (Table 1). This large introduction of organic matter influences the immobiliza- tion-mineralization dynamics and consequently nitrogen fertility management. Straw incorporation results in more nitrogen in the soil microbial biomass. Since microbial biomass is a prime source of available nitrogen for the crop, straw incorporation can lead to an increase in crop available soil nitrogen. Depending on how straw is managed it can lead to either an increase or decrease in the amount of N applied.

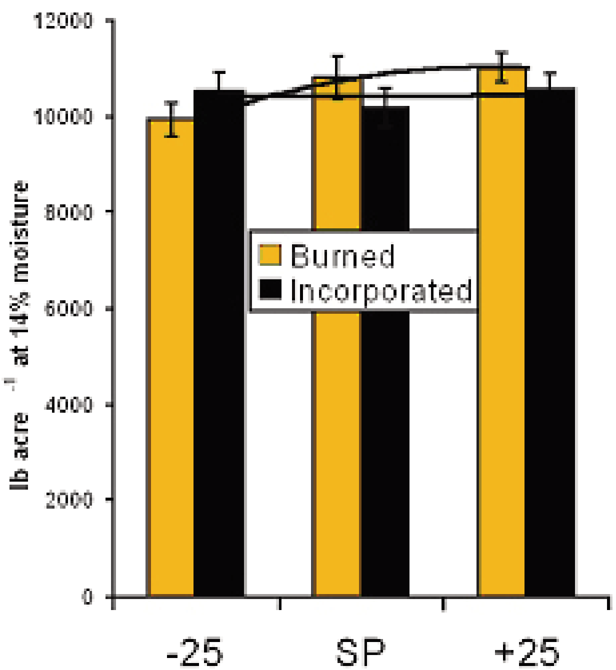


Figure 7. *Yield of burned and straw incorporated/flooded fields when fertilized at the standard grower practice (SP) and plus of minus 25 lb N/acre averaged over three years.*

A number of studies have shown that the overall N rate applied to rice can be reduced by about 25 lb N/ac when rice straw is incorporated in the fall and the field is winter flooded. An example of this is shown in Figure 7 where burned and incorporated fields were compared. In fields where the straw was burned the standard grower N rate provided optimal yields and lower yields when the N rate was reduced by 25 lb N/ac. In contrast, where the rice straw was incorporated, the N rate could be reduced by 25 lb N/ac without a yield reduction.

Importantly, this N benefit from straw incorporation is

1 Typically observed only after about three years of implementing this practice.

2 Is only observed when the straw is incorporated and flooded (or the soil remains moist) during the winter. If the straw is left standing or on the soil surface during the winter and only incorporated during the spring land preparation the rice straw can

lead to N immobilization (Table 2) at the start of the season resulting in reduced growth, yellow plants and reduced yields. If straw is managed in this fashion, it will most likely be necessary to apply additional N fertilizer to overcome early season N immobilization.

Effect of variety

There is very little difference in the overall N fertilization requirement and strategy for California's major short and medium grain conventional varieties. This is shown clearly in Table 5 where the N rate required for maximum yields was the same (in this case 150 lb N/ac) for all varieties over two sites.

Table 5. *Yield response (@ 14% MC) of selected varieties variable rates of pre- plant nitrogen in Sutter County (top) and Butte County (bottom).*

N Rate	S-102	M-104	M-202	M-205	M-206	M-402	Mean
0	3723	3878	3745	4350	3789	4074	3927
50	5902	5707	5932	5886	6182	6775	6064
100	7306	6978	6794	8181	7755	7690	7451
150	8527	7972	7791	8743	8528	8523	8347
200	7317	7709	7114	8613	8175	7820	7791
Mean	6555	6449	6275	7155	6886	6977	6716

N Rate	S-102	M-104	M-202	M-205	M-206	M-402	Mean
0	4137	3880	4479	4254	4754	4241	4291
50	6776	6428	7358	6993	7461	6863	6980
100	9568	9269	9770	9641	9936	9190	9562
150	9766	9753	10644	10181	10788	10292	10238
200	8515	8175	8538	8748	8894	8552	8570
Mean	7752	7501	8158	7963	8367	7828	7928

Nitrogen management practices do vary signifi- cantly for specialty rice varieties. Many of these specialty rice varieties are lower yielding and highly susceptible to lodging and thus require lower N rates. Furthermore, grain quality characteristics can be affected by N management. Research and grower experience demonstrated that yield and grain quality characteristics in specialty varieties benefit from split applications of nitrogen. For example, the yields of Akitakomachi responded favorably to split applica tions of nitrogen. A preplant/panicle initiation (PI) split of 40-40 lb/a nitrogen produced the highest yields across all locations (Table 6). Furthermore, gains in grain quality were associated with desirable changes in physicochemical properties and improved agronomics, such as reduced lodging. Lodging causes uneven ripening which results in a greater spread in individual kernel moisture contents. In a sample of rice with an average moisture content of 23%, it is possible for individual kernel moisture to range from 16 to 34%. Reduced lodging does not guarantee complete uniformity of ripening because plant genetics are a factor. However, good nitrogen management minimizes the moisture content range. Lodging also contributes to the development of off-odors which degrades quality, particularly for the north-eastern Asia market.

Table 6. *Yield response of Akitakomachi to different preplant and topdressing rates of nitrogen at three locations in the Sacramento Valley.*

Treatment	Pleasant Grove lb/a	Colusa lb/a	Richvale lb/a	Average lb/a
0	4916	4270	4892	4693
60 - 0 - 0	5511	6045	5623	5727
80 - 0 - 0	5307	5442	5358	5369
40 - 40 - 0	5806	6268	5943	6006
100 - 0 - 0	4901	4956	4742	4860
50 - 50 - 0	5941	5890	5297	5709

Phosphorus

Plant function

The major roles of phosphorus in plants are energy storage, transport of metabolites, and cell membrane integrity. Adequate levels in the plant promote tillering, root development, flowering, and ripening. It is particularly important during the early stages of growth. Similar to potassi- um, the uptake rate of phosphorus peaks at the early reproductive stage (Fig. 1). If an adequate soil supply was available during vegetative growth, enough will have been taken up to supply the plant requirements for grain production.

Deficiency symptoms

Phosphorus deficient plants are stunted with reduced tillering. Leaves are narrow, dark green, short, and erect. Overall plant height is compromised. Red or purple colors may develop on the older leaves, which eventually turn brown. Phosphorus deficiency also contributes to delayed maturity, unfilled grains, and reduced response to nitrogen application.

Soil phosphorus

Most soils have very high amounts of total phosphorus; however only a very small portion of this is available for plant uptake during a typical growing season. The transformation processes of phosphorus in flooded soils are quite different from those in non-flooded soils. Flooded soils exhibit a greater capacity to supply plant available phosphorus than non-flooded soils. Crops grown on flooded soils may not show a response to phosphorus applications, while crops grown on the same soil under aerobic conditions may exhibit deficiencies.

Determining a deficiency

In a study evaluating rice yield response to P fertilizer in roughly 60 California rice fields, less than 10% of the soils were deficient based on whether or not grain yields responded significantly to added fertilizer P. There are a number of ways to identify P deficiencies, each with its own benefits and setbacks as discussed at the start of this section. These tests provide a general indication of a deficiency and the use of more than one can provide a better indication.

Soil test

A number of soil tests are available; however for rice soils the Olsen-P test (also called the sodium bicarbonate test) has been shown to be best at identifying a deficiency. The Bray test has also been evaluated and is a poor indicator of P deficiency on rice soils. The Olsen-P test is also the most widely used soil test for rice soils around the world. The critical Olsen-P value is 6 ppm and this has been confirmed in California rice fields.

Leaf tissue tests

Leaf tissue tests taken at 35 days after planting (around maximum tillering) can also be useful in predicting a P deficiency. Y-leaf tissue concentrations of less than 0.2% suggests a deficiency.

Input-output budgets

A good idea of whether a soil is P deficient can be achieved by developing a P input-output budget. In terms of inputs almost all P that enters a rice field is from fertilizer (very little in irrigation water, rainfall, etc). Also, just about all outputs are the P that is removed in grain (yield) and straw (if it is removed from the field). Burning does not result in a significant loss of P. Also, very little to no P is lost via leaching or run-off. Therefore a simple budget can be developed using the following equation:

P balance = Inputs (lb/ac of P_2O_5 as fertilizer) – Outputs (lb/ac removed in grain and straw).

For best results determine the P balance using a 5-yr average of inputs and outputs over the previous 5 years. A negative balance indicates that more P is being removed from the soil than is being added and thus it could be deficient. This will be discussed later when we discuss the correct rate.

As shown in Figure 8, the P budget reflects soil P (Olsen-P) status. As the P budget becomes more negative, the soil becomes increasingly P deficient. It is also apparent that where there were significant yield responses to P fertilizer were usually were P balance was negative and Olsen-P values were low. A useful online tool that does these calculations for you can be found at www.rice.ucanr.edu/P_budget_calculator/

4R Management

—*Right rate*—

Before determining the appropriate P rate, it is first necesary to determine if it is even necessary to apply P fertilizer. This can be best determined using the Olsen-P value and the soil P balance. **Apply no P** when there is both high soil P and a positive P balance (yellow circle in Fig. 9).

Apply maintenance P rates when soil P values are between 6 and 20 ppm (green circle in Fig. 9). Maintenance rates can be determined from Table 7 depending on whether or not rice straw is being removed.

Build-up soil P when soil P is less than 6 and there is a negative P balance (red circle in Fig. 9). P build-up rates rates can be determined from Table 7 depending on whether or not rice straw is being removed. To build up P one would need to add more than the maintenance rate.

—*Right source*—

While there are many different P fertilizers, most P fertilizers using in CA rice systems are some form of ammonium phosphate (contains both N and P). In order to meet our N management objectives of applying as much N as possible in aqua form, the P fertilizer with the lowest N content should be chosen.

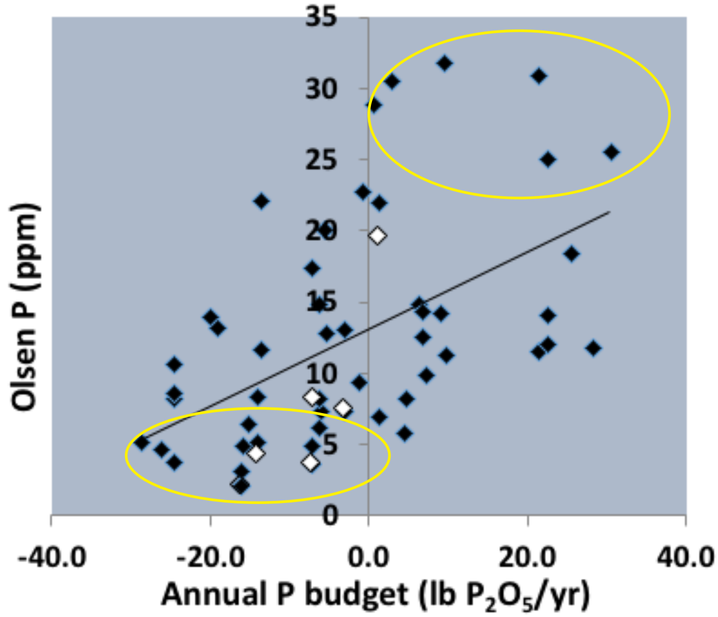


Figure 8. *The relationship between soil Olsen-P values, P balance and yield response to P fertilizer. Data are from on-farm studies and the P balance reflects the 5 yr average of inputs and outputs. The open diamonds indicate a study in which there was a significant yield response to add P fertilizer.*

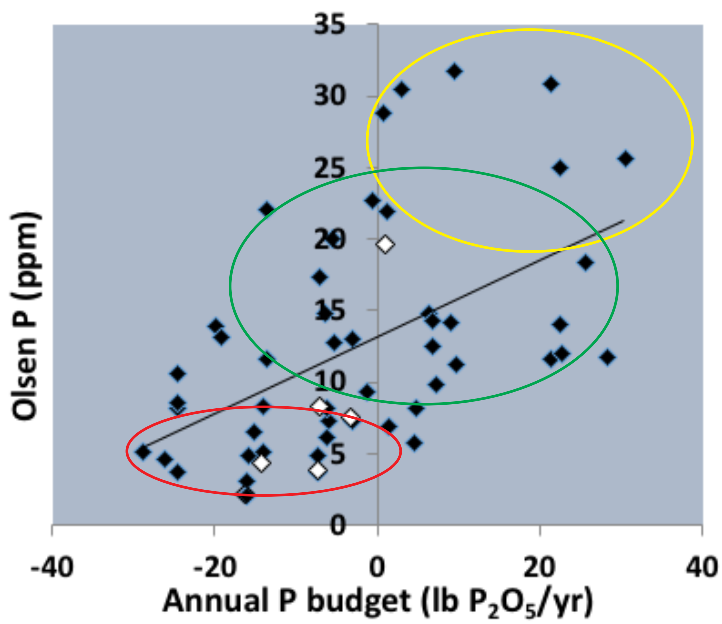


Figure 9. *The relationship between soil Olsen-P values, P balance and yield response to P fertilizer. Circles indicate fields in which different P managemen strategies need to be used.*

Table 7. *Charts relating rice yield with how much P (expressed in fertilizer equivalents-P2O5) is removed from the soil. The chart on the left assumes only grain is removed while the chart on the right is for when grain is removed and half of the rice straw. Alternatively, an on-line P budget tool has been developed based on the values in the table and is available at http://rice.ucanr.edu/P_Budget_calculator/.*

To determine P balance first determine P outputs. To do this determine average yields from field over past 5 years. Based on if straw was removed or not choose appropriate chart. The amount of P removed based on average yields will be the value under the "0" P fertilizer added or removed column.

For example if average yields were 85 cwt and only grain was removed then the amount of P removed was 44 lb/ac.

Grain yield (cwt@14%)	P fertilizer added (pounds P_2O_5/ac)														
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
	P balance (pounds P_2O_5/ac)														
50	-26	-21	-16	-11	-6	-1	4	9	14	19	24	29	34	39	44
55	-29	-24	-19	-14	-9	-4	1	6	11	16	21	26	31	36	41
60	-30	-26	-21	-16	-11	-6	-1	4	9	14	19	24	29	34	39
65	-34	-29	-24	-19	-14	-9	-4	1	6	11	16	21	26	31	36
70	-37	-32	-27	-22	-17	-12	-7	-2	3	8	13	18	23	28	33
75	-39	-34	-29	-24	-19	-14	-9	-4	1	6	11	16	21	26	31
80	-42	-37	-32	-27	-22	-17	-12	-7	-2	3	8	13	18	23	28
85	-44	-39	-34	-29	-24	-19	-14	-9	-4	1	6	11	16	21	26
90	-47	-42	-37	-32	-27	-22	-17	-12	-7	-2	3	8	13	18	23
95	-50	-45	-40	-35	-30	-24	-20	-15	-10	-5	0	5	10	15	20
100	-52	-47	-42	-37	-32	-27	-22	-17	-12	-7	-2	3	8	13	18
105	-55	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15
110	-57	-52	-47	-42	-37	-32	-27	-22	-17	-12	-7	-2	3	8	13

Grain yield (cwt@14%)	P fertilizer added (pounds P_2O_5/ac)														
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
	P balance (pounds P_2O_5/ac)														
50	-31	-26	-21	-16	-11	-6	-1	4	9	14	19	24	29	34	39
55	-34	-29	-24	-19	-14	-9	-4	1	6	11	16	21	26	31	36
60	-37	-32	-27	-22	-17	-12	-7	-2	3	8	13	18	23	28	33
65	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30
70	-43	-38	-33	-28	-23	-18	-13	-8	-3	2	7	12	17	22	27
75	-46	-41	-36	-31	-26	-21	-16	-11	-6	-1	4	9	14	19	24
80	-49	-44	-39	-34	-29	-24	-19	-14	-9	-4	1	6	11	16	21
85	-52	-47	-42	-37	-32	-27	-22	-17	-12	-7	-2	3	8	13	18
90	-55	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15
95	-58	-53	-48	-43	-38	-33	-28	-23	-18	-13	-8	-3	2	7	12
100	-61	-56	-51	-46	-41	-36	-31	-26	-21	-16	-11	-6	-1	4	9
105	-64	-59	-54	-49	-44	-39	-34	-29	-24	-19	-14	-3	-4	1	6
110	-67	-62	-57	-52	-47	-42	-37	-32	-27	-22	-17	-12	-7	-2	3

—Right time—

Generally speaking, we recommend most of the P being applied during tillage and seedbed preparation. Most growers will apply a starter blend containing P just before flooding the field. To avoid potential algae (scum) problems we recommend this fertilizer be lightly harrowed into the soil rather than sitting on top of the soil.

If algae is a severe problem, one can manage P fertilizer in a way so as to reduce the algae build-up early in the season. Many studies have shown that algae increases with increasing P concentration in water. Fertilizer P applications increase water P concentrations and can lead to increased algae build-up in rice fields.

Research has shown that incorporating P into the soil or delaying the P application by 30 days (or until the rice leaves have emerged above the soil surface) can reduce algae problems (or delay algae growth until it is not a problem for rice). An example is shown in Figure 10 which shows that overall, algae varied between the different growers. However, in both cases, algae was highest when it was applied on the soil surface. Incorporating the P into the soil reduced algae levels by over 50%; however, delaying the P application (applying 30 days after planting) reduced algae levels by almost 90% on average.

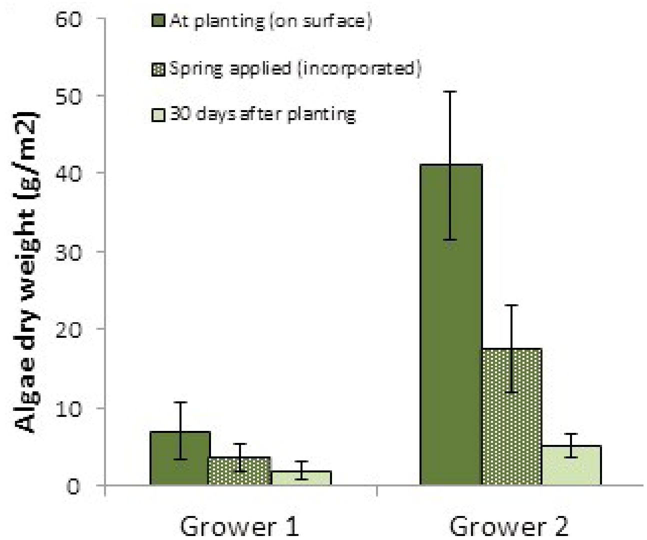
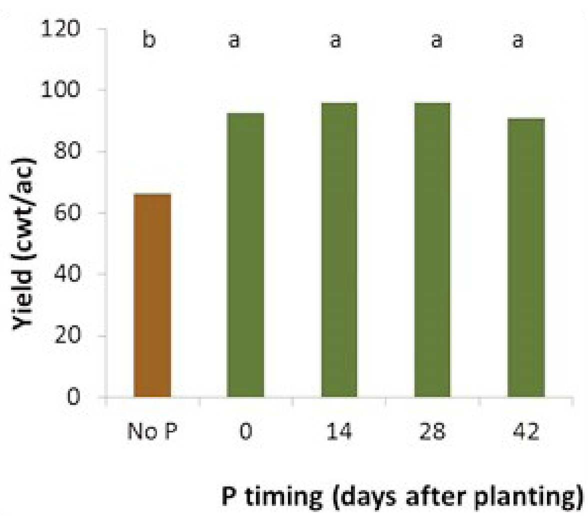


Figure 10. *Effect of P fertilizer management (timing and placement) on algal growth in two rice fields.*

It is important that delaying P fertilizer applications does not reduce yields. A number of studies have examined this and results show that in fields where P is deficient that delaying P application by up to 28 days has no negative effect on yield. However, applications later than this can result in lower yields (Fig. 11).



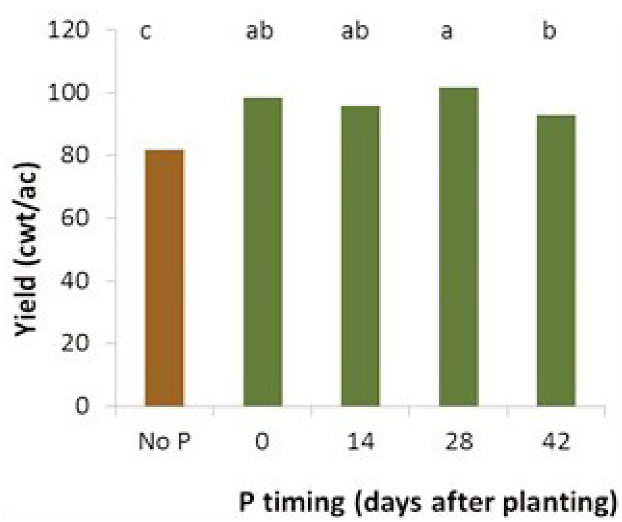


Figure 11. *Effect of P fertilizer timing on rice yields in two rice fields.*

One issue related to late P applications is that P can leave the field in the run-off water – a potential off-site pollution concern. Therefore for late P applications, the water should be held for about 2 weeks after P application.

—Right place—

As mentioned above, if P is applied before flooding and planting it should be lightly incorporated to help reduce algae problems.

Effect of straw management on P management

The main effect of straw management is whether or not it is removed from the field or not. There is approximately 5 to 6 lb P_2O_5 in every ton of rice straw. Removing straw from the field will affect the soil P budget and require that more fertilizer P be added to maintain existing P balances.

Potassium

Plant function

Potassium (K) functions in osmoregulation, enzyme activation, regulation of stomatal function, transport of assimilates, cell wall synthesis, and cellular pH. Adequate potassium nutrient increases leaf chlorophyll contents, delays leaf senescence, and therefore contributes greater photosynthesis. It improves the plants tolerance to adverse environmental conditions and improves tolerance to disease. It remains in ionic form and is very mobile within the plant. Potassium is readily transported from old senescencing to young developing leaves. Yield response to potassium requires sufficient supplies of other nutrients, especially nitrogen. Similar to nitrogen, potassium uptake rate peaks at the onset of the reproductive phase (Figure 1).

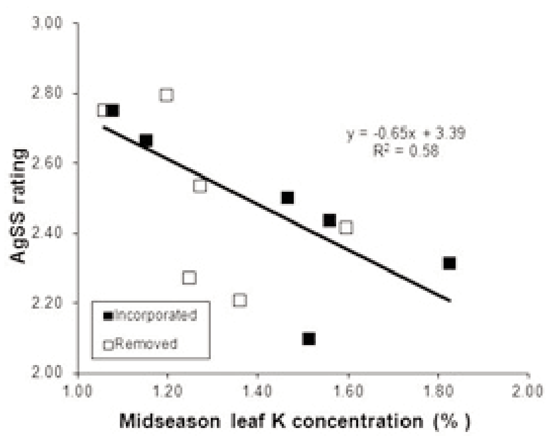


Figure 12. Aggregate sheath spot (AgSS) rat- ing as affected by Y-leaf (at panicle initiation) K concentration.

Deficiency symptoms

Potassium deficiency shows up as dark green plants with yellow/brown leaf margins starting at tip of leaf or dark brown or rusty brown necrotic spots on leaf-also starting on leaf tips and margins. These symptoms first appear on older leaves, then along leaf edge and finally at leaf base.

Yellow stripes may appear along leaf interveins and lower leaves become droopy.

K deficiencies can also lead to increased diseases in rice. This is because K deficiency results in an accumulation of sugars and amino acids that are good food sources for pathogens. An example of this is show in Figure 12 where aggregate sheath spot severity increases when K concentrations are low in the leaf.

Soil potassium

Potassium (K) is present in soils in four forms, which are in dynamic equilibrium. The forms are soluble K (readily available); exchangeable K (easily mobilized reserve); non-exchangeable K (slowly mobilized); and mineral K (semi-permanent reserve). Only about 1 - 2 % of the total potassium in a mineral soil is readily available for plant uptake. Under certain conditions, fertilizer potassium is fixed by the soil colloids and therefore not readily available to the plant. Clays of 2:1 type, such as montmorillinite, commonly found in the Sacramento Valley can readily fix large amounts of potassium. Wet-dry cycles and presence of lime influences the magnitude of the fixation. Under continuous flooding, plant uptake favors the release of fixed potassium.

Determining a deficiency

A number of factors can lead to a soil being deficient in K and, apart from visual plant symptoms or soil/tissue tests, these can be used as a guide in determining if K deficiencies are likely. In California, in a study of over 30 fields the only fields having soil K values below 100 ppm were located east of the Sacramento River. Lower soil K values were observed as one moved further east to the red soils nearer the foothills. While differences in soil K are due in part to differences in soil type, the irrigation water supplied to rice soils in these regions also varies. Irrigation water from the Sacramento River which supplies much of the irrigation on the west side of the valley is much higher in K than in the Feather River or other Sierra rivers which supply water on the east side (Fig. 13). Over time, these differences in K concentration could affect soil K values; however these differences also affect how much K fertilizer may need to be recommended.

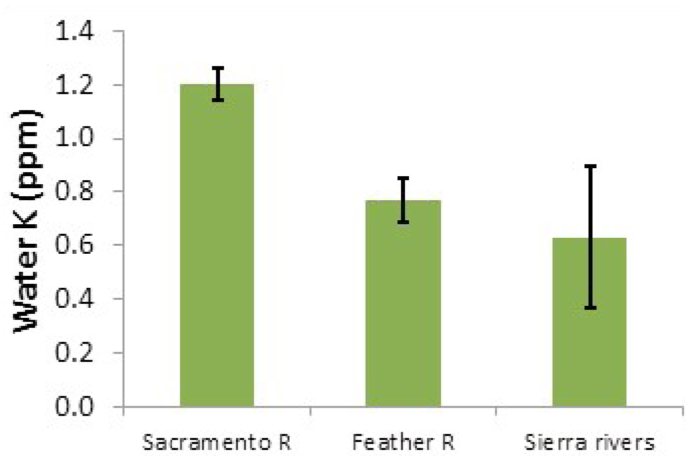


Figure 13. *Irrigation water potassium concentrations. Sierra rivers include the Yuba River and Bear River. Irrigation water was sampled from clean (not recycled) irrigation canals during the 2012 growing season.*

Soil

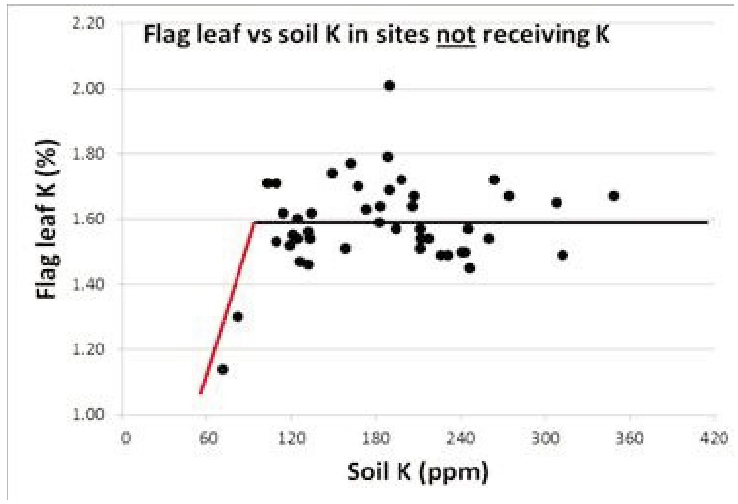


Figure 14. The relationship between soil K and flag leaf K values (taken at flowering) in fields where K fertilizer was not applied.

A soil test is a good way to determine if a soil is deficient in K fertilizer. Critical levels at which a soil is considered deficient varies with figures ranging from 60 to 85 ppm. However, in recent research where soil K values were compared to flag leaf K concentrations, it was appeared that where soil K values were above 100 ppm that flag leaf K values were high (between 1.4 and 1.8%) and unaf- fected by soil K (Fig. 14). However, when soil K was below 100 ppm (only two fields), flag leaf were lower and around the level considered to be deficient (see below). Therefore, taking a conservative approach, when soil K values are 100 ppm or below the soil may be deficient in K.

Plant leaf tissue

To determine a K deficiency using plant tissue, Y-leaf samples can be taken between tillering and panicle initiation or a flag leaf sample canbe taken at heading or flowering. Critical values for tissue samples taken during this time are 1.5% for Y-leaf samples or 1.2% for flag leaf samples. Data from Figure 14 also confirm that flag leaf samples of about 1.2% are deficient in K.

4R Management

—Right rate—

Average K fertilizer rates used in California are about 30 lb K_2O/ac. Potassium fertilizer rates will depend on a number of factors including soil test value, straw management, and irrigation water source. Given that relatively few fields in California are deficient in K, there has not been a focused effort at calibrating soil test values to K application rates. Here we provide a few guidelines.

1. To maintain soil K based on nutrient removal in harvest consider that about 5 to 6 lb K_2O/ton is removed in grain and 33 lb K_2O/ton in straw. Therefore, with a grain yield of 85 cwt, if only grain is harvested and the straw stays in the field, 24 lb K_2O is removed. However, if 2 ton/ac of straw is also removed then an additional 66

lb K_2O/ac is removed. To simply maintain soil K levels then is very different depending on how straw is managed.

2. If irrigation water is from the Sacramento River, then K rates can be reduced by about 5 lb/ac.
3. High water flow rates during the winter flood can lead to high K losses from field during the winter.

—Right source—

The main source used in California is muriate of potash (or KCl) which contains 60 to 62% K_2O. Sulfate of potash (potassium sulfate – K_2SO_4) is another option and this contains 50 to 53% K_2O. Sulfate of potash is usually more expensive but could be considered if the high chloride content of KCl is a concern or if sulfur deficiencies are of concern. Various fertilizer blends used in rice (i.e. 15-15-15) are usually made from one of the K sources blended with other N and P sources.

—Right time—

Usually K fertilizer is applied at planting or early in the season (in starter blends) where it is most beneficial and effective. If K deficiency symptoms appear early in the season it may be possible to correct deficiency with an application of K fertilizer. Research from Asia has shown responses to K fertilization as late as flowering. However, in most of the rice soils in CA which require relatively low rates and soils are heavy clays a single application at the start of the season is adequate.

—Right place—

If K is applied before flooding it should be lightly incorporated into the soil. This is of benefit to ensuring maximum use of the K fertilizer and also the P and N fertilizer in the starter blend.

Effect of Straw Management on K fertility

Incorporation of rice straw adds significant potassium to the soil. The average concentration of potassium in the straw is around 1.4% with a range of 0.6 to 1.8%. The amount of potassium removed when straw is baled can be as much as 90 lb/a. The continual removal of straw can have a profound effect on available soil potassium levels. Results from the Rice Experiment Station showed that the extractable potassium in the top inches declined to less than 60 ppm after 3 years of baling. Field studies in District 10 demonstrated that straw removal reduced soil potassium 30 ppm after one year.

Other nutrients

Zinc

Plant Function. Zinc (Zn) is essential for numerous biochemical processes, such as chlorophyll production, enzyme activation, and nucleotide synthesis.

Soil Zinc. Zinc deficiency, originally called “alkali disease,” is common in high pH, sodic soils, and in areas where the topsoil has been removed by land leveling or where irrigation water is high in bicarbonate (>4 milli-equivalents [meq]). In zinc-deficient soils (< 0.5 ppm), rice seedling growth may be reduced and, in severe cases, stand loss may occur. Preflood surface applications of 2 to 16 pounds per acre of actual Zn, depending on the source, have effectively corrected this deficiency. Zinc deficiency occurs more frequently in cool weather during stand establishment. Zinc fertilizer in the form of zinc sulfate, zinc oxide, or zinc chelate is broadcast or sprayed on the soil surface after the last seedbed tillage for maximum effectiveness.

Zinc deficiencies: There is very little translocation from old to new leaves. Consequently, deficiency symptoms are more pronounced on the young leaves. Plants may grow out of Zn deficiencies early in the season. Severe Zn deficiencies reduce tillering, delays crop maturity and can increase spikelet sterility. Midribs near the base of young leaves become cholorotic and older leaves become droopy and turn brown. Overall plant growth is stunted and leaf blade size is reduced.

The Y-leaf at tillering should have a zinc concentration of 25-50 ppm. If it is below 20 ppm it is considered deficient.

Sulfur

Plant Function. Sulfur is a component of proteins and amino acids. Most sulfur in the plant is the organic form, as opposed to inorganic forms. Sulfur concentration in the plant decrease with time.

Soil Sulfur. Rice plants absorb sulfur as sulfate, which has similar dynamics in the soil as nitrate. Thus, analysis for soil sulfur is unreli- able and of little value for predicting deficiencies in rice soils. Under flooded conditions, sulfate can change to sulfide and combine with zinc and iron to form unavailable compounds. Large amounts of decaying organic matter may intensify the immobilization of sulfur.

Sulfur deficiencies. Sulfur is not as readily translocated; thus, deficiency symptoms are more pronounced on the younger leaves. Overall light yellowing of the whole plant with the worst of such symptoms in the younger leaves are signs of low sulfur. Field symptoms are general- ly less uniform than nitrogen deficiencies. While it may be confused with nitrogen deficiency, nitrogen deficiency symptoms occur first on the older leaves. However at the early stages of growth, the two are sometimes difficult to distinguish. Healthy rice shoots at tillering should have between 0.15 and 0.30% sulfur. At maturity, if the straw contains less than 0.06% sulfur it is considered deficient.

Sulfur Fertilizers. Any sulfate containing fertilizer, such as ammonium sulfate and 16-20-0, will suffice. If either nitrogen or phosphorus are not needed, gypsum (calcium sulfate) or magnesium sulfate work well. Mixed with aqua, ammonium thiosulfate solution is effective.

Elemental sulfur can be used, but plant response will be slower. Application rates of 25 to 50 lb/a sulfur are suggested. Extreme cases may require more. Preplant applications are best, but topdressing to correct a mid-season plant deficiency is also effective. Unlike nitrogen, sulfur deficiencies may be treated late in the season. However, such late applications are unlikely to restore the full yield potential.

Adjustments for Other Establishment Systems

Drill seeding

In drill (or dry) seeded systems in California, rice is planted and then the field is flushed one to three times to establish the crop. At about the 3- to 4-leaf stage a permanent flood is bought on the field. The best time to apply all fertilizers is just before permanent flood. There have been some that have recommended a small portion of the N rate (i.e. 25 lb N/ac) being applied at planting. However, research addressing the need for this preplant N indicates there is no benefit to applying N at that time. Since N is applied when the crop is already established, aqua is not an option. Usually urea is used as the primary N source. Research evaluating urea versus ammonium sulfate shows no difference between these N sources. Therefore, unless the soil is deficient is sulfur, there is no benefit to ammonium sulfate.

For P and K applications can also be made at permanent flood – at the same time as the N application. There is no harm in applying these nutrients earlier, however if P is being applied, some N is also likely being applied and this needs to be accounted for in the overall N rate.

Stale seedbed

From a nutrient management standpoint, the stale seed be presents some challenges – especially for nitrogen management. Management is a different depending of if rice is established by drill- or water-seeding.

In water-seeded systems, flushing the soil with water prior to planting to induce weed germination can stimulate N mineralization but it can also promote N losses through denitrification. Prior to planting especially it may be likely that there is a large supply of nitrate in the soil that is lost to denitrification when the field is flooded for planting. Furthermore, the N fertilizer needs to be applied to the soil surface because in stale seedbeds one does not want to disturb the soil after the stale seedbed treatment. Urea is typically applied, but as discussed above, surface applications of N fertilizer can lead to increased N losses. These increased losses result in the need to apply a higher rate of N fertilizer to achieve desired yields than for conventionally managed water seeded systems (Fig. 15). Research conducted at the Rice Experiment Station has shown that water seeded stale seedbed systems require about 30 lb N/ac more. Other research has shown that this fertilizer is best applied as urea just before flooding the field for planting.

In drill-seeded systems there was no difference in N requirement between conventional and water seeded systems (Fig. 15). Therefore, it is recommended to apply the same N rate, using urea and at the same time as one would (just before to permanent flood) in conventionally managed drill seeded systems.

Since fertilizer N needs to be surface applied in stale seedbed systems the main fertilizer choices are urea and ammonium sulfate. Research

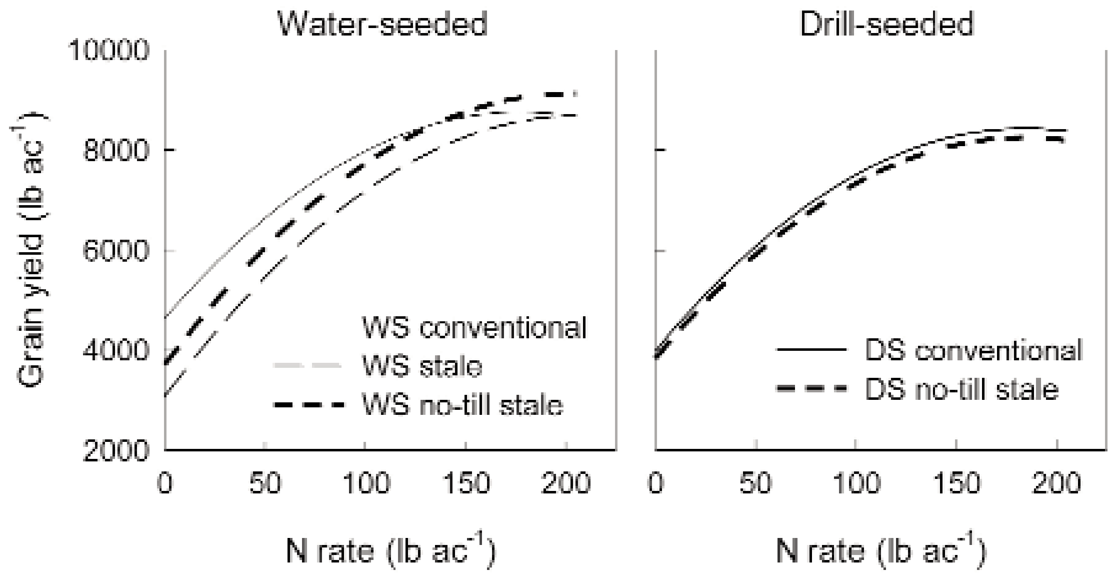


Figure 15. Grain yield response to N fertilizer in water and drill seeded rice when managed conventionally or with a stale seedbed. In the water seeded system both a tilled and no-till stale seedbed system was evaluated.

comparing these two N sources in both water and drill seeded stale seedbed systems shows no difference (Fig. 16). Unless sulfur is deficient in the soil or the soil is alkaline, urea would be the best choice of fertilizer given its high N content (45-46%) and generally more favorable cost.

Phosphorus and potassium fertilizer rates remain the same when using stale seedbed systems. These nutrients can be applied at the same time as the N fertilizer.

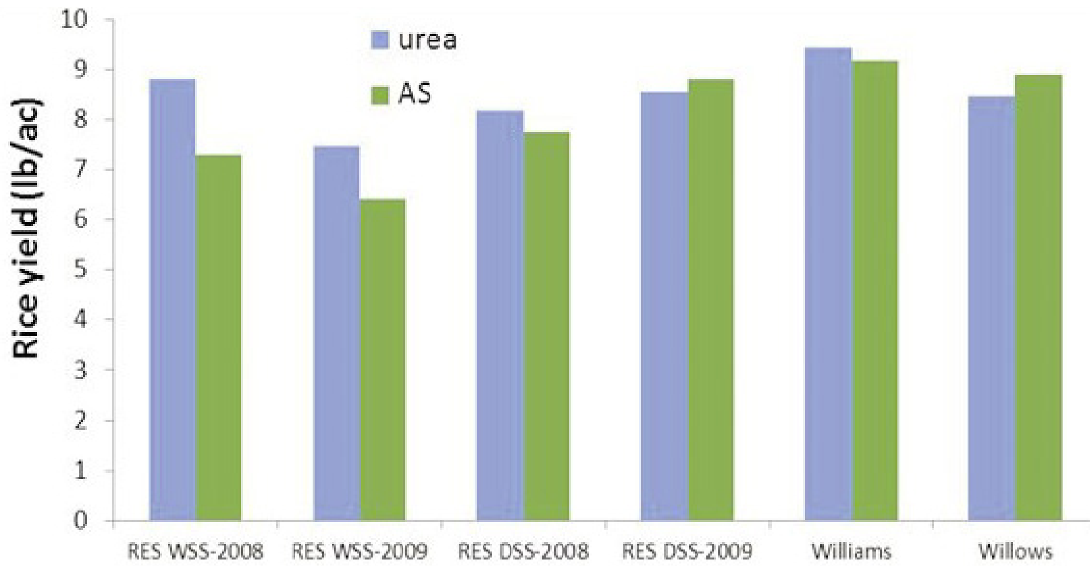


Figure 16. Comparison of urea and ammonium sulfate (AS) as the sole nitrogen fertilizer source. Data are for wet seeded stale seedbed (WSS) and drill seeded stale seedbed (DSS) systems at the Rice Experiment Station (RES) and two growers fields in Maxwell and Willows that used wet seed- ed stale seedbed systems. The N rate used in this comparison was 100 lb N/ac. In no case was the yield difference between urea and ammonium sulfate significant.

Nutrient deficiency symptoms in rice are mainly expressed in the color and size of the leaves, stems, and roots, plant height and tillering habit, the development of the root system, and the effect of nutrient deficiency on crop phenology, particularly in terms of advanced or delayed maturity. Most deficiencies are best detected during early stages of rice growth.

Localized on older leaves first				**Localized on younger leaves first**							**Not localized symptoms**
Light green, narrow, short leaves	Dark green, narrow, erect leaves	Green to dark green leaves Chlorotic necrotic leaf margins Rusty brown necrotic spots Green & yellow stripes running parallel Leaf rolling	Orange-yellow interveinal chlorosis, patchy Pale overall color Green coloring remains patchy (no stripes)	Soft, droopy leaves and culms	Light green, pale leaves Chlorotic upper leaves Whole plant affected, but upper leaves affected first	Chlorotic-necrotic split or rolled leaf tips Symptoms only visible under severe deficiency	Interveinal yellowing and chlorosis of emerging leaves Reduced chlorophyll content in leaves Later, entire leaves chlorotic or whitish	Pale grayish green interveinal chlorosis at the tip of young leaves Necrotic spotting	Chlorotic streaks Blusih green leaves Wilting young leaves	White, rolled leaf tips of young leaves Death of growth point if severe	Soft, droopy leaves
Stunted plants	Stunted plants	Shorter plants		Stunted plants	Stunted plants			Shorter plants	Reduced tillering	Reduced plant height	
Poor tillering Whole field appears yellowish Early maturity	Poor tillering Delayed maturity	Early wilting and maturity Unhealthy root system Increased incidence of diseases	Unhealty root systems	Poor tillering Uneven, patchy field growth	Reduced tillering Delayed maturity	Unhealthy root system Very rare in irrigated rice	Only on dry soil Very rare in irrigated rice	Only on dry soil Very rare in irrigated rice	Increased spikelet sterility	Panicle emergence fails Very rare in irrigated rice	Lodging Increased incidence of disease
N	P	K	Mg	Zn	S	Ca	Fe	Mn	Cu	B	Si

Diseases

Introduction

Microorganisms such as fungi, bacteria and viruses are known to cause plant diseases and limit the health, quality and production potential of crop plants. There are many factors that determine the incidence and severity of a specific disease in the field. There are three principal elements that must be present for the occurrence of a plant disease: a susceptible host, a pathogen, and favorable environmental conditions for disease development. All of the diseases discussed in the following text are fungal diseases. No bacteria or viruses are known to cause diseases of rice in California. The following discussion is meant to provide you with the tools needed to identify rice diseases in California and understand the interaction among the rice plant, pathogen and environment. With this information, you will be able to make informed disease management decisions based on biology. Remember that the best tools you have are your eyes so be sure to scout your fields regularly so you may make the most educated decision regarding your livelihood.

There are three principal elements that must be present for the occurrence of a plant disease: a susceptible host, a pathogen, and favorable environmental conditions for disease development.

Seed Rot and Seedling Disease

Seed rot and rice seedling diseases may be caused by Achlya klebsiana and Pythium species. These diseases are widespread throughout the rice growing areas of California and may occur wherever rice is water seeded. Seed rot and seedling disease often result in poor establishment of uniform stands.

Symptoms of seed rot and seedling disease appear shortly after seeding. The most common sign of the pathogen is whitish fungal hyphae growing over the surface of the seed and young seedling (fig. 1). Algae often colonize the mycelium, turning it green. A dark circular spot may also occur on the soil surface around infected seed due to the growth of algae and bacteria on the fungal hyphae and infected seed. Seed that are infected shortly after seeding often don’t germinate because the endosperm or embryo is rapidly destroyed. Growth of seedlings may be greatly impeded when seeds are infected following germination. Symptoms of seedling disease may include stunting, yellowing or rotting of the seedlings.

Unfavorable conditions for seed germination and seedling growth favor the development of these diseases. Cool weather at planting is the most common factor that predisposes seed and seedlings to these diseases because of decreased germination and seedling development rates. Once seedlings are established, they will often outgrow the disease under environmental conditions favorable for seedling growth with little effect on plant growth and survival.

The seed rot and seedling disease fungi survive in the soil and produce zoospores (swimming spores) in response to flooding of the soil. Zoospores are attracted to cracks in the seed coat where the endosperm is exposed or to the germinating seedlings. Feeding by midge or tadpole shrimp may predispose seed or seedlings to seed rot and seedling disease.

Laser leveling and maintaining a flood of 4 inches promotes rapid germination and stand establishment without the loss of weed control often associated with draining for stand establishment. Planting high quality seed with 85% germination or more when water temperatures are favorable for seed germination and growth (> 70°F) is an important cultural management practice for these diseases. In recent years, higher seeding rates have been used to compensate for seed rot and seedling disease.

Bakanae

Bakanae disease of rice is widely distributed in Asia and was first recognized in Japan in 1828. The word bakanae is a Japanese word that means "foolish seedling" and describes the excessive elongation often seen in infected plants. Symptoms of elongated seedlings led to the identification of bakanae in California rice fields in 1999. The disease has now become widespread throughout the rice growing areas of California and some infested fields suffered significant yield losses in 2002.

Bakanae is caused by the fungus Gibberella fujikuroi (anamorph Fusarium fujikuroi). The fungus infects plants through the roots or crowns and grows systemically within the plant where it produces the growth hormones gibberellin, which causes plant elongation, and fusaric acid, which causes stunting. The types of symptoms produced by an infected plant may be dependent upon the strain of the fungus and nutritional conditions. The most visually striking symptoms of the disease are chlorotic, elongated, thin seedlings that are often several inches taller than healthy seedlings (fig.s 2 to 4). Infected seedling may also be stunted and chlorotic, exhibiting a rot and crown rot. Infected seedlings usually die. Older plants infected with the fungus may exhibit abnormal elongation, stunting or normal growth and if they survive to maturity produce no panicle or empty panicles (fig. 5 and 6). As death approaches infected plants, leaf sheaths are usually covered with a mass of white or pinkish growth and sporulation of the fungus near the waterline (figs. 7 to 12). Leaves sheaths of infected plants may also turn a blue-black color with the production of sexual reproduction structures called perithecia (fig. 12).

Bakanae is primarily a seedborne disease and may be moved from one location to another on infested seed. Airborne spores of the fungus may contaminate seed after heading or during harvest. The fungus does not appear to infect the seed internally but rather contaminate the outside of the seed coat. Survival of the fungus in crop residue or the soil is thought to play a minor role in the disease cycle of bakanae.

Planting clean seed is the most effective management method for Bakanae. Destruction of crop residue in fields infested with the pathogen may provide some limited benefits by limiting the amount of inoculum that may carry over to the next crop. Soaking seed in a sodium hypochlorite soak solution is effective in reducing bakanae incidence. Since 2003, Ultra Clorox Germicidal Bleach has been labeled for bakanae control. The product label specifies using a thoroughly premixed solution of five gallons of product to 100 gallons of water, seed is soaked for two hours, then drained and soaked in fresh water for the remaining time. Alternatively, the label specifies using a thoroughly premixed solution of 2.5 gallons of product to 100 gallons of water; seed is soaked for 24 hours, then drained and planted within 12-24 hours.

Stem Rot

Stem rot disease occurs in most rice growing regions of the world and is caused by the fungus Magnaporthe salvinii. The stem rot pathogen is most often found in its sclerotial state, Sclerotium oryzae, in the field. The initial symptoms of stem rot appear after mid-tillering as very small irregular black lesions on the outer leaf sheath of the tiller at the waterline (figs. 1 to 4). As the season progresses, the lesions enlarge and the fungus moves inward, infecting interior leaf sheaths. Infected leaf sheaths often die and slough off throughout the season. In severe cases, the fungus will penetrate and rot the culm killing the entire tiller (fig. 5, 6). Tiny black sclerotia (hard resting structures) often form within diseased leaf sheaths (fig. 9). Sclerotia and white fungal mycelium may also be found inside the culm of severely infected plants near maturity (fig. 7).

The fungus overwinters mostly as sclerotia associated with diseased crop residue. When the field is flooded for the following season, the sclerotia float to the surface and infect developing seedlings at the waterline. When young plants are infected, tillers are often killed or fail to produce panicles. In severe cases where the culm is infected, yield and quality may be significantly reduced. Disease incidence and severity is positively correlated with the number of sclerotia present in the upper layer of soil prior to planting.

Management of stem rot is dependent upon cultural control methods. Since sclerotia overwinter in crop residue, one of the most valuable management tools is limiting the amount of inoculum that carries over from one season to the next. Burning of crop residue in the fall is a very effective method of reducing sclerotial inoculum levels in a field and reducing the amount of crop residue available for sclerotia to form on while overwintering. Swathing at ground level and removing the straw from the field is nearly as effective as burning. Incorporation of straw and winter flooding has also proven helpful in reducing carry over of sclerotia to the following season.

Although all of the California rice varieties are susceptible to the stem rot pathogen, slight differences between varieties exist. Stem rot is more severe in denser stands of rice and with excessive levels of nitrogen fertilization. Manage agronomic factors in an attempt to establish 20-25 plants per square foot and use only the minimum amount of nitrogen required for optimum productivity to minimize the severity of stem rot. The fungicide azoxystrobin (Quadris, QuiltXcel) is registered for stem rot control.

Aggregate Sheath Spot

The fungus Rhizoctonia oryzae-sativae causes aggregate sheath spot disease of rice. Lesions of the disease first appear at the waterline during the tillering stage as oval lesions with gray-green to straw-colored centers surrounded by a brown margin (figs. 1, 2, 3). Additional margins often appear around the initial lesion forming concentric bands. As the season progresses, aggregate sheath spot lesions move upward and form lesions on the upper leaf sheaths (fig. 4). Lesions often coalesce and cover the entire leaf sheath. Leaves of infected leaf sheaths turn bright yellow and eventually die. Under favorable conditions, the disease may spread to the flag leaf or panicle rachis and result in partially filled panicles (fig. 5, 7).

Rhizoctonia oryzae-sativae produces irregular brown sclerotia that are larger than stem rot sclerotia on the surface of infected leaf sheaths and cylindrical sclerotia inside the cells of infected tissue (fig. 8). Potassium deficiency has been associated with more severe disease symptoms. Excess nitrogen fertilization does not increase the severity of aggregate sheath spot as it does for stem rot. The same cultural management methods used for stem rot may be used for aggregate sheath spot. The disease cycles of the two diseases are very similar so reducing the carry over of sclerotia to the following season is key. Azoxystrobin (Quadris, QuiltXcel) and trifloxystrobin (Stratego) fungicides are registered for use on rice in California as a protectant against aggregate sheath spot to prevent the movement of disease to the top of the plant and should be used only in accordance with the product label.

Rice Blast

Rice blast disease is caused by the fungus Pyricularia grisea and is widely distributed throughout the rice growing regions of the world but was only identified in California in 1996. The incidence of rice blast is relatively low most years, but severe epidemics have occured. Blast is considered to be the most important disease of rice worldwide and may cause crop losses of up to 50% in some parts of the world when conditions are favorable for disease development. Pyricularia grisea may infect most aboveground parts of a rice plant including leaves, leaf collars, nodes, panicles and grains. Rice blast disease may be called by different names depending on the part of the plant infected.

Symptoms of leaf blast typically consist of elongated diamond-shaped lesions with gray or whitish centers and brown or reddish brown margins (fig. 2, 4). Leaf collars may also be infected by the fungus and produce a brown or reddish-brown necrotic area at the junction of the leaf blade with the sheath creating a “collar rot” symptom (fig. 8, 9). Collar rot may lead to death of the entire leaf, which may have a significant effect on yield when occurring on the flag leaf. Stem node infections result in a blackened node and may result in complete death of the tiller above the infection point (fig. 10). “Neck blast” is considered to be the most destructive phase of the disease and occurs when the fungus infects the node just below the panicle resulting in a brown or black lesion that encircles the entire node (fig. 13, 14). Depending on the time of infection and progress of the pathogen, neck blast may result in blanking of the panicle or incomplete grain filling. In addition, panicle branches and spiklet pedicles may also be infected resulting in reduced yield and/or milling quality.

Infected seed and crop residue are thought to be the most important sources of fungal inoculum in California. Only a small amount of starting inoculum is needed to produce a high incidence of rice blast disease as the pathogen may go through several reproductive cycles per season under favorable conditions. Each cycle consists of a spore of the fungus infecting a plant, producing a new lesion, and producing thousands of new spores that may infect other plants within a matter of 7-10 days under favorable conditions. With each spore capable of producing a new lesion, this disease may increase rapidly in a suitable environment. The fungal spores are dispersed by air and may be carried long distances so it is possible to develop collar and neck rot in a field with no previous signs of leaf blast.

Rice blast development is favored by high nitrogen fertilization, extended periods of leaf wetness, high relative humidity, little or no wind and nighttime temperatures of 63-73°C.

Spores are produced and released only under high relative humidity conditions and infection of the plant requires a lengthy period of free moisture on the plant tissue surface before the process is complete. Most years, environmental conditions appear to be permissive but not optimal for rice blast development in California rice fields.

Planting resistant cultivars is one of the primary methods of managing rice blast in many areas of the world. M-210 is currently the only California rice cultivar with resistance to rice blast. Several cultural practices are helpful in managing rice blast. Destruction of crop residue in infested fields, planting clean seed, water seeding, maintaining a continuous flood and avoiding excessive nitrogen fertilization are recommended to limit the incidence and severity of rice blast. Azoxystrobin (Quadris, QuiltXcel) and trifloxystrobin (Stratego) fungicides are registered for use on rice in California as protectants against neck blast and should be used only in accordance with the product label.

Kernel Smut

Kernel smut is generally considered a minor disease of rice in California and is caused by the fungus Tilletia barclayana. This disease may cause yield and quality losses. Kernel smut is characterized by a black mass of spores (chlamydospores) that replace the endosperm of individual kernels near maturity (fig. 1). Generally, a panicle may only have a few smutted kernels at random locations. Kernel smut is most noticeable early in the morning when dew causes infected kernels to swell and erupt in a black ooze of spores.

The disease cycle of kernel smut is rather complicated. The fungus may overwinter in or on seed or in the soil as chlamydospores dislodged during the harvest of infected grain. When fields are flooded the following spring, chlamydospores float to the surface and germinate to produce primary sporidia. Large numbers of secondary sporidia are produced from the primary sporidia and are forcibly discharged into the air where they may infect individual florets or kernels.

Short and medium grain rice varieties are less likely to have significant amounts of kernel smut compared to long grain varieties. This resistance is thought to be due to the fact that long grain varieties have a longer duration of anthesis and a larger floret opening resulting in a greater chance of encountering a spore.

Kernel smut is a difficult disease to manage. Plant certified seed and avoid excessive nitrogen fertilization that may favor disease development. If a field has a history of kernel smut avoid planting the more susceptible long grain varieties. Fungicides containing propiconazole

(QuiltXcel, Stratego) are registered for use on rice in California and may provide some protection against kernel smut and should be used only in accordance with the product label.

False Smut

False smut disease, also known as green smut, is found throughout tropical Asia, Italy, Australia, Costa Rica, the Dominican Republic, Panama, Mexico, South America, and the United States. This disease is usually considered a minor pest but epidemics have been reported in India, Burma, Peru, and the Philippines. False Smut disease was identified in a single Glenn County field in the fall of 2006 and subsequently in a couple of other Colusa and Glenn County fields. While this disease was reported to have occurred on rice in California many years ago the details of the extent of disease distribution are not well documented and this disease has not been observed/reported in California for at least 35 years.

False smut is caused by the fungus Ustilaginoidea virens. This pathogen replaces the rice kernels with globose, velvety spore balls up to 1 cm in diameter, which erupt from between the glumes. The spore balls consist of three spore-producing layers surrounding a hard core of fungal mycelium. The inner most and middle layers contain immature spores of yellow to orange coloration. The outermost layer consists of mature spores that are olive to black in color. One or more irregular, hard, black sclerotia are found at the center of the mature spore ball. Generally, only a few grains of a panicle are affected by this disease.

The disease cycle of false smut is not completely understood. The pathogen usually infects the ovary at the early flowering stage but can also infect mature kernels. The pathogen has several different spore types including conidia, secondary conidia, and sexual ascospores which have all been reported as possible infection agents. Conidia and secondary conidia are thought to be dispersed by wind, splashing and possibly grain feeding insects. Survival of the pathogen has been reported to occur as sclerotia or hardened spore balls called pseudomorphs.

There are no good management measures for this disease. In other areas, excessive nitrogen appears to favor disease development as does late planting or any condition that delays maturity of the crop. Early planting, uniform crop development and recommended nitrogen rates minimize disease incidence. Propiconazole fungicides applied during full boot have resulted in suppression of this disease in Arkansas with 5080% reductions in galls in the harvested grain.

Rice Disease Identification Guide

Seed Rot

Figure 1 - Seeds infected by seed rot show whitish fungal hyphae growing on the surface of the seed.

Bakanae Disease of Rice

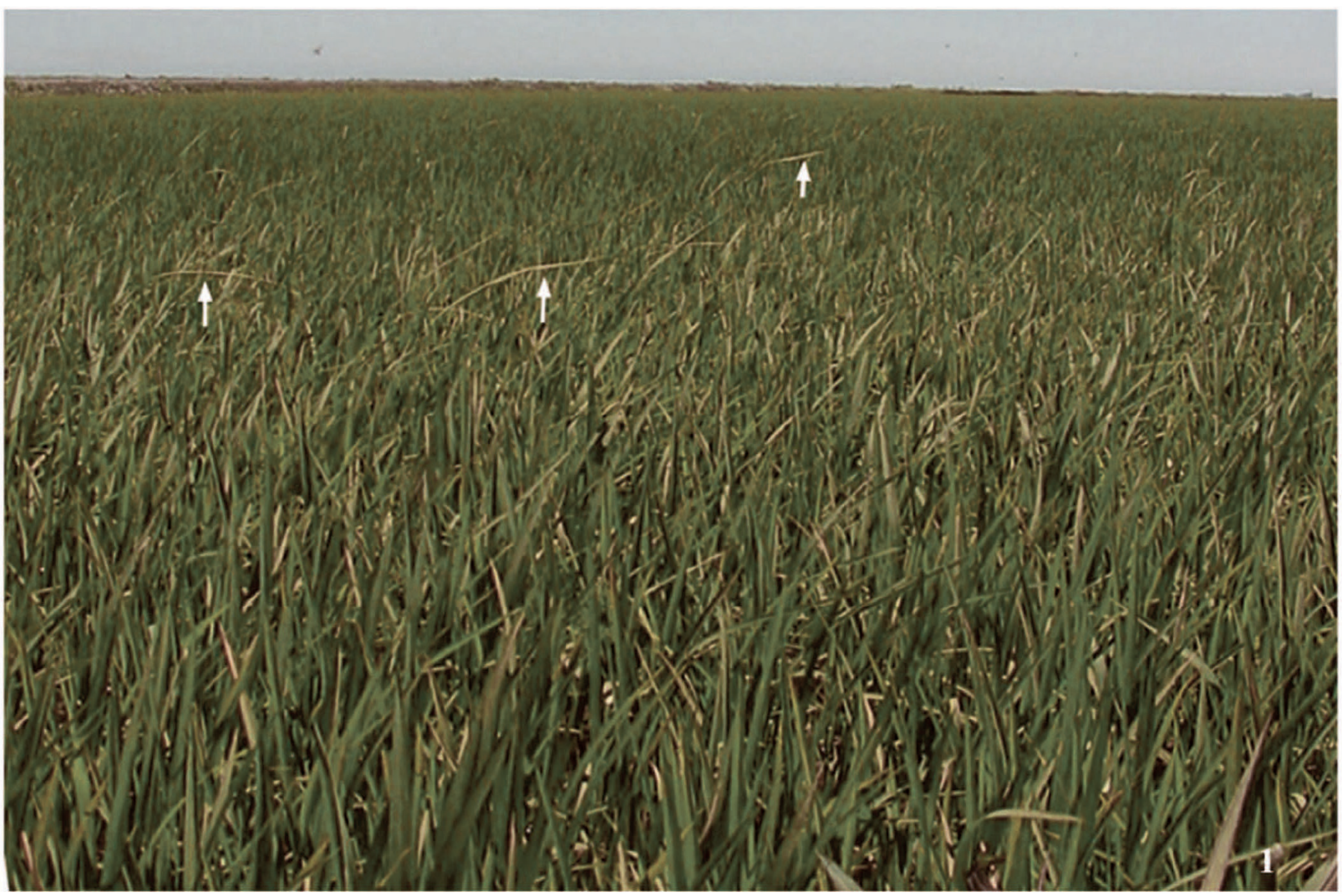


FIGURE 1 - Early symptoms of bakanae infection

Figure 2 - The bakanae diseased plant at right is taller, more slender and more chlorotic than the healthy.

Figure 3 - Plants with bakanae disease

Figure 4 - Bakanae diseased plants.

Figure 5

Figure 6

Figures 5 and 6 - Empty panicles produced as a result of bakanae infection.

Figure 7 - Mycelium of *G. fujikuroi* emerging from the node of an infected plant.

Figure 10 - Cottony mass of sporulating mycelia

Figure 11 - Stems with cottony masses of sporulation.

Figure 12 - Dark blue perithecia forming on bakanae infected plants.

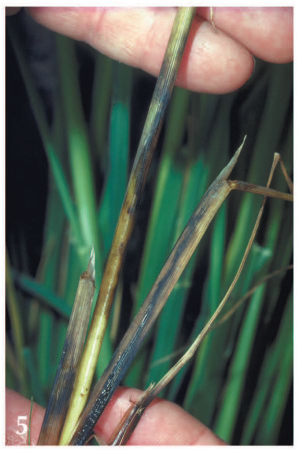
Figure 8 - A typical late season plant infected by bakanae. Note the sporulation at water level and the empty panicles.

Figure 9 - Masses of sporulation just above the water level on plants killed by bakanae disease.

Stem Rot Disease of Rice

FIGURE 1 Initial lesion of Stem Rot on rice.

FIGURES 2 and 3 Progression of Stem Rot infection at the water surface.



FIGURES 4 and 5 As Stem Rot disease progresses the fungus penetrates the culm and may kill the tiller.

FIGURE 6 Infection has progressed through all the leaves and has penetrated the culm.

FIGURE 7 Severe infection of culms by Stem Rot.

FIGURE 8 Secondary tiller killed by Stem Rot.

FIGURE 9 Round, black sclerotia of the stem rot pathogen develop on or in infected plant tissue as the rice plant matures.

Aggregate Sheath Spot Disease of Rice

FIGURE 1 Aggregate Sheath Spot symptoms first appear as oval lesions with grayish green to straw colored centers surrounded by a distinct brown margin.

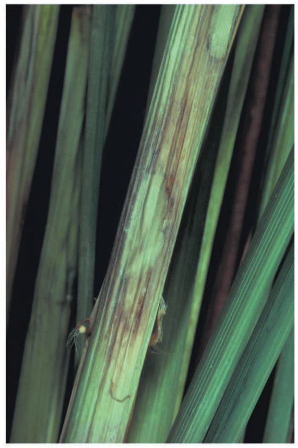


FIGURE 2 Lesions expand and may appear to coalesce.

FIGURE 3 Additional lesions are produced above the initial infections and continue to form up the tiller as the season progresses.

FIGURE 4 Spreading lesions and infection at base of leaf sheaths.

FIGURE 5 Bright yellow flag leaf of tiller with lesions below the leaf collar.

FIGURE 6 Culm rot with sclerotia produced inside the affected tissue.

FIGURE 7 Infection of the "boot" resulting in the panicle failing to emerge.

FIGURE 8 Sclerotia of *R. oryzae-sativae* produced in infected tissue.

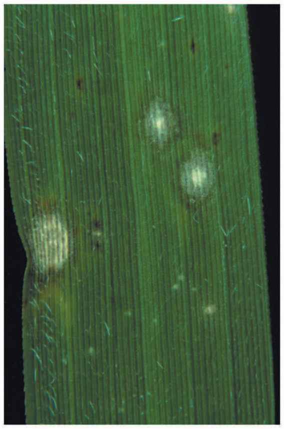


FIGURE 1 Initial leaf blast symptoms begin as gray spots, typically elliptical with gray to whitish centers.

FIGURE 2 Lesions enlarge and become typically diamond shaped with gray or white centers and narrow brown or reddish colored margins.

FIGURE 3 Mature lesion. Cottony appearance of the center is due to production of conidia.

FIGURE 4 Multiple infections with lesions coalescing. Typically there is yellowing outside the reddish borders of the lesions.

FIGURE 5 Early infection center of leaf blast showing killed plants.

FIGURE 6 Area in older field showing spot where leaf blast has killed plants.

FIGURE 7 Collar rot symptoms resulting from infection at the junction of the leaf blades.

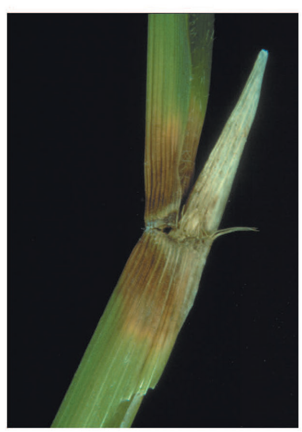


FIGURE 8 Close up of collar rot.

FIGURE 9 Collar rot where leaf has been killed.

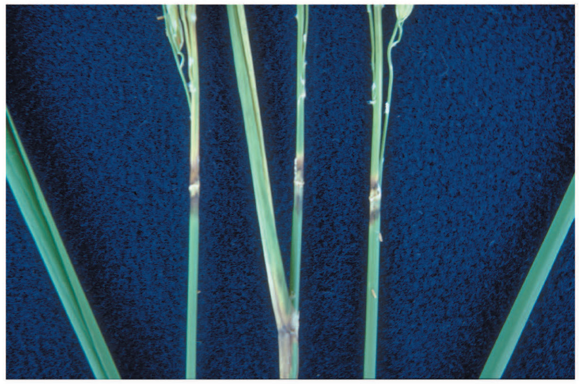


FIGURE 10 Node infections showing dark color and sporulation of the blast fungus.

FIGURE 11 Infected node and healthy node showing early symptoms of neck blast.

FIGURE 12 Typical neck blast. Note infected node below killed panicle.

FIGURE 13 Blasted panicle. Note dark purple to black color of infected node and empty glums.

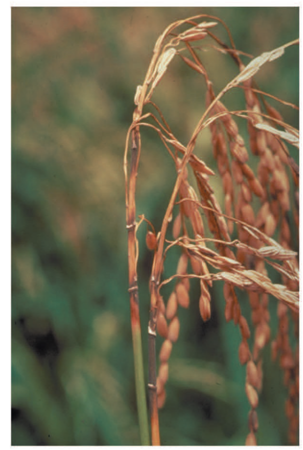


FIGURE 14 Panicle blast where only some of the panicle branches are affected due to infection of the rachis of the branches.

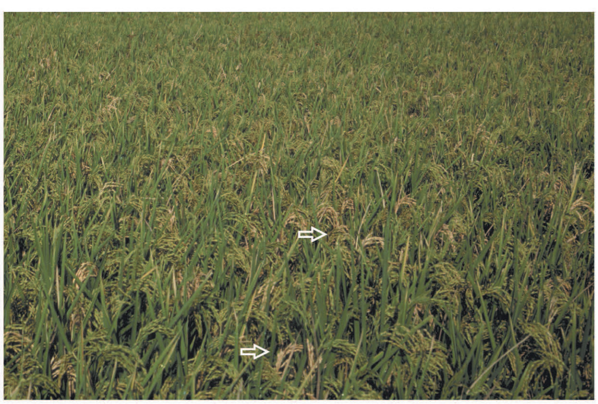


FIGURE 15 Straw colored blasted panicles appear soon after neck blast infection.

FIGURE 16 Close up of blasted panicles in the field.

Kernel Smut

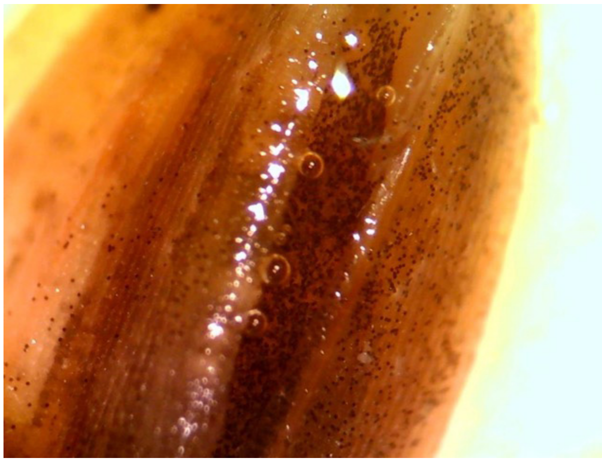


Figure 1 - Kernel smut spores replace the endosperm of kernels. Infected kernels are easily noticed early in the morning when dew causes them to swell and erupt.

False Smut

Figure 1 - Severe infection of rice grains by false smut. *Photo by Don Growth, LSU Ag Center.*

Invertebrate Pest Management in Rice

Numerous species of invertebrate animals are found in rice fields. These species are adapted to utilize the short-term aquatic environments of a typical rice field. The changing nature of a rice field, i.e., dry, followed by flooded conditions, quickly developing plant material and finally drained soil with senescent plants, limits habitat to invertebrates with specialized life histories. Insects, spiders, crustaceans, and other groups comprise the invertebrates. In a study conducted in 1990, researchers sampled and identified about 60 different species of arthropods in a survey of a California rice field. More recent efforts from the 2000's have confirmed this level of diversity in California rice fields. Most of these invertebrates inflict no damage to rice plants, whereas about ten species can hinder rice productivity and yield. Rice is most susceptible to damage during the first six weeks after seeding. A couple of species of insects and a crustacean hinder seedling establishment. During the vegetative growth phase, a few species potentially can be problematic by feeding on foliage, but populations are generally low. Invertebrate pests in California are uncommon during the grain-filling period. The rice stink bug pest that severely impacts grain quality of southern U.S. rice is absent in the California system. Similarly, leafhopper and planthopper species (and associated virus diseases they transmit) that severely impact Asian rice production, as well as stem borers, do not occur in California rice.

Management actions... have effects on populations of invertebrates

Another segment of the invertebrate complex in rice fields is the mosquito population and the natural enemies that feed upon aquatic mosquito eggs, larvae, and pupae. These individuals have no direct impact on rice plant productivity but are important from the "good neighbor" standpoint. Rice production practices can impact mosquito populations and their management. Mosquito management is gaining increased importance with the recent upswing in mosquito-vectored diseases, i.e., West Nile Virus.

A rice field is a definite "agroecosystem". Management actions intended to facilitate seedling establishment, weed control, plant growth (fertilization), etc. have effects on population levels of invertebrates. These effects could be positive or negative. Discussions of management of invertebrate pests will be divided into three portions of the growing season:

1. Seeding to 4-5 leaf stage (0 to ~30 days after seeding),
2. 5-leaf stage to heading and flowering stage (30 to ~90 days after seeding),
3. Heading to harvest.

Seeding to 4-5 Leaf Stage

Tadpole shrimp, crayfish, seed midge, and rice leafminer all have the capacity to hinder rice seedling establishment and early-season plant growth. In addition, rice water weevil adults feed during this period; however, the primary damage is inflicted later in the growing season by the rice water weevil larvae that develop on roots under the soil. Insecticidal management of this pest is targeted toward the adults so it is appropriate to consider this pest in this section.

Tadpole Shrimp

Tadpole shrimp (fig. 1) persist during dry periods in the egg stage (surviving for several years) and hatch quickly in the spring with the addition of water. Eggs hatch two to three days after the flood is initiated. Young tadpole shrimp grow fast. Initially, they feed on algae and other small organisms. When their shells are about half the length of a rice seed, individuals readily feed on germinating rice seeds, preferring the emerging radicle and coleoptile (fig 2). Large tadpole shrimp can uproot seedlings while digging in the soil. The occurrence of floating seedlings, caste skins (shed skins produced as the tadpole shrimp molts), and muddy water are indicative of tadpole shrimp infestations. Cut roots on the floating seedlings that have been injured by tadpole shrimp distinguish them from seedlings which are floating due to strong winds or other conditions.

Muddy water can reduce light penetration and further inhibit seedling growth and establishment. Once seedlings have a well established root and the prophyll (spike) is emerged, they are less susceptible to tadpole shrimp injury.

Figure 1. *Tadpole shrimp can feed on germinating seeds, uproot seedlings, and muddy water, reducing the amount of light seedlings growing underwater can get.*

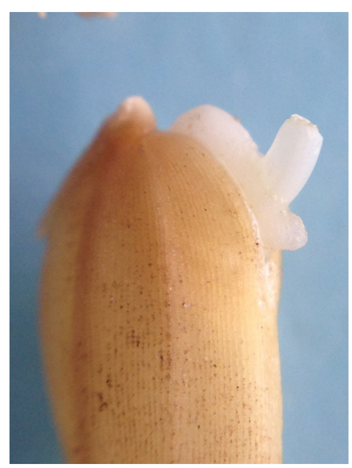


Figure 2. *Tadpole shrimp injury to the emerging coleoptile.*

Crayfish

Crayfish (fig. 3) make tunnels in levees near water boxes, compromising the structure of the levee. Crayfish's tunneling activity can cause seepage in levees, which could result in the illegal release of pesticide-treated water. Crayfish feed on dead and decaying matter, insects, and plants.

Their plant-feeding can be a problem on seedling rice. Muddy water, uprooted seedlings, and reduced stands result from crayfish infestations.

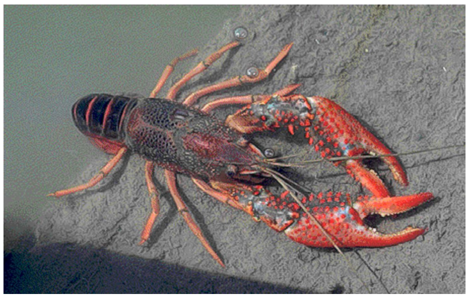


Figure 3. *Crayfish can directly affect rice by feeding on the germinating seed.*

Figure 4. *Holes dug by crayfish may cause unwanted seepage.*

Seed midge

Seed midge also hinder seedling establishment; there are several species in this group. This insect, the adult of which is a small mosquito-like fly (they actually have no functional mouthparts so cannot bite like a mosquito), is extremely mobile (fig. 5). Upon flooding a field, thousands of these adults fly to the field in a swarm and deposit eggs on the water surface. These swarms are often misidentified as mosquitoes. The eggs hatch in one to two days and the larvae feed on the soil surface of the flooded field. Larvae feed on seeds and seedlings as well as on algae. They often destroy the seed before it can germinate in the water (fig. 6). Once the seedling is 3 to 4″ long, it is not susceptible to midge damage.

Figure 5. *The rice seed midge can produce large swarms under certain conditions.*

Figure 6. *Rice seed midge developing larvae will feed on the germinating seed, killing it.*

Management of all these seedling pests is similar. Application of insecticides pre-plant or soon after seeding is effective due to the quick developing nature of the infestations after flooding. Actions that facilitate quick establishment of rice seedlings can mitigate damage from these pests. Since these invertebrates only damage rice seeds and young seedlings, once these stages are past, the potential for damage is low. Quick flooding and timely seeding reduces the risk of injury by these pests. Crop rotation can help manage crayfish and field draining soon after seeding can assist in managing tadpole shrimp and seed midge.

Rice Leafminer

Figure 7. *Rice leafminer larvae tunnel within the leaf eating the tissue.*

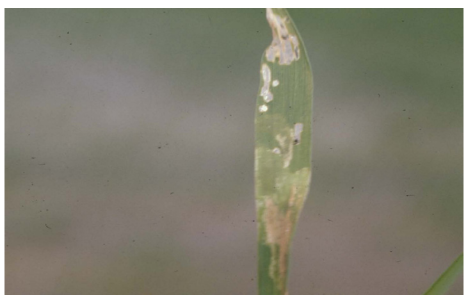


Figure 8. *Large rice leafminer numbers can cause browning of the leaf and reduce photosynthesis*

The rice leafminer was a significant pest of rice in California through the 1970's. During the 1990's, this pest could be found at low levels in most fields. Today, populations of rice leafminer are very low or absent. The adult fly, similar to a small house fly, lays a single egg on leaves. The resulting larva (fig. 7) mines between the epidermal layers of the leaf (fig. 8). This injury can resemble that of rice water weevil adults with the difference being that the leafminer larva can be seen in the leaf when it is held up to the sunlight. There are multiple generations of rice leafminers per year (up to 11), but this insect only damages rice before the plants start to grow upright. Leaves laying on the water surface are susceptible to attack. Therefore, slow growing rice (cool weather and/or deep water) is most susceptible to attack. Biological control by parasitic wasps aids in managing this pest.

Rice Water Weevil

Figure 9. *The rice water weevil is the most important pest of rice in the US. In California, it only affects areas near borders and levees.*

The rice water weevil (fig. 9) was considered one of the most damaging insect pests of rice in California after its discovery in the Sacramento Valley in the late 1950s. Currently, damage by rice water weevil is unusual and limited to areas with a history of rice water weevil pressure. Most likely, the use of new, more vigorous and productive varieties, and the intensive use of insecticides to manage tadpole shrimp explain the rice water weevil's decline in importance.

Adult rice water weevils overwinter in a diapause (reduced activity) state. The overwintering sites include levees and ditch banks, crop residue in the basins, riparian areas, etc. As temperatures increase, adults feed on leaves of grasses and eventually break the diapause. This involves regenerating their flight muscles such that adults can fly for several miles (hypothesized to be up to 20 miles).

The spring flight (April to June) occurs during days characterized by warm, calm evenings. During these periods, the adults fly and prefer to infest newly flooded rice fields; those with rice plants emerging through the water are most susceptible to infestation. Adults feed on the leaves of rice plants, which result in characteristic longitudinal feeding scars (fig. 10). This feeding has no effects on rice growth or yield.


Figure 10. *Overwintering adults emerge in the spring to feed on rice leaves*

Adults oviposit in the rice leaf sheaths found just below the water level. Oviposition occurs in plants with 2 to 6 leaves. Eggs hatch in5-7 days; the first instar larvae feed on the leaf tissue for a few days and then drop down through the water and soil to the roots (fig. 11). The remaining portion of the life cycle is spent in the flooded soil of rice fields. The larvae devlop through four instars and feed on rice roots causing significant injury. Pupation occurs on rice roots (fig. 12) and new adults emerge in late July. These adults feed to a limited extent on rice leaves and then leave the rice fields for overwintering sites.


Figure 11. *The small, legless larva drop to the soil where they feed on the roots causing the most significant amount of damage.*

Rice water weevil larvae root feeding causes reduced plant growth, chlorosis, and reduced tillering. These symptoms become noticeable four to six weeks after seeding.

In California, damaging infestations of rice water weevil larvae are limited to areas up to 50 feet next to borders of fields and levees (fig. 13). Grain losses from larval feeding of up to 45% have been recorded. In California, research results support an economic threshold of about 1 larva per plant.


Figure 12. *Feeding from the larvae will prune the root system and retard the growth of the plant resulting in costly yield reductions.*

Management of rice water weevil in California relies on chemical and cultural controls. Biological control of this pest is nonexistent. Adult weevils infest rice fields a few days after flooding and before the establishment of plant canopy or other aquatic arthropods. The larval and pupal stages live in flooded soils, protected from the activity of most arthropods.

Figure 13. *Injury by rice water weevil is observed as a reduction of plant growth, tillering and chlorosis. Damage is limited to areas near borders and levees.*

Some moderate host plant resistance has been identified for rice water weevil. However, incorporation into commercial varieties has not occurred as this does not appear to have the potential to be a stand-alone management tool. Cultural controls are useful for management of rice water weevil in California. Removal of levee vegetation in the spring helps reduce rice water weevil densities in adjacent rice basins. The additional herbicides required for this and the loss of wildlife habitat on levees are substantial drawbacks of this management technique. Two additional cultural methods assist in reducing rice water weevil densities, but may not fit all production schemes. They include dry seeding rice and delaying seeding dates. The reduced yields that can result from these techniques make them undesirable to growers. Additionaly, research has shown that winter-flooding rice basins reduces rice water weevil populations the following spring, but the reasons for this reduction are unknown.

Chemical control of rice water weevil from the late 1970's to the late 1990's relied on the insecticide carbofuran. This granular insecticide was applied before flooding and was incorporated into the soil. A small percentage of the usage of this product was made post-flood to drained fields. Since higher rice water weevil densities occur near the field edges, border applications of carbofuran were commonplace, resulting in significant savings to growers and greatly reducing the amount of insecticide going into the rice agroecosystem. Due to its toxicity to birds, carbofuran registration was cancelled after the 2000 season. In 1999, diflubenzuron (Dimilin) and lambda-cyhalothrin (Warrior), were registered as alternatives to Furadan. In 2002, zeta-cypermethrin (Mustang) was also registered as well as generic formulations of lambda-cyhalothrin. These insecticides are effective for RWW management in California; however, they have some limitations. They target rice water weevil adults, and have limited effects on rice water weevil larvae, which is the damaging stage. Dimilin sterilizes weevil adults (i.e., females produce no viable eggs) and the pyrethroid products kill adults, limiting egg laying. Application timing is of utmost importance since no control is possible with these products after a few days following oviposition. These insecticides are recommended to be sprayed at the 2-4 rice leaf stage. Additionally, lambda-cyhalothrin can be applied preflood up to five days before the field is flooded for seeding. Applications can be made to field borders and only 50 feet adjacent to the levee, in the same fashion carbofuran was used. Clothianidin (Belay), a third generation neonicotinoid, was registered in 2014. A post-flood application timing (~2-3 leaf stage) appears to be the optimal timing or this product; however, research has shown that clothianidin can be used as a rescue treatment when larvae are present in the field feeding on rice roots at the 5 to 6 leaf stage of rice. Chlorantraniliprole (Coragen), a diamide insecticide, received registration in 2017. Currently, this insecticide is only labeled for pre-flood applications.

Threshold values to determine the need for treatment developed for carbofuran were inadequate for use with the new insecticides registered for rice water weevil management. Currently, the need for insecticide applications against rice water weevil rely on grower experience and the history of the field.

5-leaf Stage to Heading and Flowering Stage

Two species of armyworms, true armyworm and western yellowstriped armyworm, are found in rice fields during the summer. In recent years, damage from these pests appears to be on the upswing.

Figure 14. *Armyworm larva.*

The armyworm moth lays its eggs in linear masses with the leaf tied around the eggs in a roll on either rice or on other grass species around and in rice fields. Larvae of both species are striped and vary in body color (fig. 14). Larvae feed predominantly at night or during cloudy days. They develop to full size and pupate in about 3 to 4 weeks in the summer. Pupation normally takes place in the upper surface of the soil or in debris, consequently many mature larvae drown in flooded paddies before reaching a suitable pupation site. However, some are able to pupate lodged between leaves or tillers. Adult moths of both species have a wing span of about 1.5 inches and are predominantly silver and gray (western yellowstriped armyworm) or buff colored (true armyworm).

Figure 15. *The caterpillars eat the rice leaves reducing the plants level of photosynthesis.*

Damage by armyworms is most serious during periods of stem elongation (early summer) and grain formation (late summer). Larvae defoliate plants, typically by chewing angular pieces off leaves (fig. 15). During outbreaks, defoliation to the water level can occur (fig. 16). Armyworm larvae may also feed on the panicle, specifically on the rachis near the developing kernels causing these kernels to dry before filling. This feeding causes all or parts of the panicle to turn white (fig. 17). The seriousness of armyworm injury depends on the maturity of the plant and the amount of tissue consumed. Significant yield reduction can occur if defoliation is greater than 25% during the early summer infestation or if panicle injury is higher than 10% later in the summer.

Figure 16. *Severe defoliation can occur when armyworms reach high population levels.*

Figure 17. *Armyworm injury during heading results in broken panicle branches and empty kernels.*

True armyworm outbreaks occurred in 2015, 2016 and 2017. Pheromone moth trapping is being used to predict armyworm activity and improve timing of field monitoring (fig. 18). The pyrethroid insecticides (lambda-cyhalothrin and zeta-cypermethrin) are ineffective controlling armyworms. The insect growth regulator diflubenzuron (Dimilin) is effective; however, it has an 80 day pre-harvest interval which prevents its use during the heading stage. The biological insecticide *Bacillus thuringensis* is effective when applied against small armyworms, which can be difficult to find timely in the field. The insect growth regulator methoxyfenozide (Intrepid) has received a Section 18 registration, allowing its use on rice on a yearly basis. Currently, the search for alternative insecticides is ongoing.

Various natural factors cause mortality of armyworms in the rice paddy. Many caterpillars drown or are killed by natural enemies including predators, pathogenic microorganisms, and parasites. Insecticide treatments are justified if more than 25% defoliation occurs and armyworms are present on the plants from late June through early July. Treatment for panicle loss is justified if 10% of the panicles in the area sampled are damaged and armyworms are observed.

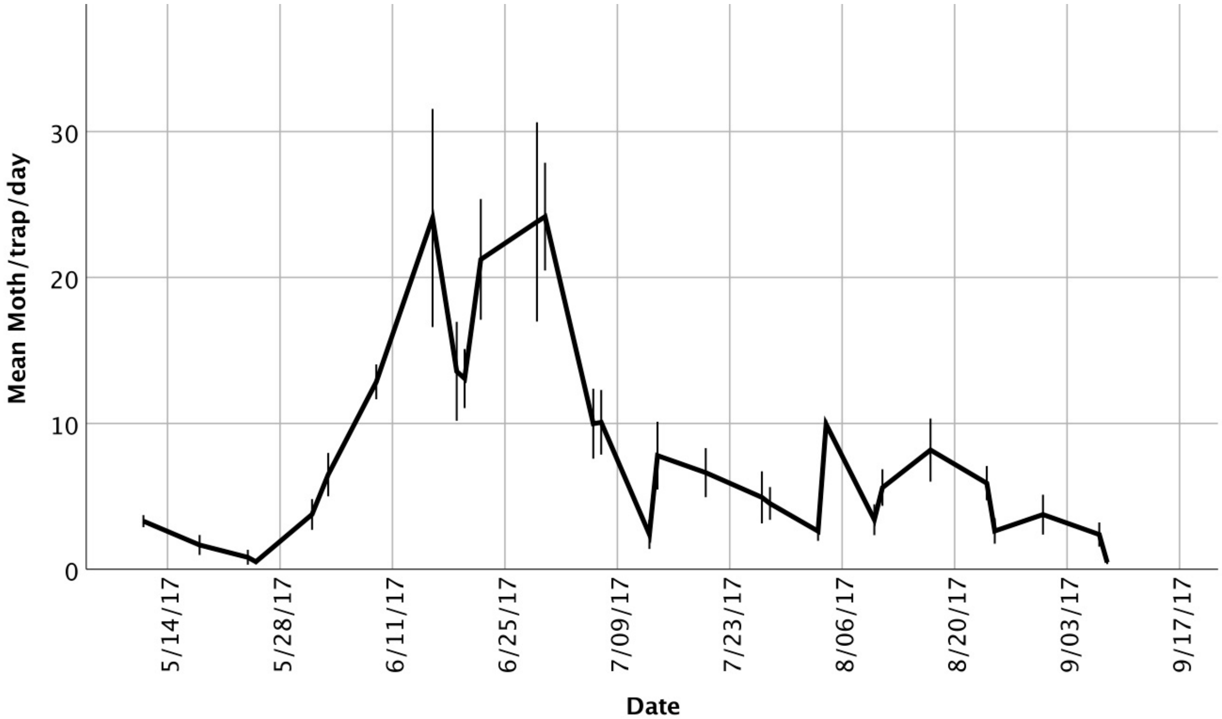


Figure 18. *Average number of true armyworm moths trapped across the Sacramento Valley in pheromone traps in 2017. The peak coincided with the period when extensive armyworm damage was observed in some fields. The second peak of moth activity, usually observed in mid August, was not detected in 2017.*

Heading to Harvest

A few instances of pecky rice (fig. 19) have occurred in California in recent years. Pecky rice refers to kernels that show a discoloration after hulling and milling. This discoloration can be caused by insects, but can also be caused by pathogens developing on the kernel due to excess moisture caused by rain or lodged rice. In fields that produced some pecky rice and some quality downgrades the previous year, collections were made in early September of a native stink bug called the redshouldered stink bug (fig.20) (*Thyanta pallidovirens* [= *T. accerra*]).

Figure 19. *Pecky Rice.*

Cage studies showed that this and other common stink bug species have the potential to feed on developing kernels and cause peck. Stink bugs can be common in rice fields with higher levels of weeds, fields near natural/riparian areas, and rice fields interspersed with other crops. Nevertheless, in most fields, stink bugs are present at very low levels and do not constitute a problem.

Figure 20. *Redshouldered stink bug*

Additional Information:

The UC Pest Management Guidelines for Rice maintains up-to-date information on management of key invertebrate pests of rice (UC IPM Pest Management Guidelines: Rice, UC ANR Publication 3465; http://www.ipm.ucdavis.edu/PMG/selectnewpest.rice.html). In addition, the publication entitled, Integrated Pest Management for Rice, 3rd Edition (UC ANR Publication 3280) is a good resource for rice IPM.

Weeds

Introduction

Weed populations have always been dynamic and the continuous use of almost any management practice alone has resulted in the loss of weed control. About the only certainty in California rice weed management is change. Within a few years after the introduction of rice in 1914, weeds were running rampant in the dry-seeded culture established at the time. Dr. Jenkins Jones wrote in 1924 that "practically all, if not all of the lands—and these represent the major portion of the rice acreage—are quite foul with watergrass," and that on these lands it was "practically impossible to grow profitable rice crops." Jones' research led to water-seeding, but large seeded biotypes of watergrass better able to emerge through the continuous flood became the dominant weed problem along with a new set of aquatic species. These included the sedge species, the aquatic broadleaf species and the late watergrass biotypes or so-called "mimics" which evolved in Asia from selection pressure of hand weeding. As weeds that looked different from rice were hand pulled the ever evolving survivors looked more and more like rice; hence, the name "mimic." Since 1992, several weed species that commonly infest California rice fields have evolved resistance to herbicides. Even multiple resistances, the resistance to more than one type of herbicide action, has evolved. This and the advent of mostly foliar applied herbicides have greatly increased the difficulty of watering and hence weed control. Adding to the complexity of rice weed management are regulatory aspects related to herbicide drift, buffer zones and waterholding periods that limit weed control choices and shape decisions. The following discussion and tables provide a framework for decision-making in the increasingly complex of rice weed control.

Weed populations have always been dynamic and the continuous use of almost any management practice alone has resulted in the loss of weed control

The Weeds: Species, Recordkeeping and Resistance

Proper identification of weed species is essential to successful weed management in rice. Weed identification is particularly important because many of the rice herbicides control one or only a few species, so incorrect weed identification can lead to poor control. It is not enough to group weeds broadly into sedges, "lilies" and grasses. Rather, we need to know with certainty that the weed is ricefield bulrush instead of smallflower umbrella sedge; or to know with certainty that the weed is California arrowhead rather than ducksalad or some other broadleaf species. Moreover, knowledge of the species and its competitive ability are critical to target the most important and potentially damaging weeds. For example, even though California arrowhead may be the dominant species in a field, will it be the most damaging? Weed species common to California rice are listed in Table 1.

Table 1. *The common and scientific names of major weeds in California rice*

Group	Common Name	Scientific Name	Weed Type
Grasses	barnyardgrass	*Echinochloa crus-galli*	annual
	watergrass (early)	*Echinochloa oryzoides*	annual
	watergrass (late)	*Echinochloa phyllopogon*	annual
	sprangletop, bearded	*Leptochloa fusca ssp. fascicularis*	annual
	sprangletop, Mexican	*Leptochloa fusca ssp. uninervia*	annual
	weedy rice	*Oryza sativa*	annual
Sedges	smallflower umbrella sedge	*Cyperus difformis*	annual
	bulrush, ricefield	*Schoenoplectus mucronatus*	perennial
	bulrush, river	*Schoenoplectus fluviatilis*	perennial
	cattails	*Typha spp.*	perennial
Broadleaf	California arrowhead	*Sagittaria montevidensis*	annual
	Gregg's arrowhead	*Sagittaria longiloba*	perennial
	ducksalad	*Heteranthera limosa*	annual
	marshweed	*Limnophilia spp.*	perennial
	pickerelweed	*Monochoria vaginalis*	annual
	pondweed, American	*Potamogeton nodosus*	perennial
	redstems	*Ammannia spp.*	annual
	common waterplantain	*Alsima triviale*	perennial
	waterhyssop	*Bacopa spp.*	annual
	winged primrose willow	*Ludwigia decurrens*	annual

Field history is a valuable tool for understanding the changes in weed populations. Although it is common to keep field records of varieties, yields and quality, it is relatively uncommon to see good records and maps of the weed species present in a field. Records of weeds (complete with field maps) coupled with good documentation of management and herbicide practices provide very useful information about the buildup of certain weed species, weed resistance and other aspects related to weed control (such as whether or not the weed infestations are related to field operations—field equipment, etc.). Furthermore, the ability to use certain herbicides depends on the ability to document resistant weed populations in the field. Most importantly, good field records will likely improve the ability to select management practices and herbicides to minimize weed problems.

Record keeping is even more important with the advent of herbicide resistance. It is now not enough just to identify a particular species, but whether or not it exhibits herbicide resistance is of paramount importance to selecting the correct herbicide, combination or sequence. Currently, the only diagnostic services to determine whether or not weeds are resistant are provided by UC Davis at the Rice Experiment Station at Biggs or by the companies whose products are involved. Submitting samples to the UC weed program requires specific records related to field history, cultural management, water delivery system and farming operations. Thus, such diagnosis depends on the records of field history. Aside from diagnostic confirmation of weed resistance, the best indicator is whether or not properly applied herbicides are able to control the weeds. If not, the chances are good that the species may be resistant. However, other possibilities should be eliminated before concluding that the weed is resistant. One telltale sign, assuming that all conditions such as weed growth stage, weather and management practices were ideal, is the survival of a single, normally susceptible species while all others are controlled. The survival of a single species year after year when it was previously controlled is also a reasonable indicator of resistance. However, allowing weeds to reproduce over time eliminates the option of prevention to keep resistant weed seed banks at low levels in the soil. Certainly, the early identification of weed resistance and even draconian efforts to reduce weed seed production are essential to combat resistant weeds—especially on a farm scale where resistant populations could be restricted to single fields rather than be allowed to spread.

Weed Management: Prevention

Prevention can be an important part of rice weed control. Prevention sounds good but unfortunately is not practiced as much as it should be. The use of certified seed is probably the best example of weed prevention in California. By comparison to most other areas of the world, California has one of the highest percentage of planted acres in certified seed — nearly 100% at its peak, but with economic downturns this has been somewhat lax at a time when resistant watergrass should have made it imperative. Passage of revisions to the law in 2018 now prohibit grower-saved seed, and all rice seed in California is now subject to regulation through the certified seed or Quality Assurance programs. Certified seed standards do not permit weedy (red) rice or noxious weed seeds. The tolerance for watergrass and barnyardgrass is 10 seeds per lb. For all other non-noxious weeds, the tolerance is 0.1% by weight. There is zero tolerance for weedy red rice or seed from red-branned cultivars. Irrigation water and farm machinery frequently transport weed seeds or other plant propagules into the field. The introduction of weed seed, tubers, and rhizomes can be reduced by cleaning farm implements when they are moved from field to field.

Weed Management: Cultural Methods

The value of good cultural practices cannot be underestimated in their importance to weed management. Although they are generally not enough by themselves, good practices can greatly suppress weeds and enhance the effectiveness of herbicides used in combination with them. Most, if not all of these cultural methods will be a necessary part of crop management anyway, so in controlling weeds, they become extremely cost effective. For example, good water management can be the most efficient method available to suppress weed species such as sprangletop, barnyardgrass, and even watergrass, to the point that herbicides can control them more effectively.

Tillage and Field Preparation

Tillage, land leveling, and preplant fertilizing all influence weed germination and growth. These management practices are covered in other chapters of this workbook and will be discussed here only in reference to weed management. Tillage and field preparation have changed dramatically with the advent of rice straw incorporation and winter flooding. Generally, the soil is wetter for longer periods and thus drying of over wintering rhizomes and corms of perennial weeds is not possible unless heavily infested fields are specifically targeted for dry tillage. Additionally, straw incorporation by wet rolling and especially discing or plowing in the fall incorporates weed seed, creating an over wintering seed bank that cannot be reduced by bird and small mammal depredation. In the spring, inadequate grading or planing of the field can leave high spots for weed germination or low areas where weeds remain under the floodwater during the application of foliar-active herbicides.

Water Management

Proper water management is the most important factor in controlling weeds in rice. Careful land grading and seedbed preparation before planting help maintain uniform water depths in rice fields. Ideally, fields should be flooded continuously to a depth sufficient to suppress weeds, particularly the grasses and smallflower umbrella sedge—generally 4-8” deep. However, this works only if the herbicides are effective when applied into the water. The advent of weed resistance to many of the into-the-water herbicides has necessitated a change to foliar-active or contact herbicides. Foliar herbicides require good coverage on the weed, thus if used early in the season when weeds are small, the field must be drained. Rapid reflooding for weed suppression and to prevent a new flush of germination is also necessary. This will be next to impossible on fields that take several days to flood or where water is insufficient to reflood rapidly. Adequate canals, drains, and water control structures are necessary to provide for efficiently regulating the flow of irrigation water. Where irrigation structures or water availability do not allow for rapid drainage and reflooding, it may be necessary to reduce field size. Large fields may be made smaller, or each basin managed independently with separate inflows and outflows to achieve the necessary water precision to optimize foliar herbicides. Land leveling, grading, and efficient irrigation management are equally important to meet state mandated water holding regulations (Table 2) following herbicide applications. Inefficient irrigation may allow too much water in the lower end of a field with no recourse but to hold deep water.

Table 2. *Waterholding requirements, pre-harvest intervals (PHI) and restricted entry intervals (REI) for rice herbicides (by trade name and active ingredient). Note: Rice pesticide waterholding requirements, the pre-harvest interval (PHI) and restricted entry interval (REI) from product labels.* **Please read and follow label directions and contact your county agricultural commissioner for label interpretations and permit conditions.**

COMMON TRADE NAME[1]	ACTIVE INGREDIENT	WATERHOLD TIME	PRE-HARVEST INTERVAL (PHI)	RESTRICTED ENTRY INTERVAL (REI)
Solution Water Soluble®	2,4-D	0 days	60-days	48-hours
Londax® Herbicide	Bensulfuron-methyl	7-days static	80-days	24-hours
BUTTE® Herbicide	Benzobicyclon + Halosulfuron	20 days	82-days	12-hours
Shark® Herbicide	Carfentrazone-ethyl	5-days static 30-days release: less closed system	60-days	12-hours
Cerano® 5 MEG	Clomazone	14-days	120-days	12-hours
Clincher® CA Clincher Granule®	Cyhalofop-butyl	0 or 7-days	60-days	12-hours
Sandea® Herbicide	Halosulfuron-methyl	0 days	69-days	12-hours
Granite® SC & GR	Penoxsulam	0-days	60-days	12-hours
Stam® 80 EDF	Propanil	7-days: less closed system	60-days	24-hours
Abolish® 8EC Bolero® UltraMax League® MVP	Thiobencarb	See appendix 1	See appendix 1	7-days
Grandstand® CA Herbicide	Triclopyr TEA	20-days: less closed system	60-days	48-hours

[1]*Restrictions apply to all rice pesticides sharing the same active ingredient and are not exclusive to the common trade name.*

Rotation

Not all rice soils can be rotated to other crops. However, rotation out of rice can greatly reduce weed populations in subsequent rice crops. Rotating to crops for which effective weed controls are available, such as tomato, safflower, cereal crops, or sunflower, is one of the best ways to manage weeds that cannot be selectively controlled with herbicides and cultural practices in rice. Non-flooded conditions, seedbank decay and alternative herbicides in the rotation crop all contribute to reducing future weed infestations. In fields where perennial weeds with tubers, rhizomes, or large rootstocks such as cattail, pondweed, Gregg's arrowhead, and bulrush, a dry fallow rotation out of rice may be necessary. Plowing the rice field to a depth of 8 to 12 inches (20 to 30 cm) during the fallow season can add to these benefits. In rice-only soils, a rice-rice rotation of the cultural method such as flooding one year and dry seeding or stale seedbed techniques the next, coupled with nonselective preplant herbicides, may help in controlling weed species resistant to normally used rice herbicides.

The Herbicides

When Londax dominated the California market for weed control in water-seeded rice in the early 1990s, there was relatively little interest in new products. With the onset of widespread weed resistance, many old and new products have entered, or are about to enter the market (Table 3).

While all the new products hold promise for improving weed management in rice, they add to the puzzle of information needed to use them safely and efficiently. For example, if a foliar applied herbicide is translocated in the plant, it may not be necessary to completely drain the field provided enough foliage is above the water; but in combination with a foliar herbicide that does not translocate (contact), weed control could be greatly compromised by not having the field completely drained to fully

Table 3. *The common and trade names of current herbicides for rice in California.*

bensulfuron	Londax
benzobicyclon + halosulfuron	Butte
bispyribac	Regiment
carfentrazone	Shark
clomazone	Cerano
cyhalofop	Clincher
halosulfuron	Sempra, Sandea, Halomax
orthosulfamuron	Strada
pendimethalin	Prowl
penoxsulam	Granite
propanil	Stam, SuperWham
thiobencarb	Abolish®, Bolero®
thiobencarb + imazosulfuron	League MVP
triclopyr	Grandstand®

expose the weeds. If the field is completely drained, of course, there is the very real possibility for a new flush of weeds such as sprangletop. Thus, it is extremely important to know the behavior of each herbicide in the plant and the environment. Most of the California rice herbicides are somewhat limited in the spectrum of weeds controlled, requiring the proper selection either alone, in combination or in sequence to give adequate weed control. The weed spectra and water management regimes for the currently available herbicides are shown in Figure 1a and 1b. Potential weed control given in the tables is based on both company and UC Davis research and represents the control that could be consistently expected of a particular product, assuming that the weed species are not resistant. Different uses of the same product, application timing, field management and environmental conditions (weather) may all increase or decrease control. For example, SuperWham or Stam (propanil) works better at or above 75º F and with eight or more hours of sunlight following application. Light is required because propanil blocks photosynthesis. Shark into-the-water may control a broader range of species than indicated in Figure 1 if used as a foliar applied herbicide, but higher rates are required. For best control, carefully read and follow the label which will state the rates, adjuvants, combinations and other requirements of the product. By mixing and matching the herbicides in Figure 1a complete spectrum of weed control may be possible. However, in addition to the weed spectrum, it is important to know how the herbicide is taken up by the weed, if it is translocated in the plant, the range of application timings for weed control and crop safety, if the herbicide has residual activity, whether or not the weeds are resistant and if tank mixes or sequences are antagonistic.

Herbicide Combinations

Tank mixtures may be used when two or more herbicides are compatible. This requires that not only must they be chemically compatible, but best management practices for their application such as timing and water depth are the same. Tank mix combinations can reduce the cost of application and often reduce the rates of one or more herbicides. The purpose of combinations is to broaden the spectrum of weed control such that each herbicide in the mix will control the weeds missed by its partner (Figure 2). Even though some herbicides compliment each other in timing and weed spectrum, they cannot be mixed because of antagonism. Antagonism can be manifested in either injury to rice or as a lack of weed control—that is one herbicide increasing the injury to rice by the other or reducing the normal effect of the other on weed susceptibility. It is important to follow the label of each herbicide with regard to tank mixes.

Herbicide sequences

To achieve good broad-spectrum weed control, most herbicides must be used in sequence rather than as tank mixes. This is because of differences in the behavior of the herbicides with respect to timing, water management, antagonism, translocation and other factors. Probably the most important aspect of these sequences is to protect against the buildup of weed resistance by using different modes of action. For example, a sequence of Clincher followed by propanil will take out any remaining watergrass with resistance to Clincher. Figures 3, 4 and 5 show the weed susceptibility of herbicide sequences with Regiment, Cerano and Clincher, respectively. Unlike herbicide tank mixes, sequences can be complicated by the need to raise and lower water depths to meet the requirements of each herbicide in the sequence. Water management requirements for the different herbicide sequences are also shown in Figures 3, 4 and 5.

Behavior of Herbicides

Table 4 provides additional information on the behavior of current and future herbicides respectively.

Foliar or Soil Activity

Most of the newer herbicides are active only as foliar sprays. However, Abolish, Bolero, Cerano, Butte, Granite, and Londax have soil activity. Generally, when the product is formulated and used as a granule such as Bolero, Butte or Granite, the activity is through the soil. Abolish, which is the same active ingredient as Bolero, is also active through the soil, but the product is designed as a spray which improves foliar uptake for pinpoint flood management. Like Abolish, Londax is also soil active when sprayed into the water. Generally, rates can be lower when used as a foliar spray than when applied into the water, but each chemical varies so the manufacturer's label should be followed. Products that are effective when applied into the water are weakly adsorbed and concentrated by the soil from where they are released and taken in through the plant roots. Field drainage to expose the weeds is very important for most foliar-only herbicides.

Table 4. *Behavior of currently used herbicides (lsr = rice leaf stage; mt = mid-tillering; ** = both foliar & soil activity)*

Herbicide	Foliar activity [1]	Applied in water [2]	Translocation index [3]	Timing window [4]	Residual (days) [5]	Mode of action [6]	Weed resistance[7]
bensulfuron (Londax)	Yes	yes *	4	0–5 lsr	35–40	2	Yes
benzobicyclon/ halosulfuron (Butte)	Yes	Yes	4	0–5 lsr	30	27/2	see comment [8]
bispyribac (Regiment)	Yes	No	4	5 lsr–mt	0	2	Yes
carfentrazone (Shark)	Yes	yes *	2	4 lsr–mt	5–8	14	No
clomazone (Cerano)	No	Yes	6	0–1 lsr	5 (water)	13	Limited
cyhalofop-butyl (Clincher)	Yes	No	4	2 lsr–mt	0	1	Yes
halosulfuron (Sandea, Halomax)	Yes	yes *	4	0–5 lsr	30	2	Yes
orthosulfamuron (Strada)	Yes	yes *	4	2–4 lsr	12–24	2	Yes
pendimethalin (Prowl)	No	No	0	soil cracking	5 (water) 20 (dry soil)	3	No
penoxsulam (Granite)	Yes	Yes	4	2 lsr–mt	0	2	Yes
propanil (Stam, SuperWham)	Yes	No	3	3 lsr–mt	0	7	Yes
propanil/ halosulfuron (RiceEdge)	Yes	No	3	1–3 lsr	0–30	7/2	Yes
thiobencarb (Abolish)	Yes	yes *	3	1–2 lsr	20–25	8	Yes
thiobencarb (Bolero)	No	Yes	3	1–2 lsr	20–25	8	Yes
thiobencarb/ imazosulfuron (League MVP)	No	Yes	3	1–2 lsr	20–25	8/2	Yes
triclopyr (Grandstand)	Yes	No	8	5 lsr–mt	0	4	No

1. Foliar Activity. Herbicides that must be directly sprayed on the plant to be effective are said to be foliar active and often require fields to be drained before they are applied so the weeds are adequately exposed to the spray.

2. Applied in Water. Herbicides that are formulated as granules (e.g., Bolero Ultramax) are active through the soil and do not require field draining. Herbicides marked with an asterisk (*) are formulated as a spray for foliar contact but are also adsorbed to the soil when sprayed into the water so that plants take them up through the roots as well.

3. Translocation Index. The translocation index provides a measure of how much the herbicide moves within the plant: numbers above 7 indicate highly mobile, numbers below 4 mean little movement. This index is important for water management when applying an herbicide. For example, if a foliar-applied herbicide is translocated in the plant, it may not be necessary to completely drain the field. If it is used in combination with a foliar herbicide that does not translocate (i.e., a contact herbicide), weed control would be compromised by not having the field drained fully to expose the weeds.

4. Timing Window. Application timing is important to minimize rice injury and optimize weed control. Timing is stated in relation *to the rice crop development: lsr=leaf stage of rice and mt = mid-tillering. Because several herbicides also work best when timed to the weed's stage of development, the timing window may be further reduced.*

5. Residual Activity. Residual activity is the length of time that the herbicide remains active in the soil and is generally determined by the amount and strength of soil adsorption and by the rate of degradation of the herbicide. Residual activity is important in herbicides that are applied early in the season because it helps to prevent reinfestation by subsequent germination of a new flush of weeds before the rice canopy is large enough to shade them out.

6. Mode of Action. Weeds are resistant to the mode of action that kills them, not to the herbicide per se; consequently, once the weeds become resistant to a particular mode of action, all other herbicides with similar modes of action will likely fail to control the weed. To distinguish between herbicide modes of action, group numbers, assigned by the Weed Science Society of America (WSSA), are listed. Weeds with the same group number have the same mode of action. Although weeds may exhibit multiple resistance (resistance across many groups), mode-of-action numbers are useful in planning mixtures or sequences of herbicides. For more information, see http://wssa.net

7. Weed Resistance. In fields where herbicide resistance has been identified, it is critically important to implement the herbicide resistance management strategies outlined below.

8. No resistance has been confirmed for benzobicyclon, but there is resistance to halosulfuron.

Contact or Translocated

Another important factor affecting the proper use of herbicides is whether or not they move in the plant. Two herbicides may be foliar active but are used quite differently with respect to field management. Translocated herbicides, such as Grandstand move from the site of uptake to other parts of the weed to kill the growing point. Contact herbicides move very little from the point of impact, and kill only that part of the plant covered by the spray. Shark, SuperWham or Stam (propanil) hardly move at all, whereas Clincher and Regiment move small distances. Cerano moves, but only upward in the translocation stream, so it will not move down from a foliar application. The translocation indices given in Table 3 are indicators of the relative movement of rice herbicides in the plant. Numbers above seven mean that the herbicide is highly mobile and below four generally means little movement. Matching water management to the translocation characteristics of the herbicide is extremely important to the success of the application. For example, the label for Grandstand, a translocated herbicide, specifies that only 70% of the foliage need be exposed, whereas some contact-only herbicides may require complete drainage.

Window of Application

Herbicides vary widely in their ability to kill weeds of different sizes and in their safety to rice at different stages of growth. The application timing on the product label is given to minimize rice injury and optimize weed control and is the "application window." Abolish and Bolero (thiobencarb) and Cerano have the smallest application windows. Abolish and Bolero require rice to be at least 1 ½ leaf but watergrass not greater than two leaf. Cerano also has a narrow window of application from just before planting to the 1 leaf stage of rice but watergrass must be less than 1 ½ leaf for most effective control. Many of the new herbicides have relatively broad windows of application timing both with respect to crop safety and weed control. Some, like Clincher, require rice to be in early tillering before the crop is safe. Regardless of the window, it is important to remove weeds before competition reduces yield. Most research shows that the onset of weed competition is about twenty days after seeding, depending on the severity of the weed pressure and rate of growth. Competition notwithstanding, the new herbicides offer the opportunity to remove weeds where applications have been delayed by weather or to cleanup where weeds have been missed by earlier applications.

Residual Activity

Residual activity is an important attribute in preventing reinfestation by subsequent germination of a new flush of weeds. Residual activity is generally determined by the amount and strength of soil adsorption and by the rate of degradation of the herbicide in the environment. Carfentrazone, for example, has a half-life of only about five days and hence a short residual activity, whereas Londax residual is 35 days. Residual activity is much more important for early applications before the rice canopy is capable of shading out weeds. Mixing a residual herbicide with early applications of foliar herbicides such as propanil can sustain control long enough for the rice canopy to cover. It is, however, a double-edged sword in that selection pressure for weed resistance continues as long as the herbicide remains active in the soil.

Mechanisms of Action

It is essential to know which herbicides have similar mechanisms of action because weeds are resistant to the mechanism that kills them, not to the herbicide *per se*. Once the weeds become resistant to a herbicide with a particular mechanism of action, all other herbicides with a similar mechanism of action will likely fail to control the weed. Table 5 shows the current rice herbicides

Table 5. *Herbicides mechanism of action*

Group	Active Ingredient	Mechanism of Action
Thiocarbamates	Thiobencarb (Abolish, Bolero)	VLCFA (Very long chain fatty acids)
Aryloxyphenoxy-propionates	cyhalofop-butyl (Clincher)	ACCase inhibitors
Amide	propanil (SuperWham, Stam)	Photosystem II inhibitor
Sulfonylurea	bensulfuron (Londax) halosulfuron (Sempra) orthosulfamuron (Strada) imazosulfuron (component of League)	ALS inhibitor
Phrimidinyl-thiobenzoates	bispyribac (Regiment)	ALS inhibitor
Triazolopyrimidines	Penoxsulam (Granite)	ALS inhibitor
Dinitroaniline	pendimethalin (Prowl)	Tublin inhibitor (mitosis inh.)
Isoxazolidinone	clomazone (Cerano)	Carotenoid biosynthesis
Unclassified	Benzobicyclon (component of Butte)	HPPD inhibitor

grouped by mechanism of action. Thus, it would not be a good idea to use Regiment or Londax where resistance to Granite has been documented. To prevent the further buildup of resistant weed seed banks, herbicides with different mechanisms of action should be rotated or used in sequence or combination to prevent resistant species from setting seed.

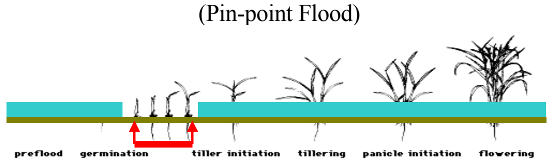
Weed Susceptibility, Application Timing and Water Management Regimes

Figure 1a. *Weed susceptibility, application timing and water management regimes for California rice herbicides.*

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Abolish or Bolero	+ / R	+ / R	+	+	-	-	-	-	-	-
Cerano, Bombard	+	+ / R	+ / R	-	-	-	-	-	-	-
Clincher	+ / R	+ / R	+ / R	-	-	-	-	-	-	-
Grandstand	-	-	-	-	+	-	-	-	+	-
Granite	+	+ / R	-	+ / R	+ / R	+	-	+	+	-
Londax	-	-	-	+ / R	+ / R	+ / R	-	+	+ / R	-
Regiment	+ / R	+ / R	-	± / R	±	+ / R	-	±	-	±
Shark	-	-	-	+	+	+	-	±	±	±
Stam or Superwham	+	+	-	+ / R	+ / R	±	-	±	±	±
Sandea	±	±	-	+ / R	+ / R	+ / R	-	+	+ / R	-
Prowl	+	+	+	±	-	-	-	-	-	-

+ control
- no control
± suppression
R resistant, poor control

Abolish
(Pin-point Flood)

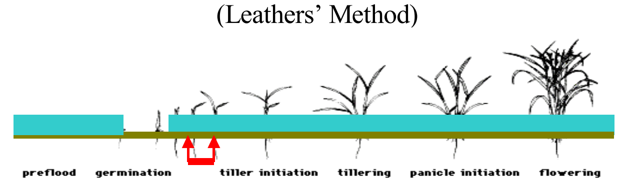


Emrg. shoot, 1st. lf.	Yes
Appl'd in water	No
Translocated	Little
Timing	1-3 lsr
Resistance	Yes

Application timing

1.0 to 3.0 lsr (4 lb ai/ac)

Bolero
(Leathers' Method)



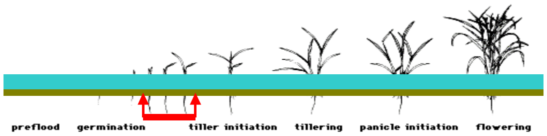
Emerg. shoot	Yes
Appl'd in water	Yes
Translocated	Little
Timing	2 lsr
Resistance	Yes

Application timing

2.0 lsr (4.0 lb ai/ac)

Bolero

(Permanent Flood)



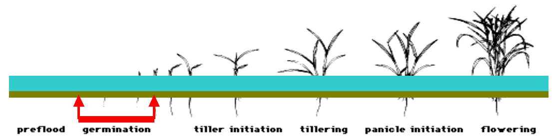
Emerg. shoot	Yes
Appl'd in water	Yes
Translocated	Little
Timing	1-2 lsr
Resistance	Yes

Application timing

1.0 to 2.0 lsr (4 lb ai/ac)

Cerano

(Permanent Flood)



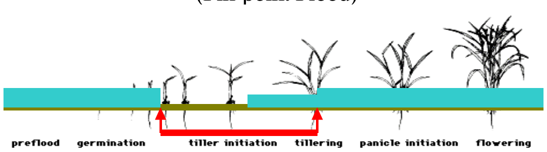
Roots, emerg. Shoots	Yes
Appl'd in water	Yes
Translocated	Yes
Timing	preseed-lsr
Resistance	Yes

Application timing

Preseed to 1.0 lsr (0.6 lb ai/ac)

Clincher

(Pin-point Flood)



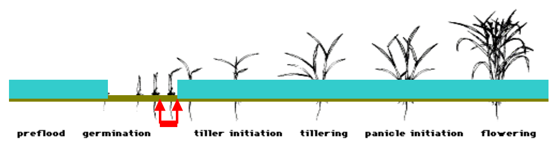
Foliar	Yes
Appl'd in water	No
Translocated	Yes
Timing	2 lsr-midtil
Resistance	Yes

Application timing

2.0 lsr to til (0.25 to 0.31 lb ai/ac)

Clincher

(Leathers' Method)



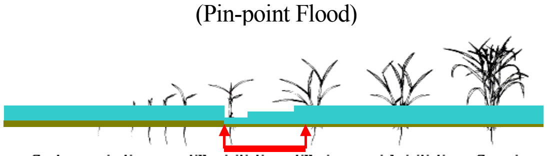
Foliar	Yes
Appl'd in water	No
Translocated	Yes
Timing	2 lsr
Resistance	Yes

Application timing

2.0 lsr (0.25 lb ai/ac)

Grandstand

(Pin-point Flood)



Foliar	Yes
Appl'd in water	No
Translocated	Yes
Timing	1 till-maxtil
Resistance	No

Application timing-

1.0 til to maxtil (0.25 to 0.375 lb ai/ac)

Londax, Sandea

(Permanent Flood)

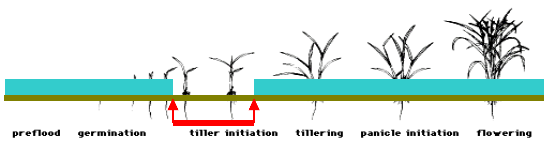
Foliar and roots	Yes
Appl'd in water	Yes
Translocated	Yes, moderate
Timing	0-5 lsr
Resistance	Yes

Application timing-

1.0 to 3.0 lsr (0.06 lb ai/ac)

Londax, Sandea

(Pin-point Flood)



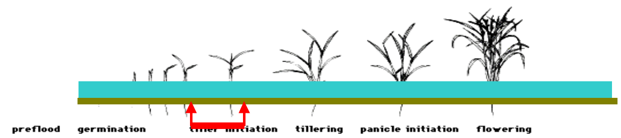
Foliar and roots	Yes
Appl'd in water	Yes
Translocated	Yes, moderate
Timing	0-5 lsr
Resistance	Yes

Application timing

3.0 lsr to 1-2 til (0.06 lb ai/ac)

Granite GR

(Continuous Flood)



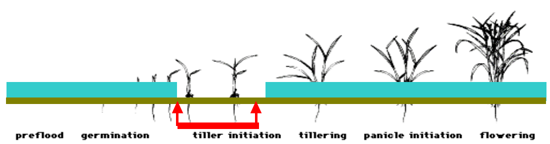
Foliar and roots	Yes
Appl'd in water	Yes
Translocated	Yes, moderate
Timing	2-3 lsr
Resistance	Yes

Application timing

2-3 lsr (0.04 lb ai/ac)

Granite SC

(Pin-point Flood)



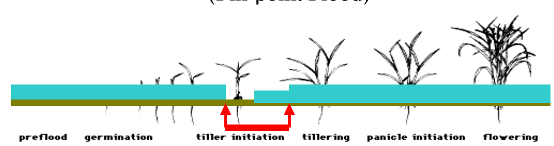
Foliar and roots	Yes
Appl'd in water	No
Translocated	Yes, moderate
Timing	2 lsr to 1 Till
Resistance	Yes

Application timing

2 lsr to 1-2 til (0.035 lb ai/ac)

Regiment

(Pin-point Flood)



Foliar and roots	Yes
Appl'd in water	No
Translocated	Yes, moderate
Timing	5 lsr-1 til
Resistance	Yes

Application timing

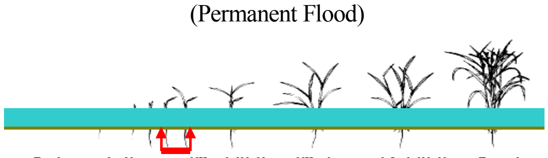
1.0 til to midtil (15 g ai/ac) (18 g ai/ac*)

*** For resistant late watergrass**

Shark

(D.D.A./D.S.A.)

(Permanent Flood)



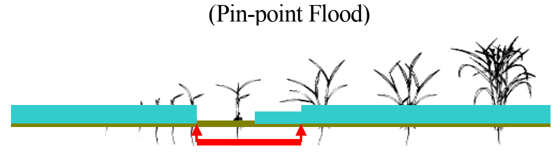
Foliar	Yes
Appl'd in water	Yes
Translocated	No
Timing	2-3 lsr
Resistance	No

Application timing

2.0 to 3.0 lsr (0.20 lb ai/ac)

propanil

(Pin-point Flood)



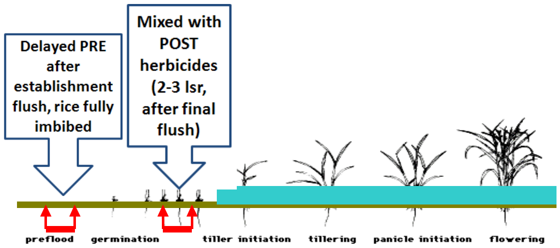
Foliar	Yes
Appl'd in water	No
Translocated	No
Timing	3 lsr-midtil
Resistance	No

Application timing

3.0 lsr to midtil (3 to 6 lb ai/ac)

Prowl

(Dry-seeded)



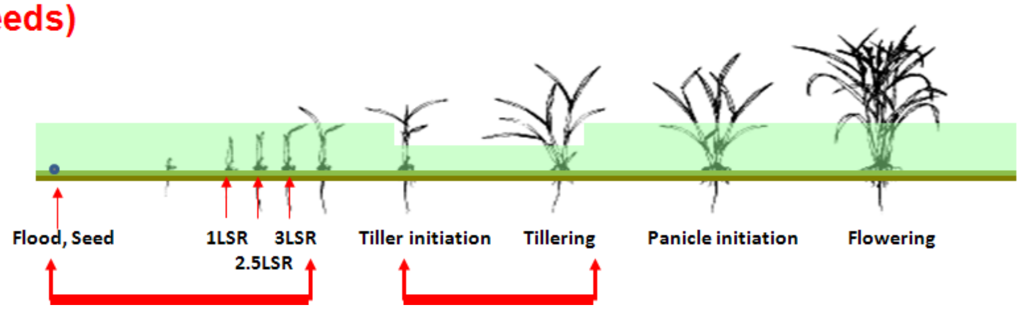
Foliar	No
Appl'd in water	No
Translocated	No
Timing	Delayed PRE or 2-3 lsr (as PRE)
Resistance	No

Application timing

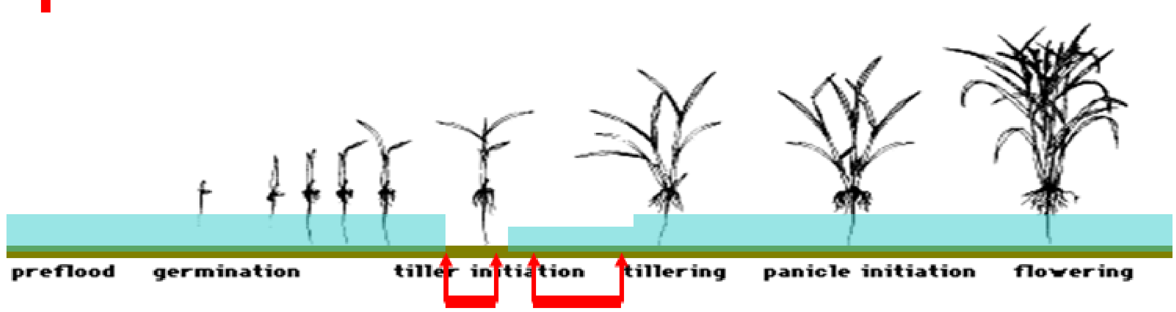
DPRE (1 lb ai/ac)

Figure 1b. *Major herbicide-based weed control systems for rice in California.*

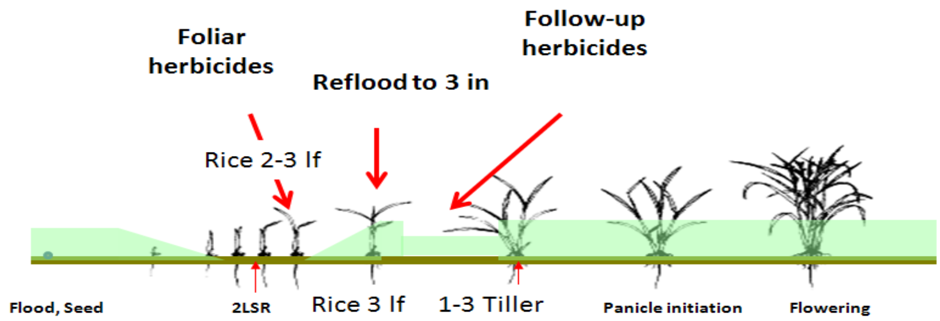
Permanent Flood (use granular herbicides into the water at early stages, then lower the water to spray foliar herbicides onto weeds)



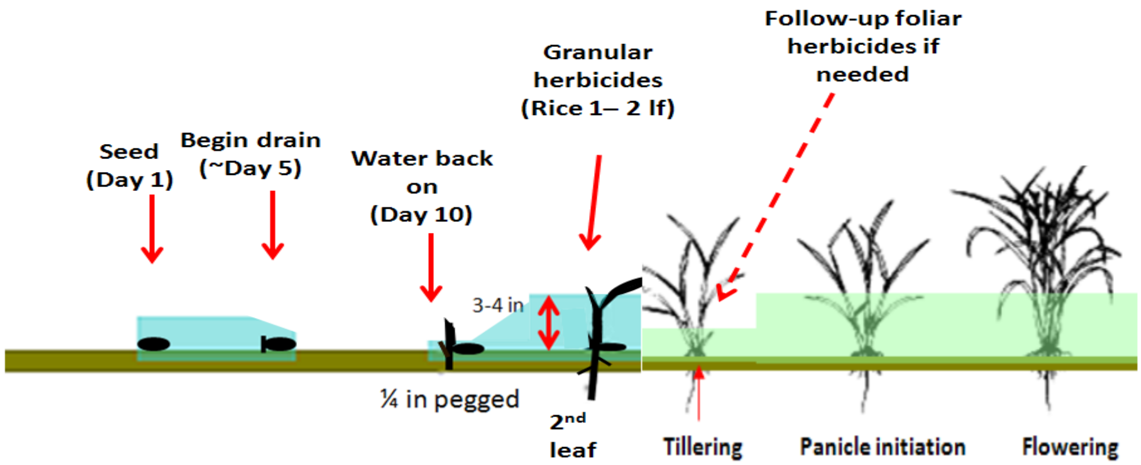
Pin-point Flood



Early Drain-foliar (Pin-point Flood/Leathers'): Drain to spray weeds while they are small; Then lower water to expose weed foliage to second spray)



Early Drain-granule: for granular herbicides into the water after reflood (requires ability for rapid reflood)



Drill-seeded (field is initially dry and then is gradually flooded deeper)

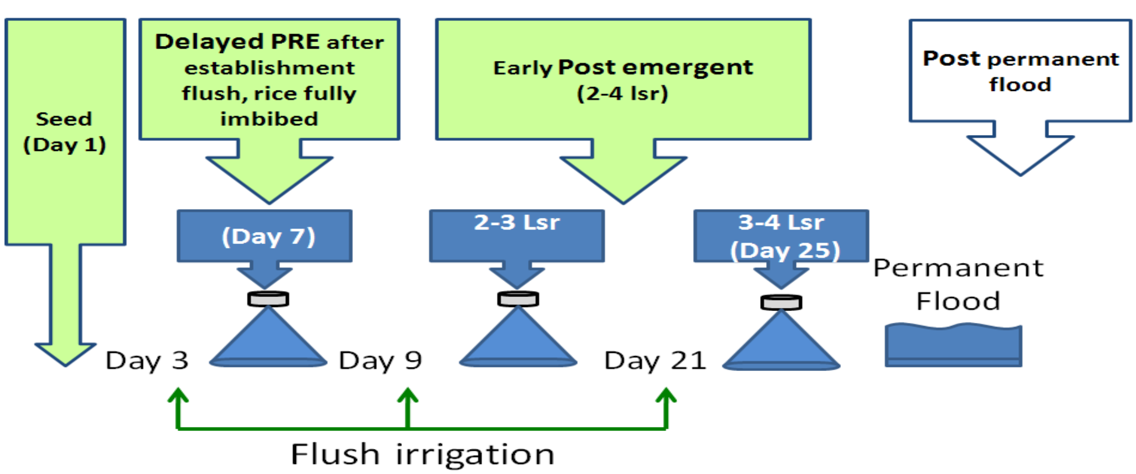


Figure 1b (continued). *Major herbicide-based weed control systems for rice in California.*

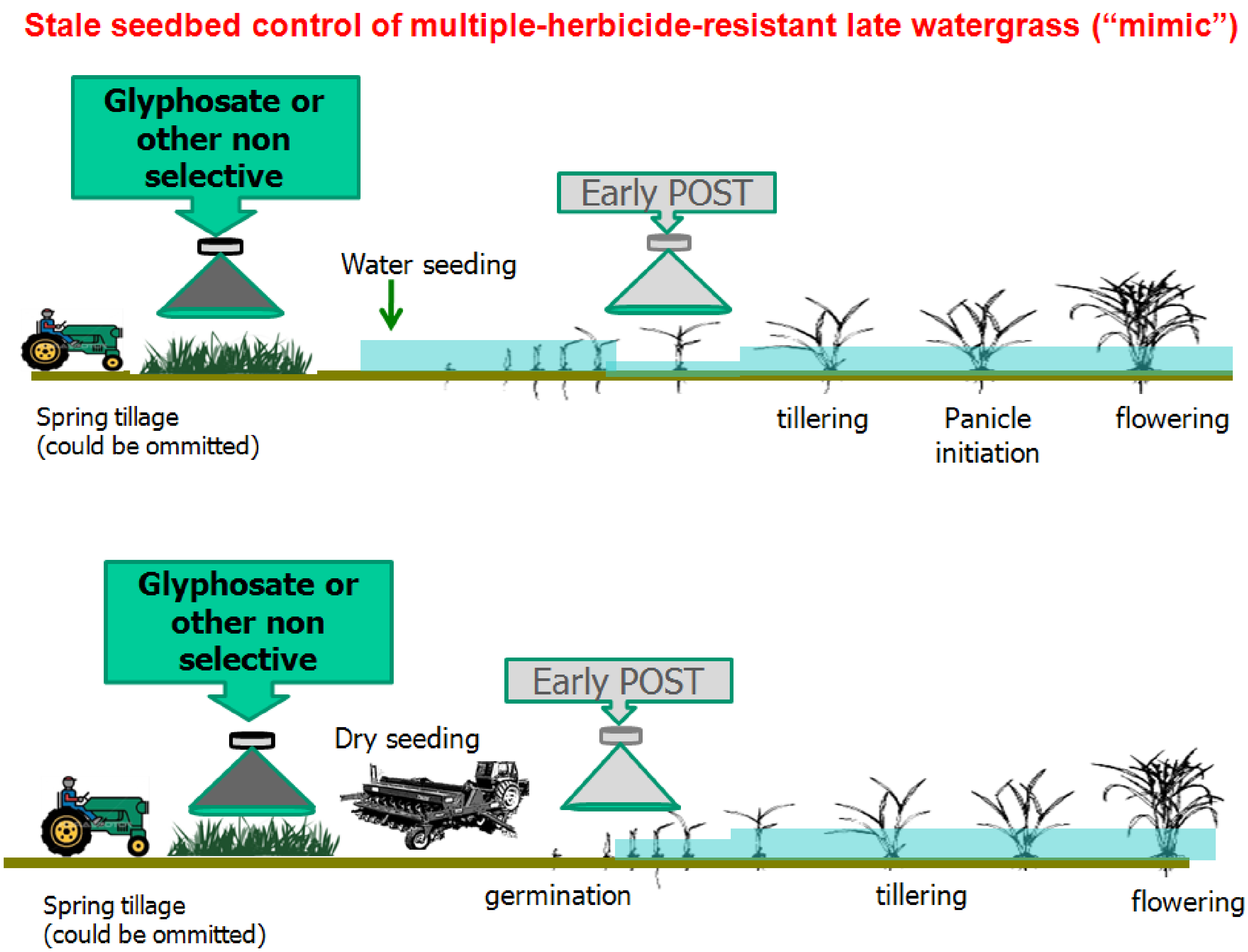


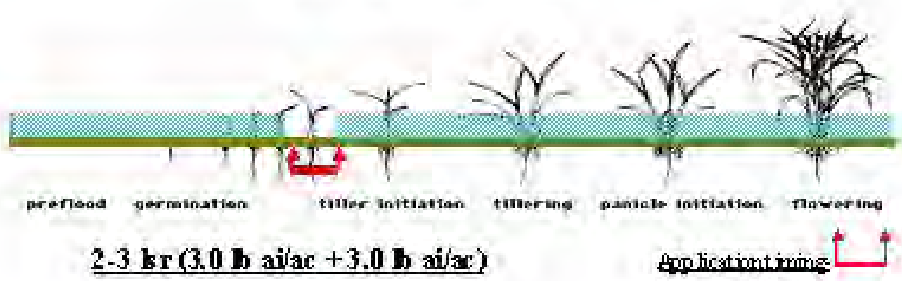
Figure 2. *Weed susceptibility, application timing and water management regimes for tank-mixed herbicides in California rice*

Weed susceptibility of tank mixes

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Stam or Superwham	+	+	-	+	+	±	-	±	±	±
Tank mixed with										
Abolish	+ / R	+ / R	+	+	-	-	-	-	-	-

\+ control
\- no control
± suppression
R resistant

Propanil + Abolish
(Pin-point Flood)



Weed susceptibility of tank mixes

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Regiment	+ / R	+ / R	-	-	+ / R	+ / R	-	±	-	±
Tank mixed with:										
Abolish	+ / R	+ / R	+	+	-	-	-	-	-	-
Shark	-	-	-	+	+	+	-	±	±	±

\+ control — no control R resistant ± suppression

(Pin-point Flood)

*** Synergistic mixture intended only for late watergrass**

Application timing

5-6 lsr (10-15 g ai/ac + 2.0-3.0 lb ai/ac)

- Can also have effect on small flower and ricefield bulrush

Regiment + Shark

(Pin-point Flood)

Application timing

4-5 lsr (12-15 g ai/ac + 0.20 lb ai/ac)

- Broad-spectrum

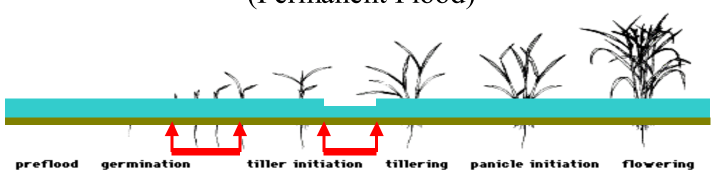
Figure 3. *Weed susceptibility, application timing and water management regimes for herbicide sequences with Regiment.*

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Bolero	+ / R	+ / R	+	+	-	-	-	-	-	-
Followed by										
Regiment	+ / R	+ / R	-	-	+ / R	+ / R	-	-	-	±

\+ control
\- no control
± suppression
R resistant

Bolero fb. Regiment

(Permanent Flood)



1.0 to 2.0 lsr (4.0 lb ai/ac)

Fb.

1-3 til (15 g ai/ac)

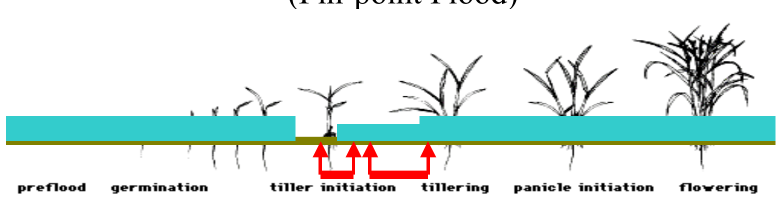
Application timing

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Regiment	+ / R	+ / R	-	-	+ / R	+ / R	-	-	-	±
Followed by										
Stam or Superwham	+	+	-	+	+	±	-	±	±	±

\+ control
\- no control
± suppression
R resistant

Regiment fb. propanil

(Pin-point Flood)



Application timing

NO WATERGRASS RESISTANCE TO PROPANIL

5 lsr to 1 til (15 g ai/ac)

Fb.

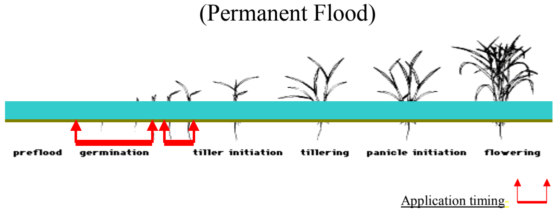
2-3 til (6 lb ai/ac)

Figure 4. *Weed susceptibility, application timing and water management regimes for herbicide sequences with Cerano in California rice.*

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Cerano	+	+ / R*	+ / R	-	-	-	-	-	-	-
Followed by:										
Londax	-	-	-	+ / R	+ / R	+ / R	-	+	+ / R	-
Regiment	+ / R	+ / R	-	± / R	±	+ / R	-	±	-	±
Shark	-	-	-	+	+	+	-	±	±	
Stam or Superwham	+	+	-	+ / R	+ / R	±	-	±	±	±
Grandstand	-	-	-	-	+	-	-	-	+	-

Cerano fb. Londax

(Permanent Flood)



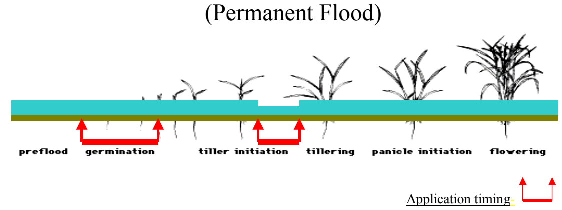
Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

2-3 lsr (0.06 lb ai/ac)

Cerano fb. Regiment

(Permanent Flood)



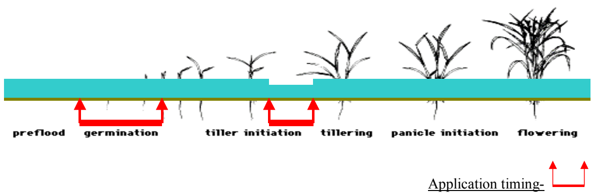
Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

2-3 Tiller (15 g ai/ac)

Cerano fb. propanil

(Permanent Flood)



NO RESISTANCE TO PROPANIL

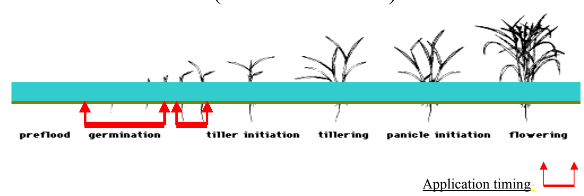
Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

1-3 til (6 lb ai/ac)

Cerano fb. Shark

(Permanent Flood)

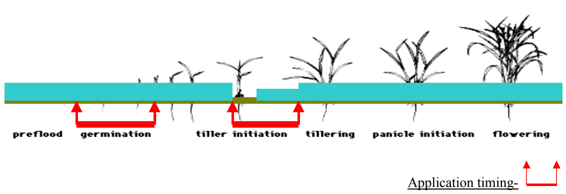


Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

2-3 lsr (0.2 lb ai/ac)

Cerano fb. propanil + Grandstand



Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

1-3 til (6.0 lb ai/ac + 0.25 lb ai/ac)

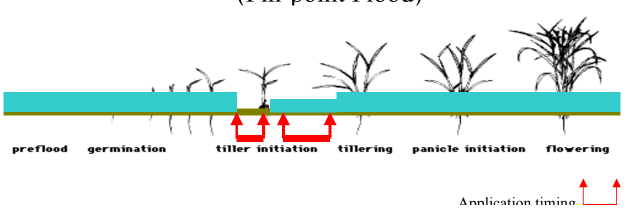
Figure 5. *Weed susceptibility, application timing and water management regimes for herbicide sequences with Clincher in California rice.*

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Clincher	+ / R	+ / R	+ R	-	-	-	-	-	-	-
Followed by:										
Londax	-	-	-	+ / R	+ / R	+ / R	-	+	+ / R	-
Regiment	+ / R	+ / R	-	± R	+ / R	+ / R	-	±	-	±
Stam or Superwham	+	+	-	+ R	+ R	±	-	±	±	±
Shark	-	-	-	+	+	+	-	±	±	

\+ control - no control R resistant ± suppression

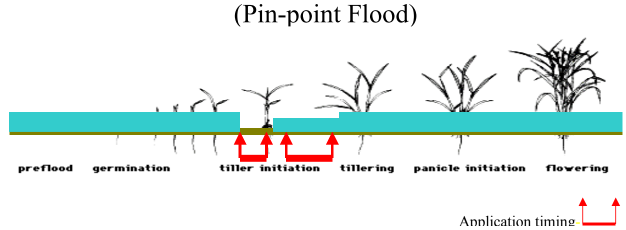
Clincher fb. Londax

(Pin-point Flood)



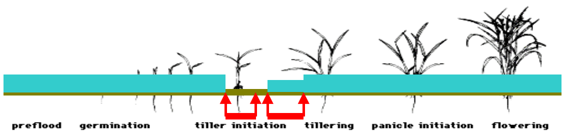
Clincher fb. Regiment

(Pin-point Flood)



propanil fb. Clincher

(Pin-point Flood)



Application timing

NO WATERGRASS RESISTANCE TO PROPANIL

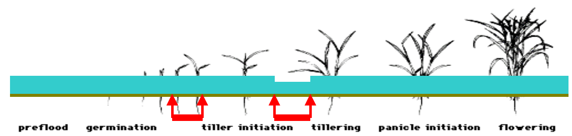
5-6 til (6.0 lb ai/ac)

Fb.

1 to 3 til (0.28 lb ai/ac)

Shark fb. Clincher

(Pin-point Flood)



Application timing

NO SEDGE RESISTANCE TO SHARK

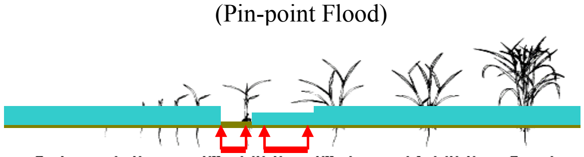
2-3 lsr (0.2 lb ai/ac)

Fb.

1 to 3 til (0.28 lb ai/ac)

Clincher fb. propanil

(Pin-point Flood)



Application timing

NO WATERGRASS RESISTANCE TO PROPANIL

3.0 to 6.0 lsr (0.25-0.28 lb ai/ac)

Fb.

2-3 til (6.0 lb ai/ac)

Figure 6. *Weed susceptibility, application timing and water management regimes for herbicide sequences with Granite. In the case of watergrass, resistance is strongest with late watergrass ("mimic"); resistance to ALS inhibitors may or may not involve all herbicides in that group.*

	barnyardgrass	watergrass	sprangletop	smallflower umbrella	ricefield bulrush	CA arrowhead	Gregg's arrowhead	ducksalad	redstem	monochoria
Granite	+	+ / R	-	+ / R	+ / R	+	-	+	+	-
Followed by										
Stam or Superwham	+	+	-	+ / R	+ / R	±	-	±	±	±

+ control

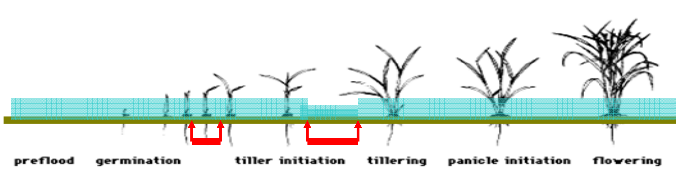
- no control

± suppression

R resistant, poor control

Granite (GR) fb Propanil

(Permanent Flood)



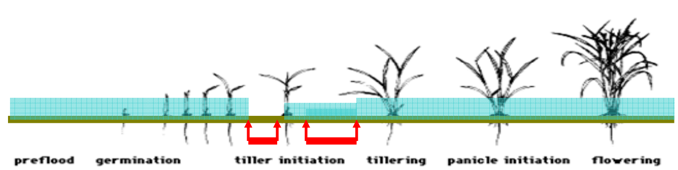
Application timing-

- If the WG population is already widely R to Granite, this sequence will not protect propanil

2.5 lsr (0.04 lb ai/ac)
Fb.
1-3 til (6 lb ai/ac)

Granite (SC) fb Propanil

(Pin-point Flood)



Application timing-

- Will not control sprangletop
- But Granite can be mixed with Clincher

3.0 to 4.0 lsr (0.031 lb ai/ac)
Fb.
2-3 til (6 lb ai/ac)

HERBICIDE RESISTANCE STEWARDSHIP IN RICE

University of California Cooperative Extension

June 2018

What is Weed Resistance?

- The ability of a weed biotype to survive treatment with a given herbicide to which the weed species is normally susceptible
- Herbicide-resistant biotypes are present within a weed species' population as a part of normal genetic variation
- Repeated use of the same herbicide or mode of action (MOA) will select for herbicide-resistant biotypes
- In California, we have two types of herbicide resistance: 1) **Target-Site** resistance and 2) **Non-Target Site** resistance
- Certain weed biotypes can be simultaneously resistant to herbicides that differ chemically and in their MOA
- Weeds that are not on the label will tolerate the herbicide, but are not resistant biotypes

Symptoms of Weed Resistance in the Field

Resistance needs to be ultimately confirmed by a specific test. Failure to control weeds can occur due to factors such as faulty spraying, incorrect dose or timing, weeds too large, subsequent weed germination after treatment, very large infestations, poor coverage, and other factors. The presence of resistance in the field is characterized by the following:

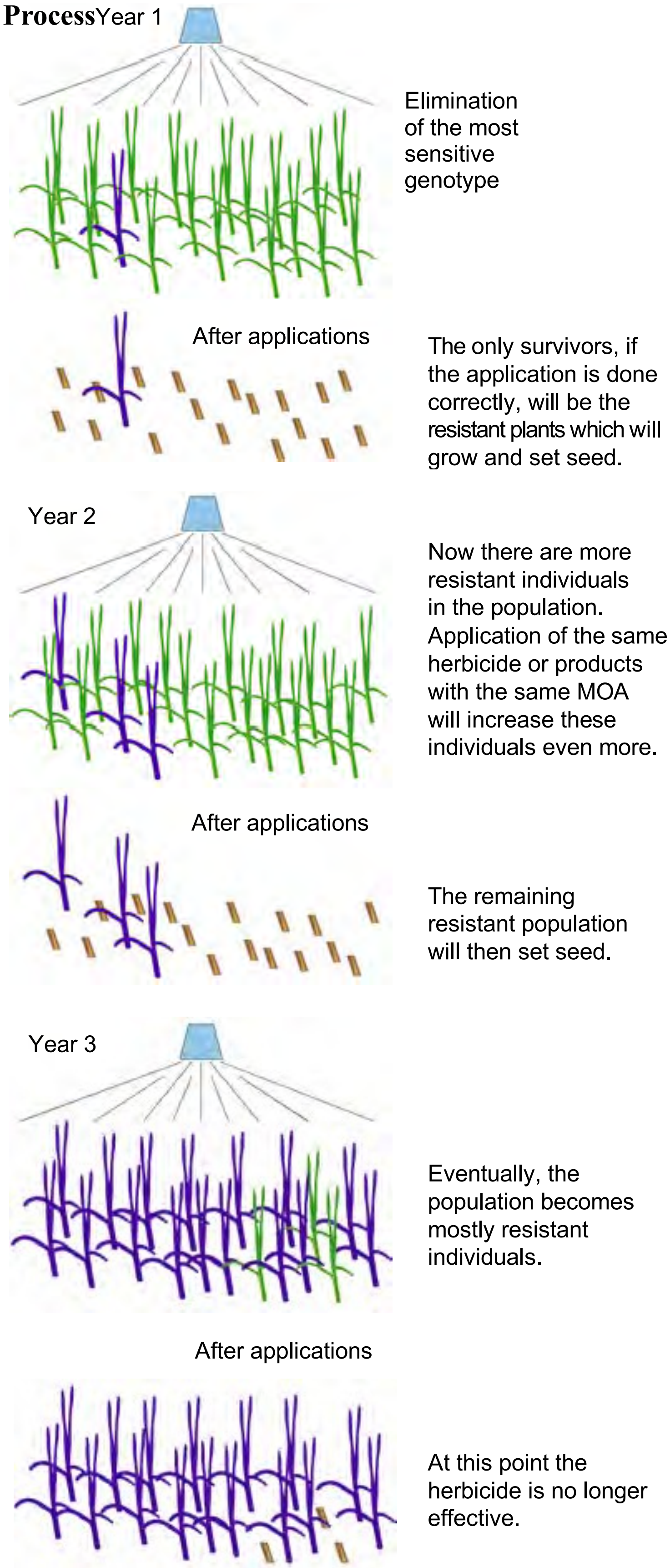
- There are healthy looking plants alongside dead plants of the same species after treatment
- One susceptible species is poorly controlled, while other adjacent susceptible species are well controlled
- The species was previously well controlled by the same herbicide and rate but a gradual decline in control has been noticed over time
- The same herbicide (or herbicides with the same MOA) has been used repeatedly on the same site
- Discrete patches of the target weed persistently survive treatment with a given herbicide(s)
- Resistance in the same weed species and herbicide occurs in neighboring field

What Factors Favor the Evolution of Resistance?

- Excessive reliance on chemical control and repeated sequential use of the same MOA
- A monoculture of continuous rice production
- Weeds that that have annual growth habit and produce lots of seeds with little dormancy
- A herbicide that has high efficacy on a specific wee species
- A herbicide with prolonged residual activity

Endorsed by the California Rice Commission and the California Rice Research Board

Stages of Herbicide Resistance Evolutionary Process



CALIFORNIA RICE WEED HERBICIDE SUSCEPTIBILITY CHART

Mode of action	Product name (active ingredient)	Grasses: Barnyardgrass	Grasses: Early watergrass	Grasses: Late watergrass	Grasses: Sprangletop	Sedges: Ricefield bulrush	Sedges: Smallflower umbrella sedge	Broadleaf weeds: Ducksalad	Broadleaf weeds: Monochoria	Broadleaf weeds: Redstem	Broadleaf weeds: California arrowheads
ACCase inhibitor ►	Clincher® CA (cyhalofop)	R	R	R	R (spreading)	No control	No control	No control	No control	No control	No control
Pigment synthesis inhibitor ►	Cerano® 5 MEG (clomazone)	R	R	R	R (spreading)	No control	No control	No control	No control	No control	No control
Lipid synthesis inhibitors ►	Abolish® 8 EC	R	R	R	R (spreading)	No control	Control	No control	No control	No control	No control
	Bolero® Ultramax (thiobencarb)	R (partial)	R (partial)	R (partial)	R (spreading)	No control	Control	No control	No control	No control	No control
Photosystem II inhibitors ►	RiceShot® 48 SF, Stam® 80 EDF CA, SuperWHAM!® CA (propanil)	R (spreading)	R (spreading)	R (spreading)	No control	R (spreading)	R (spreading)	Partial control / Suppression	Partial control / Suppression	Partial control / Suppression	Partial control / Suppression
ALS inhibitors	► Three classes of ALS inhibitors ►										
Protox inhibitor ►	Shark® H_2O (carfentrazone)	No control	No control	No control	No control	Control	Control (good control only when applied early)	Partial control / Suppression	Partial control / Suppression	Control (good control only when applied early)	Control
Auxin mimic ►	Grandstand® CA (triclopyr)	No control	No control	No control	No control	Control	No control	No control	No control	Control	No control
Cell divison inhibitor ►	Prowl® H_2O (pendimethalin) Drill-seeded rice only	Partial control / Suppression	Partial control / Suppression	Partial control / Suppression	Partial control / Suppression	No control	Partial control / Suppression	No control	No control	No control	No control

TSA = Triazolopyrimidine sulfonamide POB = pyrimidinyl oxybenzoate SU = sulfonylurea

Class / Mode of action	Product name (active ingredient)	Grasses: Barnyardgrass	Grasses: Early watergrass	Grasses: Late watergrass	Grasses: Sprangletop	Sedges: Ricefield bulrush	Sedges: Smallflower umbrella sedge	Broadleaf weeds: Ducksalad	Broadleaf weeds: Monochoria	Broadleaf weeds: Redstem	Broadleaf weeds: California arrowheads
SU	Londax® (bensulfuron)	No control	No control	No control	No control	R	R	Control	Control	R	R
SU	Halomax® Sandea® (halosulfuron)	No control	No control	No control	No control	R	R	Control	Control	R	R
SU	Strada® CA (orthosulfamuron)	R (partial)	R (partial)	R (partial)	No control	R	R	Control	Control	R	R
POB	Regiment® CA (bispyribac)	R	R	R	No control	R (partial; controls if the susceptible weed is emerging at the time of application)	R (partial)	Control	Control	R (partial; controls if the susceptible weed is emerging at the time of application)	R
TSA	Granite® GR	R	R	R	No control	R (partial)	R (partial)	Control	Control	R (partial)	R
TSA	Granite® SC (penoxulam)	R	R	R	No control	R (partial)	R (partial)	Control	Control	R (partial)	R
Lipid synthesis inhibitor + ALS inhibitor (SU)	League® MVP (thiobencarb + imazosulfuron)	R	R	R (partial)	Control	R	R	Control	Control	R	R
Photosystem II inhibitor + ALS inhibitor (SU)	RiceEdge® 60 DF (propanil + halosulfuron)	R (spreading)	R (spreading)	R (spreading)	No control	R	R	Control	Control	R	R
HPPD inhibitor + ALS inhibitor (SU)	Butte® Herbicide (benzobicyclon + halosulfuron)	Control	Control	Partial control / Suppression	Control	Control	Control	Control	Control	Partial control / Suppression	Control

Control | Partial control / Suppression | No control

R R No control of resistant plants. The resistance is already widespread.

R No control of resistant plants. The resistance is spreading.

Good control only when applied early | Controls if the susceptble weed is emerging at the time of application

http://rice.ucanr.edu

Weed Identification Pictures

Grasses

Barnyardgrass & Watergrass

Barnyardgrass and watergrass can easily be distinguished by the absence of a ligule around the collar region, or the region where the leaf blade encloses the stem, as compared to the presence of a membranous ligule with rice.

Left: Barnyardgrass and watergrass – no ligule
Right: Rice – membranous ligule present

Barnyardgrass
(Echinochola crus-galli)

Seedling

Tillering plant

Seedhead

Early Watergrass
(E. oryzoides)

Seedhead

Late Watergrass
(E. phyllopogon)

Seedhead

Bearded Sprangletop

(Leptochloa fusca ssp. fascicularis)

Ligule

Seedling

Tillering

Flowering structures

Sedges

Ricefield Bulrush

(Schoenoplectus mucronatus)

Seedling: Side-view

Seedling: Above-view

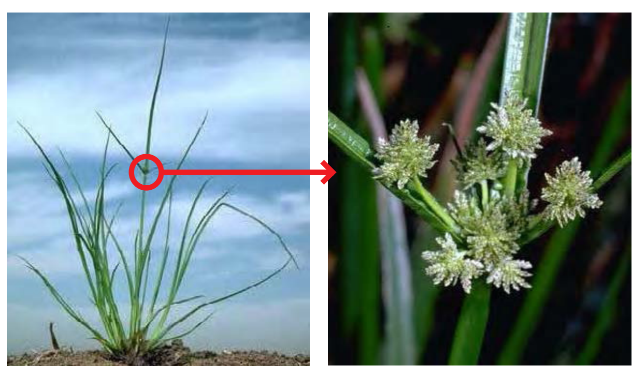
Flowering

Smallflower Umbrella Sedge

(Cyperus difformis)

Seedling

3-4 leaf stage



Flowering Sedge

Close-up: flowering structures

Broadleaveves

California and Gregg's Arrowheads

California and Gregg's arrowheads have similar seedling as shown to the left. They can not be distinguished until they have put on their first true leaf.

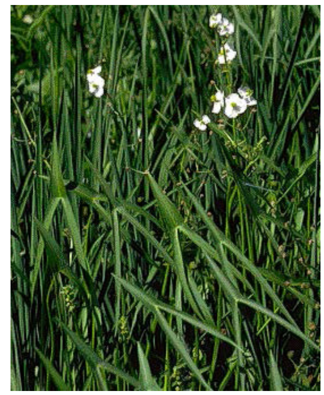
California Arrowhead
(Sagittaria montevidensis)

Leaf

Flowering Plant

Gregg's Arrowhead
(S. longiloba)

Leaf

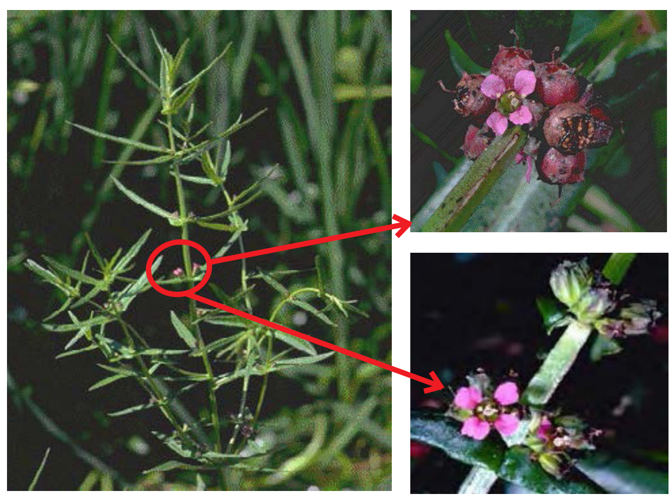


Flowering Plant

Redstem
(Ammannia species)

Emerging seedling

Seedling



Flowering redstem *Flowering structures*

Waterhyssop
(Bacopa rotundifolia)

Seedling

Mature Plants

Flowering Plant

Ducksalad
(Heteranthera limosa)


Emerging seedling


Mature plants in flower. The flowers may also be blue.

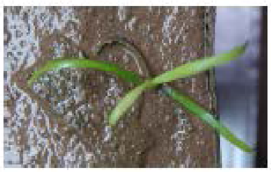
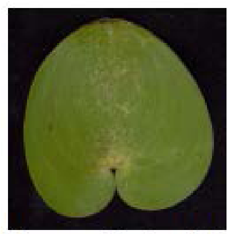
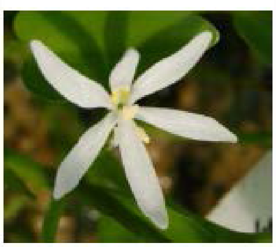
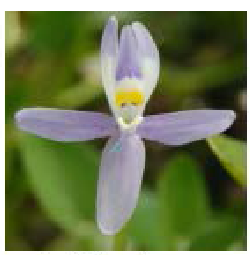
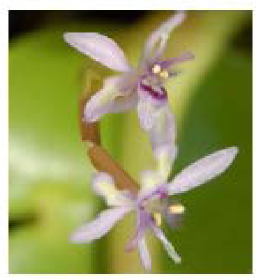
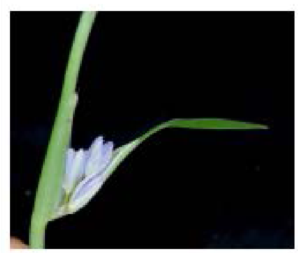

Ducksalad infestation

Common Waterplantain
(Alisma plantago-aquatic)


Seedling

Monochoria
(Monochoria vaginalis)

Ducksalad species found in Sacramento Valley rice fields

White-flowered *Heteranthera limosa* (Sw.) Willd.	**Blue-flowered** *Heteranthera rotundifolia* (Kunth) Griseb.	**Bouquet mudplantain** *Heteranthera multiflora* (Griseb.) Horn	**Monochoria** *Monochoria vaginalis* (Burm. F.) Kunth
 Adult plant	 Adult plant	 Immature and adult leaves	 Adult plant
 Seedling	 Seedling	 Seedling	 Monochoria seedling
 Leaves with rounded tips	 Leaves with rounded tips	 Adult Leaves with deep lobes at petiole attachment	 Leaves with pointed tips
 Single white flower	 Single blue flower	 Multiple blue-purple flowers	 Cluster of blue flowers

James Eckert, University of California, Department of Plant Science, Davis, CA

Weedy or "Red" Rice

Type 1:

- Short grain
- No color on nodes

Seeds:

- Awnless
- Straw-hulled seed
- High shattering
- High dormancy

Type 2:

- Medium grain
- No color on nodes

Seeds:

- Awnless
- Bronze-hulled seed
- High shattering
- Low dormancy

Type 3:

- Medium grain
- No color on nodes

Seeds:

- Awned
- Straw-hulled seed
- High shattering
- High dormancy

Type 4:

- Medium grain
- No color on nodes

Seeds:

- Awned
- Black-hulled seed
- High shattering
- High dormancy

Type 5:

- Medium grain
- Purple bands on nodes

Seeds:

- Awnless
- Straw-hulled seed
- High shattering
- Low dormancy

All California weedy rice types have the following characteristics:

- Red pericarped (red-branned)
- Light green leaves
- Pubescent (fuzzy) leaves
- Taller in height than Calrose varieties

Solitary weedy rice plant at mid-season

Weedy rice leaf collars

Patch of weedy rice next to levee prior to heading

Weedy rice ligule & auricles

UC CE

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Appendix 1.

Rice Pesticides Water Management Requirements Summary

Water must be held for the indicated number of 24-hour periods on the treated field, or within the containment area specified below before release into State waters.		Thiobencarb		Thiobencarb Plus Imazosulfuron	
		Bolero® UltraMax	Abolish® 8 EC	League® MVP	Malathion
		Hold	Hold	Hold	Hold
NORTH SAC VALLEY	Single treated fields.	30	19	30	4 (b)
	Release into tailwater recovery system or ponded onto fallow land or contained in other systems appropriate for preventing discharge.	19	19	19	
	System controlled by one permittee, then water may be discharged into the system in manner consistent with product labeling.	14	14	14	
	System includes drainage from more than one permittee, then water must be retained on site.	6	6	6	
	Water on fields within bounds of areas that discharge negligible amounts of drainage onto perennial streams. Commissioner must evaluate such sites and verify the hydrologic isolation of the fields.	6	6	6	
	CAC may authorize emergency release of tailwater.	19	19	19	
SOUTH SAC & SJ VALLEY (a)	All water on treated fields must be retained on the treated fields.	19	19	19	4 (b)
	Release into tailwater recovery system or ponded onto fallow land or contained in other systems appropriate for preventing discharge.	19	19	19	
	System controlled by one permittee, then water may be discharged in manner consistent with product labeling.	14	14	14	
	System includes drainage from more than one permittee, then water must be retained on site.	6	6	6	
	Water on fields within bounds of areas that discharge negligible amounts of drainage onto perennial streams. Commissioner must evaluate such sites and verify the hydrologic isolation of the fields.	6	6	6	
	CAC may authorize emergency release of tailwater.	19	19	19	

(a)- South Sacramento & San Joaquin Valley defined as: South of the line by Roads E10 and 116 in Yolo County and the American River in Sacramento County

(b) Volunteer hold.

Vertebrate Pests of Rice

Rice fields provide excellent habitat for some bird and rodent species. The Norway rat is probably the most serious vertebrate pest of rice, feeding on newly planted seed, seedlings, or ripening grain. Muskrats burrow in rice levees, damaging drainage systems and irrigation structures. Waterfowl and blackbirds may also cause yield losses in some localized areas.

The most successful vertebrate pest management program is one that manages pest populations at levels at which significant damage never occurs. This requires knowledge of the biology and behavior of the potential pests and regular monitoring for them in and around fields. Historical records of pest population levels, control measures implemented, economics of control procedures and the success of methods used, can be used to help determine the best management approach. Consideration also should be given to the presence of non-pest species and the potential risks of a control method.

The most successful vertebrate pest management program is one that manages pest populations at levels at which significant damage never occurs.

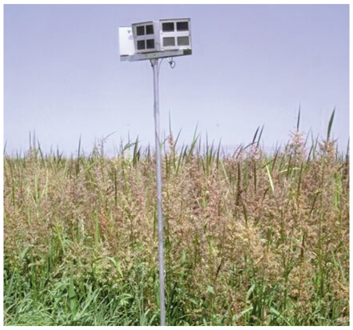
The methods and materials available for vertebrate control are constantly changing. Check with your County Agricultural Commissioner on laws and regulations concerning the status of wildlife species and the methods and materials available to control them.

Waterfowl

Annually, large numbers of waterfowl (ducks, geese, coots) migrate along the Pacific flyway to and from their northern breeding grounds and may spend from a few weeks to months in fall and winter in California's Central Valley. Flooded rice fields provide an ideal habitat for waterfowl and have an important role in the conservation of these birds. Because most rice in California is harvested prior to the arrival of migrating waterfowl, and planted after their departure, damage to rice is usually kept to a minimum. Most problems occur where waterfowl become 'resident'. Ducks and geese cause the most serious losses in rice by feeding on maturing grain and sometimes causing lodging. Coots may sometimes damage newly planted fields.

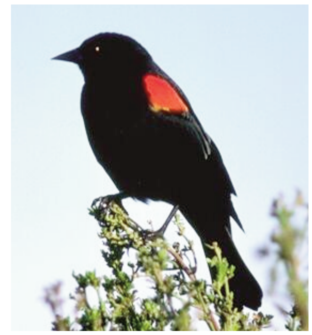
Management guidelines

All species of waterfowl are migratory game birds that are protected by federal and state laws. Waterfowl cannot be lethally controlled



without a depredation permit. Damage can usually be alleviated using frightening (hazing) techniques. Propane cannons, electronic noise makers, pyrotechnics, mylar tape and other sound and visual scare devices may be used to frighten waterfowl from areas where they are causing damage. Waterfowl may habituate to these techniques so they might only have short-term effectiveness. Persistence in applying the methods and alternating frightening devices are important in achieving success.

Blackbirds



Blackbirds may damage ripening rice, especially during the milk and dough stages. Losses may be quite high in some fields that are close to important roosting areas.

Management guidelines

Frightening techniques are most commonly used to manage blackbirds. Unfortunately, these techniques are even less effective for blackbirds than waterfowl. To be effective, you must instigate these controls as soon as birds appear in the field. A permit is not needed to lethally remove blackbirds that are causing or threatening to damage rice crops. To date, repellents have not proven to be effective in reducing blackbird damage to rice in California.

Norway rats

Rat damage to growing rice is usually most serious shortly after planting when the water is temporarily lowered for seed germination and stand establishment. This can be especially severe where fields are not leveled and high spots are exposed to air. The rats pull up the sprouting plants and eat the seeds. Rats may also consume ripening grain as the cereal heads come into the milk stage but losses are generally not as serious.

The Norway rat (*Rattus norvegicus*) is responsible for most rat damage in rice fields. Norway rats have a bulky appearance and a tail that is shorter than the length of their head and body combined. Rats are mainly active at night but if their numbers are high,

activity may be observed during the day. They are omnivorous and feed on a wide variety of plant and animal materials. Norway rats dig burrows and burrow systems are frequently found along levees beside rice fields. These burrows can weaken levees systems and affect irrigation.

Norway rats are prolific breeders. They are capable of breeding year-round under optimal conditions but most breeding is in spring and fall. Females produce about 4 litters per year. Average litter size is about 6, and the young are weaned at 3 weeks and become sexually mature at 2 to 3 months of age. These reproductive characteristics enable rat populations to rapidly increase and become widespread in response to onset of optimal environmental conditions. Populations typically undergo cycles of abundance. Problems are most likely to occur following mild winters and when food supply is abundant.

Management guidelines

Norway rats are non-native mammals and may be taken at any time and in any manner when they are causing damage to crops or other property. Where possible, non-crop habitats should be managed year round to reduce shelter and food supply for rats. Good weed control on levees is essential. Ground vegetation in areas adjacent to rice fields should be kept to a minimum by grazing or mowing.

When rat populations continue to be high despite habitat modification, rodenticides may be used. Currently (2003) registered rodenticides for Norway rat control on levees and adjacent non-cropped areas include the acute toxicant zinc phosphide and the anticoagulants diphacinone and chlorophacinone. The rodenticide and application method should be chosen with regard for potential non-target hazards. Consult your Agricultural Commissioner for specific information.

Zinc phosphide is an acute toxicant that is metabolized quickly within the target animal, and has minimal (if any) secondary poisoning risks. However, because of its fast action, rodents might only ingest a sublethal dose of bait before becoming sick. This may result in rodents becoming 'bait shy'. Consequently, it is best to wait at least 3 months, and preferably 6 months between applications. Zinc phosphide bait is placed according to label instructions in active burrows or in places frequented by rats but inaccessible to livestock, poultry, non-target wildlife, pets and children. When possible, prebait with clean grain several days before bait application to determine if rats are taking the bait and to overcome any bait shyness. Prebaiting is especially important where other foods are abundant.

Anticoagulant baits act by reducing the clotting ability of the blood. The target animal must consume a number of doses of bait over a period of several days to obtain a lethal dose. Because a residue of the anticoagulant bait may remain in the target animal (primarily in the liver), predators or scavengers may also be at risk of consuming a lethal dose of bait. Risk increases where treated rat populations levels are extremely high (i.e., high availability of carcasses containing anticoagulant) and in areas where and at times when predator and scavenger populations are especially abundant. Risk also increases when too much bait is applied. As with all rodenticides, follow the label carefully and use as little bait as possible to bring the population under control.

Anticoagulants may be applied in bait stations, by spot application, or in paraffinized bait blocks. Bait stations protect bait from rain and prevent non-target species feeding on the bait. To achieve control, keep the stations well-supplied until feeding ceases. Bait blocks made from paraffin may be placed in areas of rat activity. These blocks aren't as readily accepted as loose baits but are relatively waterproof and eliminate the need for bait boxes. Replace blocks as necessary and discard of uneaten bait when the control program is completed.

Muskrats

Muskrats (*Ondatra zibethicus*) are semi-aquatic rodents named for their conspicuous odor resulting from secretions from musk glands at the ventral base of the tail. They sometimes inhabit water supply canals and drainage ditches near rice fields. Their burrowing, especially around headgates can cause breaks in levees and dikes. Significant yield loss may occur before repairs can be completed. Muskrats also occasionally cut and eat rice plants.

Muskrats have dense fur, a long, laterally flattened tail and partially webbed feet. Adults are about 18 inches long and weigh from 1.5 to 2.5 pounds. Their native range in California was along the Colorado River by the Arizona border and in scattered locations on the eastern side of the Sierra Nevada from Mono to Lassen County. Construction of irrigation canals in the early 1900's enabled them to expand their range into southern California. A high demand for muskrat fur during the 1920's resulted in the release of muskrats elsewhere. Muskrats now occupy canals, ponds, and irrigation ditches throughout most of California.

Muskrats are very prolific. Most females have two or three litters per year, with an average of about 6 or 7 kits per litter. Most births occur in spring. The gestation period is between 25 and 30 days. The young become active and able to swim within 14 days, and are weaned at 28 days. Most become sexually active the spring after their birth.

Depending on the environment and season, muskrats construct either houses or dig burrows into banks. Unless the population is very dense, muskrats prefer to burrow into banks rather than build houses. Soil type and slope of the bank determine the permanence and complexity of a burrow system. Burrows often begin in the water, from 6- to 8-inches below the surface, and penetrate the embankment on an upward slant. Burrows are not typically found when banks are less than 0.2 meters high, slope is less than 10 degrees, or when combined sand/gravel content is less than 90 percent. Burrows may extend 20 feet or more into banks. Houses are usually constructed from the dominant emergent plants in the area. They are built at water level with several underwater tunnels or "leads" for entrances.

Muskrats are primarily herbivorous although animal matter like crayfish may occasionally be consumed. Muskrats feed on aquatic vegetation growing in the vicinity of their dwellings. Characteristic signs of muskrat feeding activity include food platforms and feeding houses. Most activity occurs at night, with peaks at dusk and dawn.

Management guidelines

Muskrats are classified as furbearers but can be taken at any time when they are causing damage to crops or other property. Management of vegetation to reduce muskrat food sources on levees and on ditch banks can help minimize muskrat problems. In some situations however, lethal control of muskrats is necessary. Trapping can be very effective in reducing muskrat populations and damage. Conibear traps are probably the most effective but it is important to note that while they can be used to remove muskrats causing damage, they cannot be used to trap muskrats for fur (see Fish and Game Code).

Anticoagulant baits (diphacinone and chlorophacinone) may also be used. Bait can be placed in floating bait boxes or bait blocks (also used for Norway rat control) may be placed in muskrat feeding areas on levees and banks.

Water Quality

Water is essential to agriculture. Without it, farmers could not grow crops or produce livestock. Fertilizers and crop protection chemicals are also essential to agriculture and their application needs to be carefully controlled to prevent contamination of water. People are becoming increasingly concerned about environmental issues and the safety of their water for drinking. Since some of the water used in rice irrigation passes through the field and is reused downstream, often for urban domestic purposes or for recreation, it is critical that rice growers and chemical applicators maintain the quality of drainage water. In the 1980s fish kills in the Sacramento River and off tastes in Sacramento drinking water (Fig. 1) due to pesticides in the waterways highlighted the importance of being good stewards of water resources. This chapter discusses current water quality regulations, what are the potential problems in regards to water quality for rice growers and how can we best manage rice systems to maintain high water quality standards.

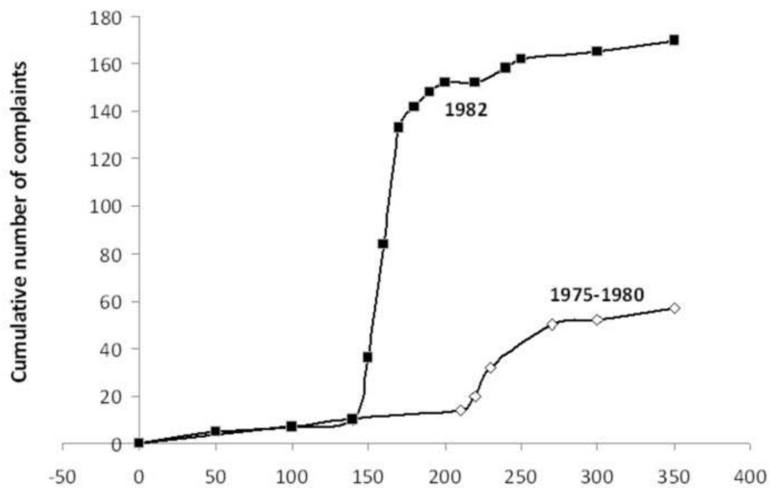


Figure 1. *Water taste complaints received by the City of Sacramento prior to (1975- 1980) and during the use of thiobencarb (1982).*

Water quality regulation in California's rice systems

The Clean Water Act (CWA) is the source for water quality regulation in California and the United States. In California, additional water code requirements, enacted by the Porter-Cologne Water Quality Control Act are found in California Water Code, Division 7. The California Water Code provides a broad scope in regulating waste or proposing to discharge waste within any region that could affect the quality of waters of the State. The term "waste" is a broad definition and the term "waters of the state" includes all surface water and ground water within the State. The California Water Code applies to point and non-point sources. Regulation occurs in several ways to dischargers: prohibition of discharge, waste discharge requirements (permit), or a waiver of waste discharge requirements.

> *Water is essential to agriculture. Without it, farmers could not grow crops or produce livestock.*

The California agricultural community received a waiver from a permit for discharging waste into waters of the State. The waiver expired on December 31, 2002. Since, 2003, all agriculture in California must comply with an agricultural discharge program referred to as the Ag Waiver. In 2008, the pro-gram was renamed the Irrigated Lands Regulatory Program (ILRP) because the word "waiver" implied that agriculture was exempt from regulation. Instead, agriculture is exempt from a permit as long as there is compliance with ILRP conditions to monitor pesticides and other constituents of concern (waste) discharged from the land into waters of the State. Current requirements allow for development of management plans when a certain number of exceedances occur. The California Rice Commission (CRC) manages the only commodity specific, general program under the waiver of waste discharge requirements (or ILRP program).

Constituents of concern

There are many constituents of concern listed in the ILRP as this program is for all irrigated lands. The constituents of concern for the rice industry are listed in Table 1. These constituents have been monitored by the CRC or during a two-year UC Davis study. While many of these constituents will be discussed in more detail later it is important to understand the effect of rice systems on these con- stituents. Natural waters do not contain pesticides and it is through the process of growing rice that pesticides are introduced into the water. Water does, however, contain carbon, nutrients and metals. Results from the UC Davis study found that water leaving rice fields (tailwater) had generally higher concentrations of dissolved organic carbon (DOC), total suspended solids (TSS), total disolved solids (TDS) and to a lesser extent ammonium and potassium (Fig. 2) throughout the year than the inlet water. Also, in the winter, phosphorus concentrations were higher in tail water than in the inlet water. This indicates that rice systems contribute to increases in these values.

Definitions

What is a "discharge"? A discharge would occur when any amount of wastewater that leaves your property enters surface waters of the State. The discharge does not have to be directly to surface water. For purposes of this program, it may first flow over a neighbor's property or through a toe drain along the edge of the field.

Who is a "discharger"? A discharger may include persons, individuals, corporation cities, special districts, farm owners, tenant farmers who release waste that could affect the quality of the water of the State.

What is "waste"? Waste is broadly defined in the California Water Code to include any and all waste substances that may include, but are not limited to soil, silt, sand, clay, rock, metals, salts, boron, selenium potassium, nitrogen, pes- ticides and fertilizers.

What are "waters of the State"? Waters of the State include any surface or groundwater with- in the boundaries of the Slate. Waters of the State include, for example natural streams, irri- gation ditches or canals, ponds, agriculturally- dominated waterways, and constructed agri- cultural drains.

Table 1. . *Constituents of concern monitored by the CRC or evaluated in a 2006/07 study.*

Constituent of Concern	*Water quality objective*	*Comment*
Herbicides		
Carfentrazone-ethyl (Shark)	ne*	
Clomazone (Cerano)	ne	
Cyhalofop-butyl (Clincher)	ne	
Fenoxaprop-p-ethyl (Whip)	ne	
Propanil (Stam)	ne	
Triclopyr TEA (Grandstand)	ne	
Thiobencarb (Bolero/Abolish)**	1.5 ug/L	Basin Plan performance goal under prohibition of discharge
Insecticides		
Diflubenzuron (Dimlin)	ne	
(s)-cypermethrin (Mustang)	ne	
Lambda cyhalothrin (Warrior)	ne	
Fungicides		
Azoxystrobin (Quadris)	ne	
Trifloxystrobin/ Propiconazole (Stratego)	ne	
Physical parameters		
pH	6.5-8.5	
Electrical conductivity (EC)	700 umhos/cm	CVRWQCB threshold
Dissolved oxygen (DO)	7 mg/L	Basin Plan water quality objective for lower Sacramento R.
Temperature	68^{o} F	Basin Plan water quality objective for lower Sacramento R.
Color	ne	
Turbidity	ne	
Total disolved solids (TDS)	ne	
Dissolved organic carbon (DOC)	3 mg/L	CALFED drinking water control program
Nutrients		
Total N	ne	
Nitrite-N	ne	
Nitrate-N	10 mg/L	EPA standard
Ammonia-N	25 mg/L	
Total phosphorus	ne	
Soluable phosphorus	ne	
Potassium	ne	
Metals		
Copper	10 ug/L	
Biological		
E. coli	235 CFU	

** ne=not established, ** City intakes have a thiobencarb maximum contamination level (MCL) of 70.0 ug/L (toxicity), and a secondary MCL of 1.0 ug/L (off taste), CVRWQCB=Central Valley Regional Water Quality Control Board*

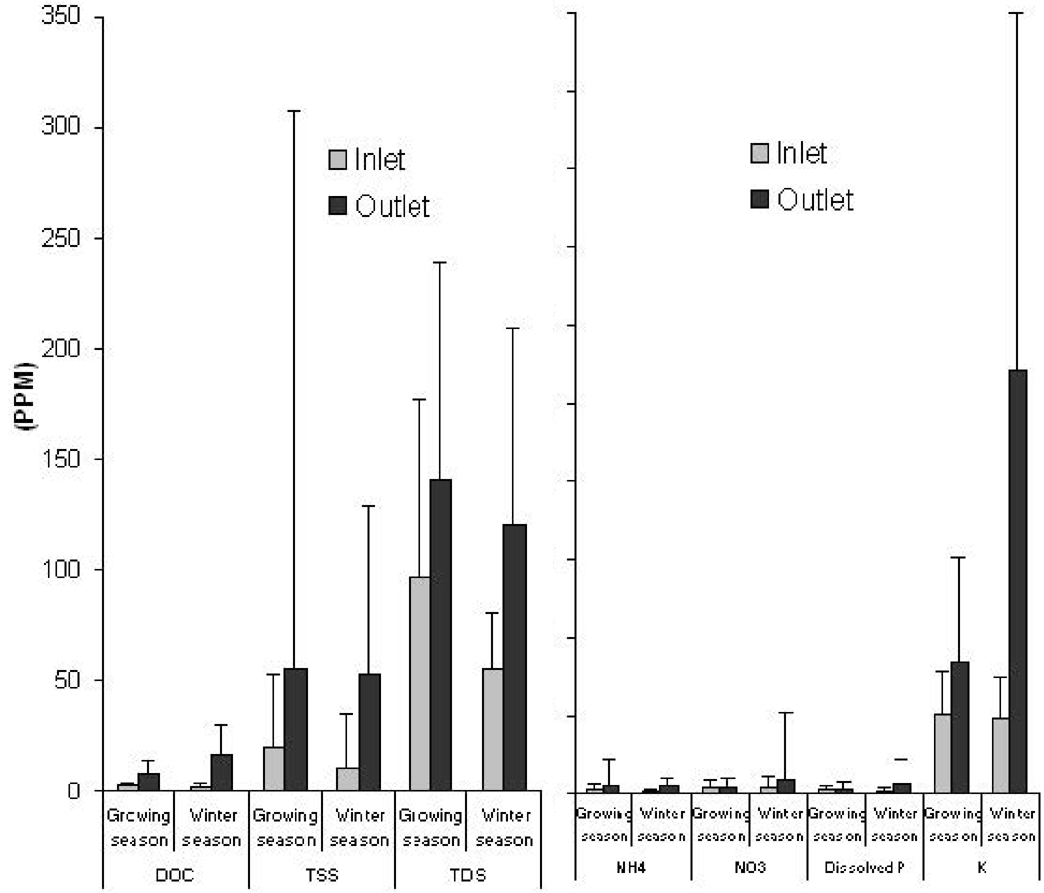


Figure 2. *Concentrations of dissolved organic carbon (DOC), total suspended solids (TSS), total dissolved solids (TDS), ammonium (NH4), nitrate (NO3), dissolved phosphate and potassium (K) from rice field water inlets and outlets averaged over two growing and winter seasons. Error bars are standard deviations of all of the fields and sampling events within that period.*

Pesticides

California rice growers receive regulations under a prohibition of discharge program, the Rice Pesticides Program (RPP). The RPP began in the late 1970's, early 1980's and was officially adopted into regulation under the Basin Plan in 1990. Under the RPP, rice growers must follow approved management practices and monitor specific pesticides to meet performance goals in agricultural drains. The five pesticides under the RPP include two herbicides thiobencarb, molinate (cancelled and no longer monitored after 2009), and three insecticides no longer monitored: carbofuran (cancelled and no longer monitored on rice), malathion and methyl parathion (little or no use on rice).

Monitoring for thiobencarb in 2008 found that there were 37 detections of thiobencarb in water from the main rice drains and the Sacramento River. However, only two of these samples had thiobencarb concentrations above the performance goal of 1.5 ug/L (1.5 ppb). Monitoring results at the city intakes show two detections at Wes Sacramento, and one detection at Sacramento with no exccedances of the secondary max- imum contaminant level (MCL) for off taste of 1.0 ug/L (1.0 ppb). During this same period there were only three detections of molinate and no exceedances (greater than 10 ppb).

Propanil is an important herbicide in the rice industry. It was reintroduced in the rice industry after being cancelled for drift issues in 1969. Propanil was never a consideration for the RPP because the product never caused any water quality impairments. The water board currently has concerns only because propanil is used a lot. The majority of loca- tions sampled by the CRC had no detectable levels of propanil; howev- er, it was detected during a one to two week period from the mid to end of June. This highlights the importance of all growers to adhere to the hold times for all pesticides as indicated on the label. This will be dis- cussed later.

Physical parameters

Dissolved oxygen (DO)

DO is the amount of gaseous oxygen (O_2) dis- solved in water. Oxygen diffuses into water from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. Adequate DO is necessary for good water quality as oxygen is a neces- sary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for fish and other aer- obic life forms.

Factors that contribute to low DO values are biological oxygen demand from the decomposition of organic matter. Low DO may also be caused by high levels of algae in the water (and the resulting diurnal oxygen depletion resulting from nighttime algae uptake), and/or flow of water that limits natural aeration. Warm water temperature can also contribute to low DO values. As temperatures increase oxygen solubility decreases. Due to the above factors (primarily temperature) low DO values were found in some of the major rice drains between June and September.

pH

The pH of water is a measure of the concentration of hydrogen ions. The pH determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients and heavy metals (i.e. lead, copper, cadmium). In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble. The water quality objective is to maintain water pH values between 6.5 and 8.5. Sampling the main rice drains in 2008 found no water samples outside of this range.

Electrical conductivity (EC)

EC estimates the amount of total dissolved salts, or the total amount of dissolved ions in the water. The salt content of water has a large impact on aquatic life and can have a negative impact on rice. The threshold cited by the CVRWQCB for reporting is 700 umhos/cm (NOTE: this value is for monitoring purposes only and should not be adopted as a salinity water quality objective). The 2008 sampling season yielded three samples above this critical level. These were all during storm events which occurred outside of the growing sea- son.

Total Suspended Solids (TSS)

Total suspended solids include all of the particulates suspended in water. In a two year UC Davis study TSS ranged from almost 0 to over 500 mg/L; however in most cases it was less than 100 mg/L (Fig. 3). High TSS is most likely the result of wind or storm events that stir up the water. Also, high TSS values are found when the flash boards are first removed and the high volume of water flowing out of the outlet churns up the soil around the outlet.

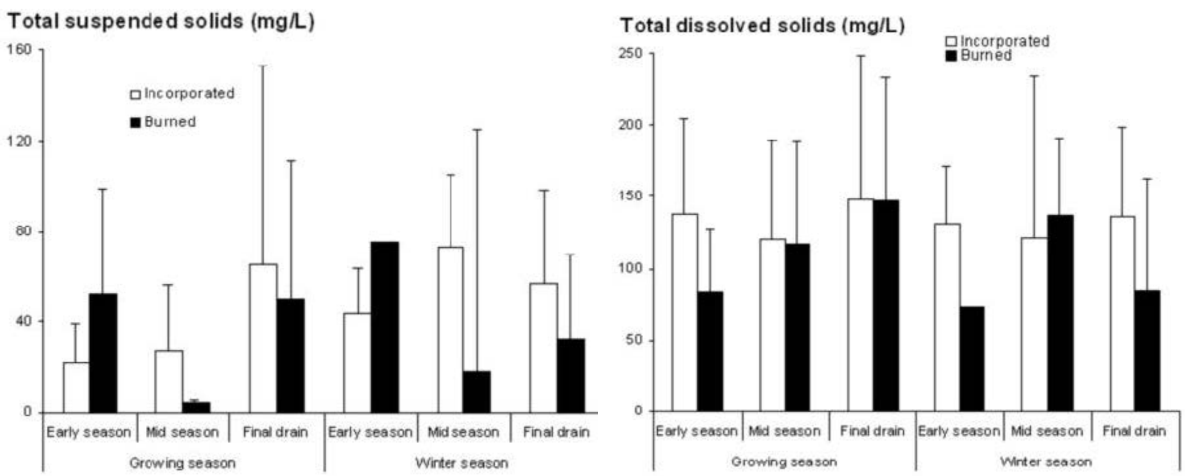


Figure 3. *Total suspended solids and total dissolved solids in water leaving rice fields. Data are averaged over two growing seasons.*

Total Dissolved Solids (TDS)

TDS is an expression for the combined content of all inorganic (minerals and salts) and organic substances in water. Although TDS is not generally considered a primary pollutant (e.g. it is not deemed to be associated with health effects), but it is rather used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of presence of a broad array of chemical contam- inants.The Sacramento River typically has TDS values less than 100 mg/L and agricultural watersheds are generally between 250 and 500 mg/L. A UC Davis study found only one water sample with a TDS greater than 500 mg/L. Most of the values were less than 200 mg/L(Fig. 3).

Dissolved organic carbon (DOC)

The amount of dissolved organic carbon (DOC) in water is often used as a non-specific indicator of water quality. Organic carbon is a precursor to the formation of harmful disin- fection byproducts (DBPs) in municipal water supplies when water is treated with chlorine. For example, trihalomethanes are one DBP that is considered to be a potential carcinogen. Source water with high DOC concentrations requires additional treatment steps to remove DOC and this increases the cost of treatment. Since the tap water of 22 million Californians originates in the Delta, DOC is an important public health concern. The CALFED Drinking Water Quality Program has the goal of achieving an average TOC concentration of 3 mg/L.

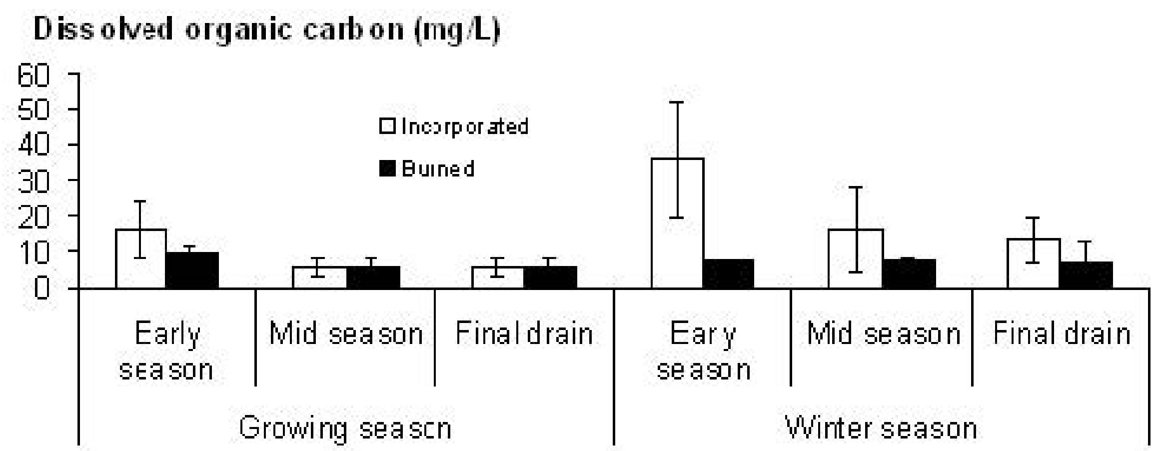


Figure 4. *Dissolved organic carbon in water leaving rice fields. Data are averaged over two growing seasons.*

A UC Davis study found that the DOC in rice tail water was higher than that entering the field (Fig. 2). On average the water entering the rice fields had DOC concentrations of 2.4 (+/- 2.4) mg/L which is low because none of the fields in the study used recycled water. While the average is below the 3 mg/L water quality objective, there were samples that were above 3 mg/L. On average, the DOC of the tailwater was 8.6 (+/- 5.4) mg/L. There were seasonal and straw management effects on DOC concentrations (Fig. 4). During the winter and early part of the growing season straw incorporated fields had higher DOC levels than burned fields. This difference was most pronounced at the onset of the winter flood period. During the growing season straw incorporated fields had slightly higher DOC levels at the beginning of the season. Best management practices (BMP) could be developed from this study; however, until critical levels of DOC are established for drainage waters from agricultural fields it is not necessary to adopt management strategies to control it.

Nutrients

Nutrients occur naturally in water as is shown in Figure 2 but they are also added to the water such as when fertilizers are applied. Good management of fertilizers will help ensure that nutrient levels remain low in rice field tailwater. Nitrogen (N), phosphorus (P) and potassium (K) are applied to farm fields as fertilizers but become a problem only when precipitation or flood water washes nutrients off the land and into water- ways.

Nitrogen (N)

High levels of N in water can to produce algae blooms. When the algae blooms die and decompose, oxygen in the water is depleted which causes problems for many aquatic plants and animals that require oxygen.

Some nutrients may pose a health risk to humans. Nitrates, a byproduct of N, are especially dangerous. In drinking water for instance, babies under 6 months of age can develop blue baby syndrome. Nitrates in the infant are converted by the body to nitrites that oxidize blood hemoglobin to methemoglobin. The altered blood cells can no longer carry oxygen, which can result in brain damage or suffocation. Epidemiological studies also show a correlation between high nitrate levels and gastric and stomach cancers in humans. The risk is so serious that the environmental protection agency (EPA) tightly regulates the levels allowed in drinking water. The upper limit for nitrates in drinking water is 10 mg/l as N which is about 45 mg/l of the nitrate ion.

In a two year study, NO_3-N water concentrations ranged from almost 0 to 2 mg/L, however, 85% of the waters sampled had NO_3-N levels less than 0.1 mg/L (Fig. 5). During the growing season the highest NO_3-N values were at the beginning of the season and may relate to fertilizer management practices-especially the application of starter fertilizers to the soil surface. In the winter, NO_3-N values varied throughout the season. High values in the winter may relate to water fowl. However, these values are well below 10 mg/L which is the drinking water quality standard.

Ammonia-N values were less than 1 mg/L in our study (Fig. 5). These values are very low and there was not a large affect of season or straw management.

Phosphorus (P)

Phosphorus is one of the principle causes of algal blooms in waterways. In rice fields high concentrations of P in the water also lead to algae problems. In a two year study, P concentrations in the outlet water was always less than 1.0 mg/L with the exception of one sample (Fig. 5). 77% of the samples had P values less than 0.1 mg/L which was the average P concentration of the inlet water. The highest P values were recorded during the winter from fields where the straw had been burned. The ash following burning is high in soluble P and may have accounted for the high P values found in water leaving these fields.

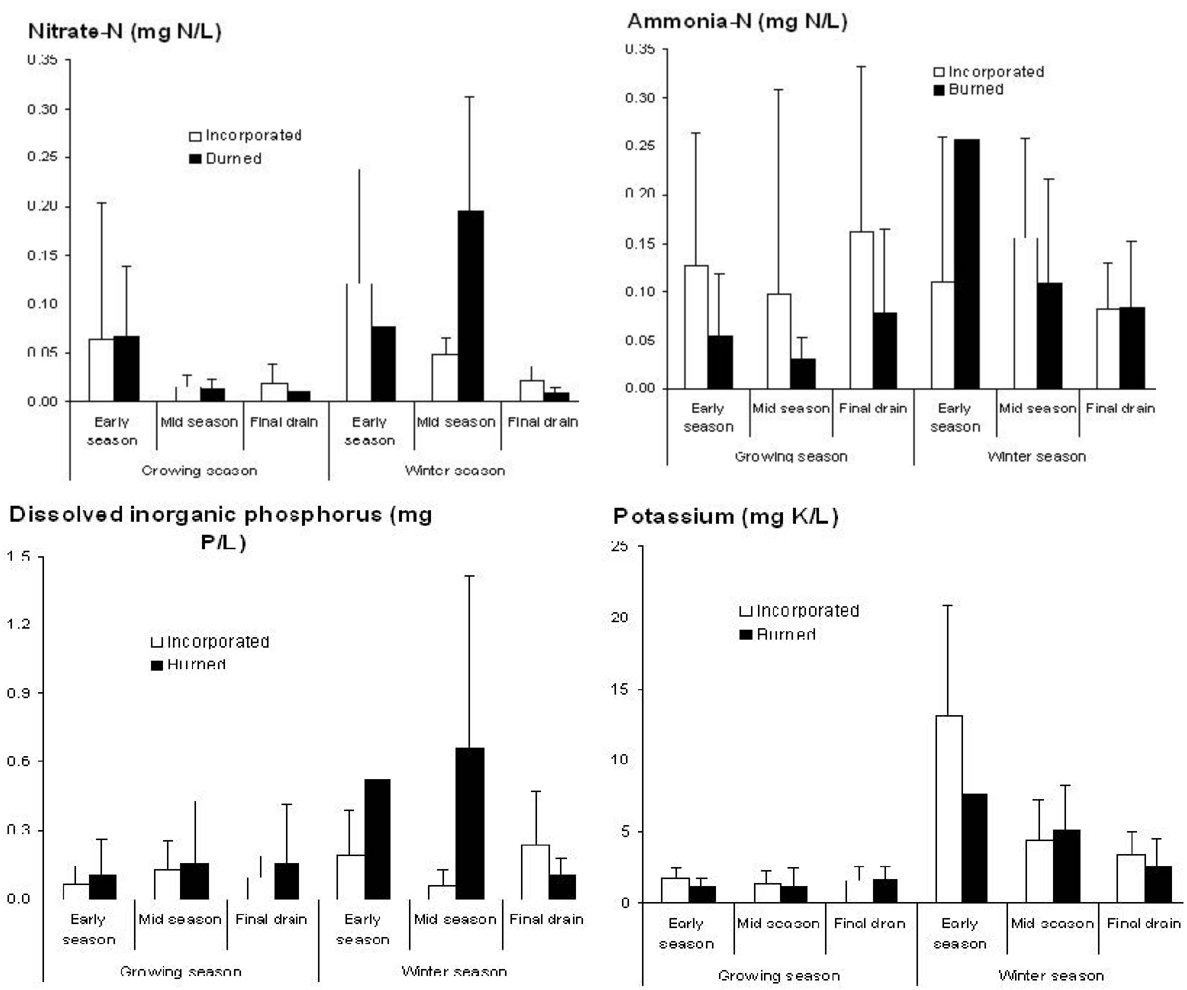


Figure 5. *Nitrate-N, ammonia-N, phosphorus and potassium concentrations in water leav- ing rice fields. Data are averaged over two growing seasons.*

Potassium (K)

Potassium is not normally considered a water quality problem and it is present in most irrigation water. The highest water K concentrations were during the early part of the winter season in fields where straw was incorporated (Fig. 5). Rice straw has a high amount of K in it which can be readily leached out into the flood water. K concen- trations were also high in burned fields during the winter period. The rice straw ash contains a high amount of soluble K. The ash and remain- ing rice stub- ble are likely the source of water K from these fields.

Metals

Copper (Cu) is the only metal being monitored from rice fields. The source of copper is from the pesticides that are used at the beginning of the growing season primarily to control algae and other pests. In 2006 almost 200,000 rice acres were treated with copper sulfate. In a two year study, Cu in rice tailwater was not detectable, however, copper sulfate was not used on any of the study fields.

E. coli

E. coli is a type of fecal coliform bacteria that comes from human and animal waste. Elevated levels of E. coli is an indicator that disease-causing bacteria, viruses and protozoans may be present. The water quality limit is 235 CFU (coliform forming units). Water was sampled from rice field inlets, outlets and drains over a two year period were conducted to determine if E. coli may be a concern. Importantly, the sample size in this study was very small, however, there are some trends worth discussing. First, E. coli levels were generally higher in the winter than during the growing season (Table 2), possibly due to the presence of waterfowl. Second, water entering and leaving rice fields was generally low in E. coli. In one rice field outlet sample the E. coli levels were above the 235 CFU limit. Third, the drains accepting rice field outflows is higher than the rice outlet water and in four cases exceeded the 235 CFU limit. High E. coli values in the drain may be the result of water fowl and other animals that live in and around the drains.

Table 2. *E. coli (CFU – coliform forming units) in water samples from rice field inlets, outlets and drains.*

Sample location	Season	Total number of samples	Fields sampled	Range	Mean	Number of samples above 235 CFU
				CFU		
Inlet	Growing	5	5	0-49	16	0
	Winter	3	3	22-80	44	0
Outlet	Growing	5	5	0-62	21	0
	Winter	5	6	0-551	133	1
Drain	Growing	3	1	82-3460	1410	2
	Winter	6	4	4-351	139	2

Management methods to maintain water quality - Nutrients

There are currently no water quality guidelines for nutrients, TDS, TSS, and DOC; therefore, we will not discuss in detail management options for these constituents. However, we can provide some general guidelines to reduce the levels of some of these constituents from rice field tailwater.

DOC

DOC concentrations are lower in burned vs incorporated fields during the onset of the winter flood period. Flooding is necessary when straw has been retained in rice fields to encourage straw decomposition. The primary way to reduce the amount of DOC leaving rice fields during the winter is to restrict the flow of water leaving the field.

Phosphorus

While P levels were generally low, levels can be high when P fertilizer is left on the soil surface prior to flooding for planting. Water P levels are greatly reduced by incorporating fertilizer or applying the P fertilizer at a different time (i.e. before fall straw incorporation, before spring tillage, or up to 30 days after sowing). These practices reduce P levels in water and also reduce algae growth in fields. Reductions in algae will reduce the amount of copper applied to fields which is another constituent of concern.

Alternative establishment systems

Alternative establishment systems can reduce herbicide use. California rice systems have more herbicide resistant weeds than any other single crop or geographic area in the US. In an effort to control these weeds growers may apply multiple applications or additional herbicides. Applying more herbicides increases the possibility of increasing resist- ant weed populations and increases the potential for herbicide drift which can end up in surface waters even if hold times are adhered to.

No spring tillage, combined with a stale seedbed, offers new opportunities to control herbicide-resistant weeds and use less and more environmentally friendly herbicides. A stale seedbed refers to the practice of flushing or flooding a field with water to induce weed seed germination and then killing the weeds (usually with glyphosate) before planting. The choice between flushing or maintaining the soil surface fully saturated depends on whether or not the field is infested with aquatic obligate weeds which require water saturation to germinate. The soil is then left undisturbed (no tillage) to ensure that buried weed seeds are not brought to the surface to germinate. This practice can be effective for controlling all types of herbicide-resistant weeds in rice systems because they are not resistant to glyphosate. In some studies conducted at the

California Rice Experiment Station the single application of glyphosate was the only herbicide needed season-long.

Holding periods for pesticides.

The primary water quality concern of the California rice industry is residue from pesticides applied to the fields. In 1984, state regulations began which required rice growers to hold pesticide-treated waters on their fields. Long term water holding following application is the primary management method for reducing pesticide concentrations in rice tailwater. This allows for degradation of pesticides within the field (Fig. 6). Different pesticides have different rates of degradation and thus different lengths of required holding periods (Table 3).

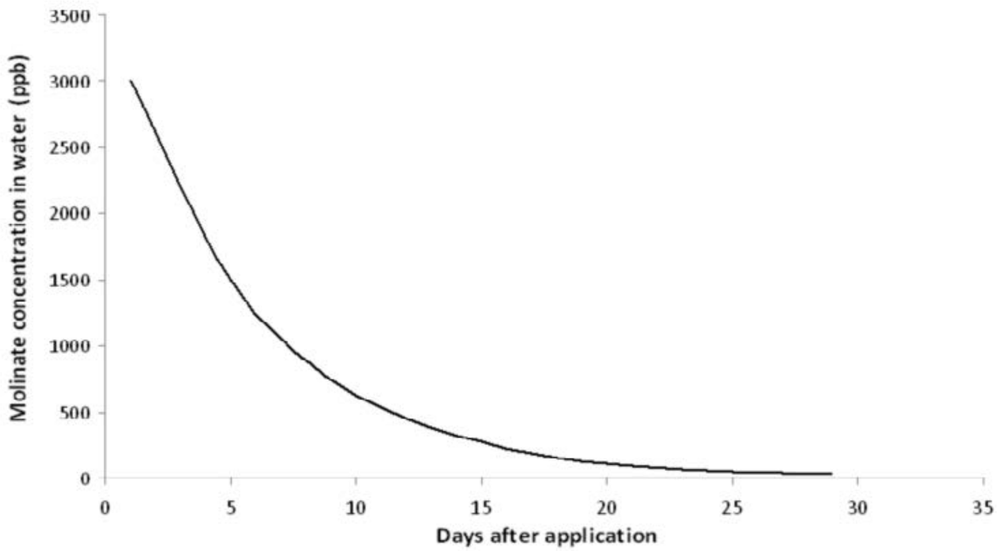


Figure 6. *E. Typical dissipation curve of molinate (Ordram®) in a typical commercial rice field. While molinate is no longer used in rice systems, such dissipation curves lead to the required holding period for molinate shown in Figure 7.*

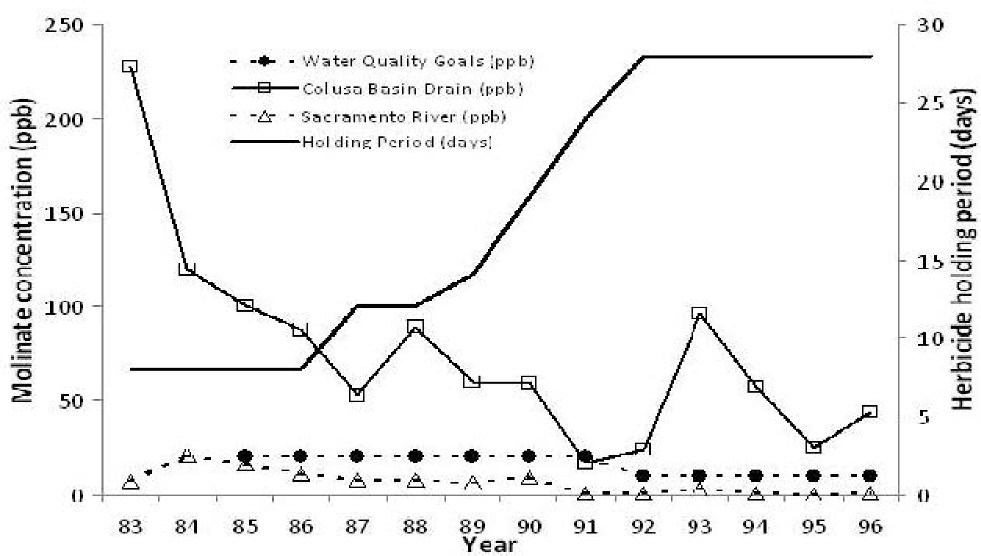


Figure 7. *Maximum concentrations of molinate (Ordram®) in the Colusa Basin Drain and the Sacramento River. While molinate is no longer used on rice this figure shows the effect of holding periods on water quality.*

Table 3. *Water holding and reentry requirements for various pesticides used in rice.*

COMMON TRADE NAME[1]	ACTIVE INGREDIENT	WATERHOLD TIME	PRE-HARVEST INTERVAL (PHI)	RESTRICTED ENTRY INTERVAL (REI)
INSECTICIDES:				
Sevin® Brand 4F	Carbaryl	0-days	14-days; propanil timing	12-hours
DuPont™ Coragen®	Chlorantranilprole	14-days	0 – soil applied	4-hours
Belay® Insecticide	Clothianidin	14-days	Up to 3rd leaf	12-hours
Mustang® Max Insecticide	(s)-cypermethrin	7-days	14-days	12-hours
Dimlin® 2L Insect Growth Regulator	Diflubenzuron	14-days	80-days	12-hours
Warrior® Insecticide	Lambda cyhalothrin	7-days	21-days; 27-days at the higher rate	24-hours
Malathion 8	Malathion	4-days	4-days: propanil timing	12-hours
FUNGICIDES:				
Quadris® Flowable Fungicide	Azoxystrobin	14-days	28-days	4-hours
Tilt® (propiconazole) Stratego® Fungicide	Propiconazole/ Trifloxystrobin	7-days	35-days	12-hours
HERBICIDES:				
Solution Water Soluble®	2,4-D	0 - days	60-days	48-hours
Londax® Herbicide	Bensulfuron-methyl	7-days static	80-days	24-hours
BUTTE® Herbicide	Benzobicyclon	20 - days	82-days	12-hours
Shark® Herbicide	Carfentrazone-ethyl	5-days static 30-days release: less closed system	60-days	12-hours
Cerano® 5 MEG Bombard™ Herbicide	Clomazone	14-days	120-days	12-hours
Clincher® CA Clincher Granule®	Cyhalofop-butyl	0 or 7-days	60-days	12-hours
Sandea® Herbicide	Halosulfuron-methyl	0 - days	69-days	12-hours
Granite® SC & GR	Penoxsulam	0-days	60-days	12-hours
Stam® 80 EDF	Propanil	7-days: less closed system	60-days	24-hours
Abolish® 8EC Bolero® UltraMax League® MVP	Thiobencarb	See table on reverse		7-days
Grandstand® CA Herbicide	Triclopyr TEA	20-days: less closed system	60-days	48-hours

The use of holding periods has been highly successful in reducing the level of rice pesticides in public waters. For example, molinate concentrations in the Colusa Basin Drain dropped from 230 to about 120 ppb in the first year that holding periods were required (Fig. 7). As the required holding period increased molinate concentrations continued to decline. However, water quality goals in the Colusa Basin Drain, and elsewhere, were exceeded in a number of years suggesting that seepage and off tar- get applications (e.g. drift) remain important sources of pesticides.

Current regulations provide for emergency release if a written request documents the crop is suffering because of the water management requirements. Emergency release will only be granted for problems related to rainfall, high winds, other extreme weather or salinity.

Adoption of other rice irrigation systems for tailwater management

Mandatory holding periods have made it difficult for rice growers with conventional irrigation systems to maintain flexibility in managing their irrigation water. Two systems are discussed in this section that will provide greater management flexibility and reduce or eliminate the possibility of spillage during water holding periods.

Gravity tailwater recapture irrigation system. The gravity tailwater recapture irrigation system utilizes pipes and gravity flow to divert tailwater from field to field thereby keeping drain water and pesticide residues out of public waterways. The water flows by gravity, eliminating tailwater pump and sump. Bypass drain pipes in upstream fields are installed in bottommost basins (checks) for maximum effectiveness. The pipe can enter the downstream field at any point, although entry into the upper portion of the field allows the greatest flexibility. The advantages of this system include improved tailwater and pesticide residue containment, management flexibility during water holding periods, and low construction and operation cost. The disadvantages are: when many basins are interconnected, the large water surface area may make quick and precise water management difficult; requires coordination of water among many fields; the system is not completely closed and may allow some tailwater and pesticide residue to enter public waterways.

The float valve rice box

The conventional irrigation system can be improved by replacing the conventional rice weir with a “smart box”. A smart box operates on the same principle as a toilet tank or a horse- trough valve. The plastic container or float of a smart box is adjusted so that it opens and closes a vertically-hinged butterfly valve. When the water in the downstream basin is low, the plastic container floats downward and opens the flap gate, allowing water into the basin. When the water depth reaches the set level (adjustable by adding or removing water from the hollow plastic float) the container floats upward, closing the valve: water cannot enter the basin. As long as a source of water is available to the topmost basin, the series of basins is regulated. Each basin takes in water as needed, and shuts off when the desired water depth is reached, thereby eliminating much of the day-to-day manage- ment associated with traditional flash-board weirs. Once smart boxes are properly adjusted, no spill should occur from the bottommost basin.

Seepage water management

Seepage is the lateral movement of irrigation water through a rice field levee or border to an area outside of the normally flooded production area. Seepage can occur through levees into adjacent dry fields or into existing drains and canals. Leakage caused by crayfish and rodent burrowing is not considered seepage, but can also result in the movement of irrigation water off rice fields. Seepage will be readily apparent later during the growing season as water accumulates and by green weedy growth along the edge of the field. Occasionally, seepage appears as a wet area that can damage a perimeter road. It is not currently regulated, but recommendations to reduce seepage include,

- Block any exits of seepage ditches that may drain into agricultural drains;
- For severe seepage, pump the water back into the field or fallow land;
- Inspect levees for crayfish or rodent damage, and repair any leaks;
- Build levees in the fall so they will compact;
- Build levees with enough soil moisture for good compaction;
- Avoid building levees with excessive straw;
- Compact levees with a tracklayer;
- Control crayfish and rodents.

Seepage water that contains high concentrations of pesticides can hinder efforts to comply with California's water quality goals. Efforts to meet these goals depend on long holding periods, which allow pesticides to dissipate almost completely in rice fields before release. Nevertheless, the concentrations of rice pesticides found in many agricultural drains exceed the levels found in tailwater released from rice fields after an adequate holding period. Therefore, seepage and off-target applications (for example, drift) are believed to be the source of the high concentrations currently found in agricultural drains. As holding periods for rice pesticides increased during the last decade, and the contribution of tailwater runoff to pesticide loading of surface waters declined, the relative contribution of seepage to such loading was recognized. Currently, seepage is regarded as an important contributor to pesticide loading in Sacramento Valley waterways.

Rice pesticides that do not strongly adsorb to soil particles, for example, molinate can move with seepage water from treated fields into agricultural drains or other nontarget areas. This seepage water will contain approximately the same concentration of certain rice pesticides as in the field.

In an effort to determine if rice pesticides, particularly molinate, can move with seepage water, the Department of Pesticide Regulation undertook a study to determine the extent of molinate movement from treated commercial rice fields through levee banks into adjacent ditches or fallow fields. In 1992, two sites, located in commercial rice fields in Colusa County, were chosen because they were known to have seepage problems in previous years. Prior to the application of molinate, the suspected seepage areas were covered with heavy plastic tarps to prevent contamination from aerial drift and kept covered throughout the study. At the first site, on a Willows clay, the molinate concentration in the seepage water peaked two days after application at 205 parts per billion (ppb). At the second site, on a Wikoda silty clay, concentrations at six days after sampling were as high as 720 ppb. At the time of the study the water quality goal for molinate was 10 ppb for all public waterways. While this study was not able to determine the extent of seepage throughout the Sacramento Valley, it did show that molinate can move with seepage water through levees to nontarget areas. Other studies conducted by the Central Valley Regional Water Quality Control Board found that both molinate and carbofuran are present in seepage water in ditches adjacent to treated fields. The concentration of these pesticides is likely to be present in the seepage water soon after the field has been treated.

Recognizing seepage and what causes it as well as when and where it occurs can be the first step to good seepage or leak control. For a more complete discussion, see “Seepage Water Management, Voluntary Guidelines for Good Stewardship in Rice Production”, UC Division of Agriculture and Natural Resources Pub. 21568.

Maintaining ground water quality

The above discussion has largely focused on maintaining surface water quality. However, there is increased interest by the ILRP in maintaining ground water quality.

Most rice is grown on impermeable heavy clay soils and thus there is relatively little percolation of surface water to below the root zone. Therefore, it is expected that constituents of concern do not readily leach below the root zone and into ground water in most rice fields.

There has been limited research on how rice farming affects ground water quality outside of research done on nitrate leaching (Liang et al., 2014). Research focused on nitrate leaching has shown that less than 2.5% of fertilizer N moves below the root zone annually. This is much lower than other crops grown on more permeable soils. The low amount of nitrate leaching in rice fields is due to several things:

1. The low permeability of soils
2. Fertilizer N is applied as ammonium or a form that quickly concerts to ammonium. Fertilizer N is not applied as nitrate.
3. Soils remain flooded or saturated for much of the season. This creates anaerobic conditions which prevents the ammonium from nitrifying to form nitrate.

This low potential for nitrate leaching is also seen in ground water monitoring wells in the Sacramento Valley (Figure 8). In just about all cases, ground water wells near rice fields had less than 5 ppm nitrate-N.

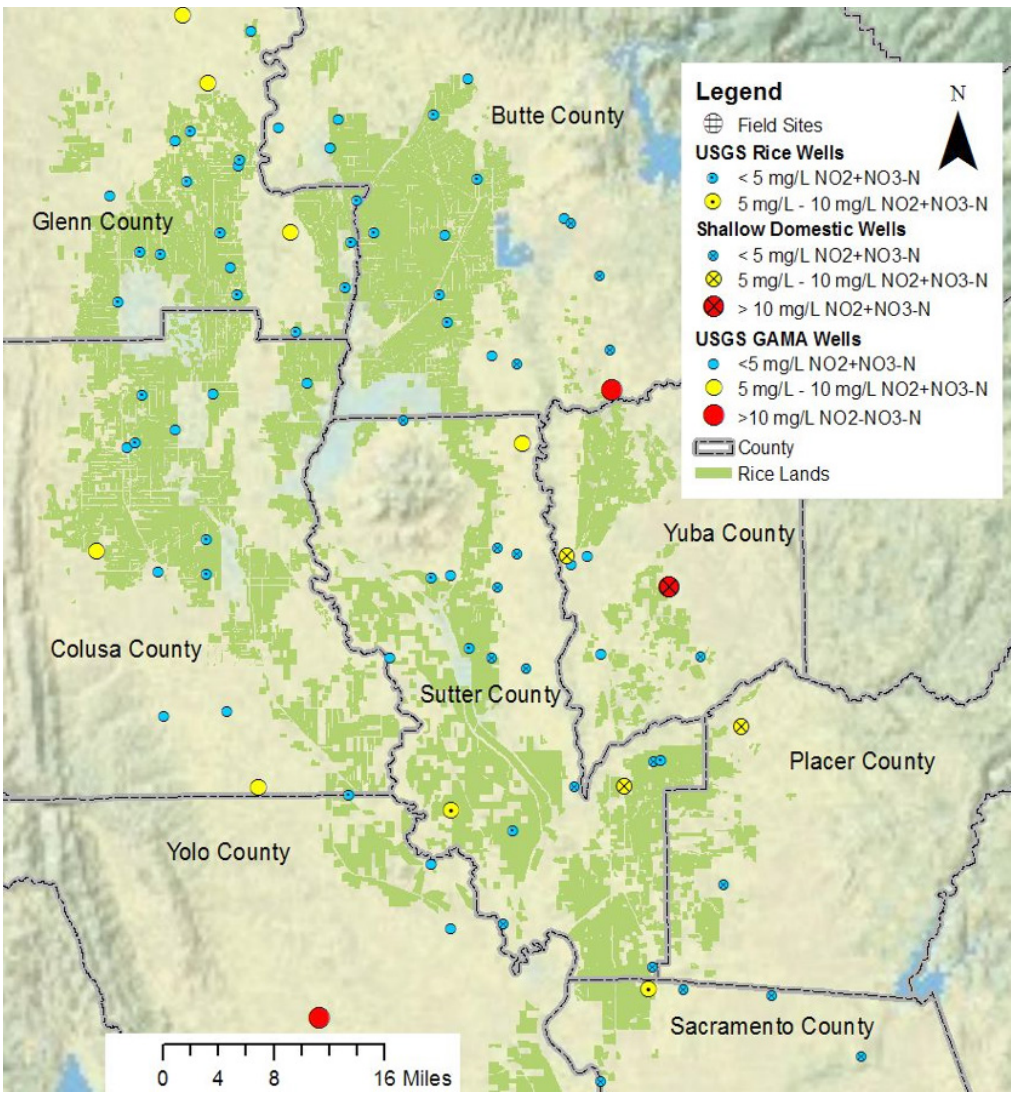


Figure 8. *Locations of Sacramento Valley monitoring wells.*

Further reading:

1. Ruark, M.D., B.A. Linquist, J. Six, C. van Kessel, C.A. Greer, R.G. Mutters and J.E. Hill. 2010. Seasonal losses of dissolved organic carbon and total dissolved solids from rice production systems in northern California. Journal of Environmental Quality 39:304-313.
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UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION

2015

Amended-June 2016

SAMPLE COSTS TO PRODUCE

RICE

SACRAMENTO VALLEY

Rice Only Rotation, Medium Grain

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UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION

SAMPLE COSTS TO PRODUCE RICE

Sacramento Valley – 2015

Amended-June 2016

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INTRODUCTION

Sample costs to produce medium grain rice in the Sacramento Valley are presented in this study. This study is intended as a guide only, and can be used in making production decisions, determining potential returns, preparing budgets, and evaluating production loans. Practices described are based on production practices considered typical for the crop and area, but will not apply to every situation. Sample costs for labor, materials, equipment, and custom services are based on current figures. A blank column titled, "*Your Costs*", is available in Table 1 and Table 2 to enter your own costs.

For an explanation of calculations used in the study refer to the section titled Assumptions. For more information contact Donald Stewart; University of California Agriculture and Natural Resources, Agricultural Issues Center, Department of Agricultural and Resource Economics, at 530-752-4651 or destewart@ucdavis.edu.

Sample Cost of Production studies for many commodities are available and can be down loaded from the website, http://coststudies.ucdavis.edu. Archived studies are also available on the website.

ASSUMPTIONS

The assumptions refer to Tables 1 through 7 and pertain to sample costs to produce medium grain rice in the Sacramento Valley. The cultural practices shown represent production operations and materials considered typical of a well-managed farm in the region. Costs, materials, and practices in this study will not apply to all situations. Timing and types of cultural practices will vary among growers within the region and from season to season due to variables such as weather, soil, insect, and disease pressure. **The use of trade names and cultural practices in this report does not constitute an endorsement or recommendation by the University of California, nor is any criticism implied by omission of other similar products or cultural practices.**

Land. The hypothetical farm consists of 840 acres. The grower owns 10 acres and rents 830 acres. Medium grain rice (Calrose) is grown on 800 acres and 40 acres are roads, irrigation systems, equipment and shop area, and homestead. Typically, a grower with this amount of rice acreage will have several non-adjacent fields and the cultural practices will vary among fields. Additionally, extra costs may be incurred moving equipment between fields, but are not included in this study. No other crops are grown in rotation with rice. All operations are done on 100% of the acres unless noted otherwise.

This study assumes the grower owns 10 acres, valued at $10,000 per acre, and rents 830 acres, rented at $425 per acre. This study assumes 100% of farmed land is rented. For more details about owned and rented land, please refer to the "Cash Overhead Costs" and "Non-Cash Overhead Costs" sections.

Cultural Practices and Material Inputs

Land Preparation. Most of the primary tillage, including chiseling, plowing, discing, land leveling, laser leveling, and rolling is normally done from March through May. In this study, the permanent levees, which comprise 5% of the acres, are reworked, and drains are maintained as necessary. Environmental regulations may affect the way the drains and levees are maintained and additional costs may be incurred, which are not accounted for in this study. All fields are chiseled two times to open the ground and dry the soil. This is followed by one discing to break up large clods with a stubble disc, and then disced twice more with a finish disc, which increases the soil's drying surface. The field is then leveled with a dual GPS scraper. Precision leveling is done once every other year and one-half of the cost is charged to the cultural operations annually. In between GPS land and laser leveling years, the grower triplanes the fields to maintain even ground for water flow. The ground is rolled with a corrugated roller (with starter fertilizer) prior to flooding and planting.

Fertilizer. Aqua ammonia is applied pre-plant at 130 pounds of N per acre with an aqua fertilizer injector ground rig, 3 to 4 inches deep. A starter fertilizer, 12-23-20 at 200 pounds per acre, is applied by ground and incorporated using a corrugated roller (can also be applied by air). Zinc sulfate is applied by air to 50% of the acres at 30 pounds per acre before the aqua and pre-plant fertilizer which is incorporated with those operations. In July, 75% of the acres are top dressed with 31.5 pounds of N, or 150 pounds of ammonium sulfate, per acre. Adding soil amendments such as calcium and sulfur should only be done if a soil test indicates a need.

Planting. Water seeding, in contrast to drill-seeding or dry-seeding, is the primary seeding method in California. The soil is flooded, the seed is soaked and drained, and then the seed is broadcast by air into a few inches of water on the fields at a rate of 165 lbs. /acre. Most planting is done from April 20 to May 20, but sometimes continues into June.

Irrigation. The grower purchases the majority of irrigation water from an irrigation district; however growers may also use well water. The grower pays the water costs on the farmed land, which varies widely between irrigation districts in the Sacramento Valley. The seasonal cost of irrigation water for this study is $150.00 per surface acre. Typically, 4 to 6 acre-feet of water are applied during the growing season. This results in a water depth of 4 to 6 inches during the growing season. This does not include water needed for straw management.

Pest Management. The pesticides and rates mentioned in this cost study are listed in *UC Integrated Pest Management Guidelines, Rice*. For information on other pesticides available, pest identification, monitoring, and management visit the UC IPM website at www.ipm.ucdavis.edu. **Although growers commonly use the pesticides mentioned, many other pesticides are available. Check with your PCA and/or the UC IPM website for current recommendations.** To purchase pesticides for commercial use, a grower must be a Certified Private Applicator to obtain a Pesticide Identification number. For information and pesticide use permits, contact the local county agricultural commissioner's office. Pesticides with different active ingredients, mode of action, and sites of action should be rotated as needed to combat species shift and resistance. Adjuvants are recommended for use with many pesticides for effective control and are included in this study.

Weeds. Grass weeds and broadleaf weeds are controlled with separate aerial and ground applications. An herbicide (e.g. Cerano, Clincher, Bolero, Granite GR, or a combination) to control grass weeds is applied to 100% of the rice shortly after planting. The study assumes that Cerano is applied to 100% of the acres by air in May. Tank mixes of two foliar active herbicides are often used for the second herbicide application. This study assumes that a Propanil (Super Wham) and Grandstand tank mix is applied by ground, as stated above, on 100% of planted acres. Final weed control is a cleanup herbicide (e.g. Regiment) application in late June that is applied using a ground rig on 80% of the acres. Weed material programs vary amongst growers due to management of herbicide resistant weeds or other production circumstances. However, material costs per acre are within similar ranges.

Insects. Rice water weevil control begins in May after planting, by treating 15% of the acres, which includes the field borders or edges, levees, and field area adjacent to these areas with Warrior insecticide. Armyworms are controlled with one insecticide application of Warrior in July, on 5% of the acres.

Algae and tadpole shrimp. After planting in May, copper sulfate is applied to 60% of the acres to control algae and tadpole shrimp.

Diseases. Aggregate sheath spot and blast are controlled July through August with one application of Quadris on 80% of the acres.

Harvest. The rice crop is harvested at 20% kernel moisture (green rice) using one combine with a cutter-bar header. The grower also owns a pulled grain cart. The grain is dumped from the one combine into the grain cart, which is then taken to bulk grain trailers for transport to the dryer.

*Transportation***.** The grower pays the transportation of green rice from the field to the dryer. Hauling grain from the dryer to storage may be considered a processing or marketing expense, but is a cost and is reflected in the price returned to the grower. In this study, the cost of transporting the rice from the field to the dryer is included, but the hauling cost between the dryer and warehouse is not. The cost of transporting rice is based on a green weight of 98 hundredweight (cwt) per acre and a $0.50 per cwt field pickup and hauling charge. In this study, green weight is the calculated weight of the harvested rice at 20% moisture, including ‘invisible shrink’.

Drying and Storage. Drying charges increase with moisture content. Most dryers use a rate schedule that reflects the loss of moisture plus other ‘invisible’ losses in the system associated with immature kernels, dockage and dust. The non-moisture factor varies among dryers, but usually ranges from 2% to 6%. Together, these losses are called ‘shrink’. Rice is assumed to be dried to 13% moisture. The drying rate charge is based on a green weight of 98 cwt. The current cost of drying the rice in this study is $0.95 per cwt. Storage is charged at $0.78 per cwt on the dry weight and is similarly increased to estimate future power costs. Most of the drying cost is related to natural gas prices, and the storage cost to electricity prices.

Yields. The crop yield used in this study is 8,500 pounds (85 cwt) per acre at 13% moisture. Yields have varied over the years in California and are shown in Table A.

Returns. A selling price of $20.70 per cwt. of grain rice (with an assumed loan value of $6.60, or $14.10 above loan value) is used to estimate market income, based on 2013 USDA prices. A range of yields and prices are presented in Table 4 (page 16). Direct Payments and Counter cyclical Payments (but not the Marketing Loan Program) have been eliminated in the Agricultural Act of 2014 (ACT) and are replaced with alternative commodity programs that provide growers with some income protection in the event of a downturn in price, yield or a combination of both. In March, 2015 producers chose between Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC), and remain enrolled in the selected program over the life of the current Farm Bill. The PLC program pays indemnities when the crop price drops below the established reference price for the commodity, which is $16.10 per cwt for Temperate Japonica, as of 2015. The ARC program pays indemnities when revenues (individual or county averages) fall below the revenue guaranteed value, based on 5-year historical yields and the commodity reference price. These programs are administered by the United States Department of Agriculture's (USDA), Farm Service Agency (FSA). A single limit of $125,000 for each "person…actively engaged in farming" (as defined by the ACT) applies to all payments under these programs. Payments are tied to a farm's historical rice and other commodity base acres and yields, and are not available to producers whose average adjusted gross income exceeds $900,000. The study assumes that a grower selects the PLC program, however selection criteria should be based on individual farm analysis. For more information on these and other programs, or on meeting minimum requirements to comply with the programs please contact the USDA FSA, or visit the website: http://www.usda.gov/wps/portal/usda/usdahome?navid=farmbill.

Table A. Average California Yields and Prices

Year	Yield/Acre (Medium Grain)	Return/Cwt. (all types)
	Cwt.	*$/Cwt.*
2000	80.00	4.99
2001	83.00	5.28
2002	83.00	6.32
2003	78.40	10.40
2004	88.00	7.34
2005	75.50	10.10
2006	78.80	13.00
2007	85.00	16.20
2008	85.50	27.40
2009	87.40	19.50
2010	82.00	20.80
2011	85.00	18.40
2012	83.50	18.40
2013	86.70	20.70
2014	88.00	-

Source: USDA NASS Historical Data

Net Returns. A grower will achieve a positive cash flow when net returns above cash costs (gross returns less operating costs) are positive. This means that returns are sufficient to cover annual operating expenses (material inputs, labor costs, harvest, fuel, lube and repairs, and interest on operating loans). However, a positive cash flow does not include consideration of a return on investment in owned capital, also called non-cash overhead expenses. Nor does it include loan payments on capital investments such as equipment, irrigation system, and buildings. Net returns over total cost (gross return less total costs) include both cash costs and non-cash costs. If net returns above operating costs are positive but net returns above total costs are negative, over time gross returns will be insufficient to replace equipment and other investments necessary for production.

Assessments. Under a state marketing order a mandatory assessment fee is collected and administered by the California Rice Research Board (CRRB). This assessment of $0.07 per dry cwt pays for rice research funded by the CRRB. In addition, the California Rice Commission (CRC) assesses each rice grower $0.07 per dry cwt. Rice millers and marketers also contribute an equal amount of $0.07 per dry cwt. This provides the CRC with a total budget based on $0.14 per cwt for all California rice produced to work on a variety of issues facing the California rice industry.

Straw Management. Post-harvest operations for straw management are usually done using a single or a combination of commonly used methods, including: 1) burning (up to 25% of acres), 2) chopping, discing, and flooding, 3) chopping and flooding, 4) chopping, flooding and rolling (stomping), 5) chopping and discing, and 6) baling. In this study a combination of methods 1, 4, and 5 are used post-harvest.

Rice straw burning is done on 8% of the acres in the fall and/or spring for straw management. Burning permits and fees vary for each air pollution control district. For this study, a $90 burn permit is charged to the farm and an additional $2.50 per acre is charged for each acre burned. Check with the air pollution office in your county for burning regulations and fees. The rice straw is chopped, flooded, and then rolled on 30% of the acres. The balance 62% of acreage is chopped and disced twice. The winter water costs for single and continuous flooding vary by district, and may be rain fed.

Labor, Equipment and Interest

Labor. A labor rate of $21 per hour for machine operator labor, $35 per hour for irrigation labor and $20.55 for non-machine labor are used, and include in payroll overhead of 40%. The basic hourly wage is $15 for machine operator labor, $25 for irrigation labor and $14.68 for non-machine labor. The overhead includes the employer's share of federal and California state payroll taxes, workers' compensation insurance for field crops, and a percentage for other possible benefits. Workers' compensation costs will vary among growers, but for this study the cost is based upon the average industry final rate as of March 1, 2014.

Wages for management are not included as a cash cost. Any return above total costs is considered a return to management and risk. However, growers wanting to account for management may wish to add a fee. The manager makes all production decisions including cultural practices, action to be taken on pest management recommendations, and labor.

Equipment Operating Costs. Repair costs are based on purchase price, annual hours of use, total hours of life, and repair coefficients formulated by American Society of Agricultural Engineers (ASAE). Fuel and lubrication costs are also determined by ASAE equations based on maximum Power Take Off (PTO) horsepower, and fuel type. Prices for on-farm delivery of red dye diesel and gasoline are $3.88 (excludes excise tax) and $3.79 per gallon, respectively. Fuel costs are derived from the Energy Information Administration, 2014 January to December monthly data. The cost includes a 2.5% local sales tax on diesel fuel and 7.5% sales tax on gasoline. Gasoline also includes federal and state excise tax, which are refundable for on-farm use when filing your income tax.

Interest on Operating Capital. Interest on operating capital is based on cash operating costs and is calculated monthly until harvest at a nominal rate of 5.75% per year. A nominal interest rate is the typical market cost of borrowed funds. The interest cost of post-harvest operations is discounted back to the last harvest month using a negative interest charge. The interest rate will vary depending upon various factors. The rate is this study is considered a typical lending rate by a farm lending agency as of January, 2015.

Risk. The risks associated with crop production should not be underestimated. While this study makes every effort to model a production system based on typical, real world practices, it cannot fully represent financial, agronomic and market risks, which affect profitability and economic viability.

Cash Overhead Costs

Cash overhead consists of various cash expenses paid out during the year that are assigned to the whole farm and not to a particular operation.

Rent. Cash rents range from $350 to $500 per acre with surface water rights attached to the land, but water is not paid for by the landowner. The cost of water is borne by the grower renting the land. A rental price of $425 per acre is used in this study. All farmed acres are assumed to be rented, and considered a cash cost. This study assumes all farmed acres are rented to account for the current cost of farming on rice land.

Rented Equipment. A 325 HP 4WD tractor is rented for one month (250 hours). The tractor is used for tillage operations over the 800 acres.

Property Taxes. Counties charge a base property tax rate of 1% on the assessed value of the property. In some counties special assessment districts exist and charge additional taxes on property including equipment, buildings, and improvements. For this study, county taxes are calculated as 1% of the average value of the property. Average value equals new cost plus salvage value divided by 2 on a per acre basis.

Insurance. Insurance for farm investments varies depending on the assets included and the amount of coverage. Property insurance provides coverage for property loss and is charged at 0.843% of the average value of the assets over their useful life. Liability insurance covers accidents on the farm and costs $17.85 per acre or $14,994 for the entire farm.

Office and Business Expense. Office and business expenses are estimated at $50 per acre. These expenses include office supplies, telephones, bookkeeping, accounting, legal fees, and shop and office utilities.

Regulatory Compliance and Administrative Costs. Compliance and administrative costs are estimated to be $25 per acre. This includes expenses such as managing paperwork for compliance, as well as miscellaneous administrative costs that accompany the compliance paperwork.

Crop Insurance. Crop insurance is a tool that some growers use to help offset revenue loss risk. This study assumes that all acres in the farm are eligible for Prevented Planting (PP) coverage, which is available under catastrophic (CAT) crop insurance and buy-up insurance policies. A buy-up insurance policy offers growers more coverage and flexibility to tailor a crop insurance plan to a specific operation. Yield and revenue insurance are the most common buy-up policies and offer coverage levels between 50% and 85%. The USDA RMA sets crop insurance policies and costs, which are administered by private insurance companies. Various crop insurance policies are offered for rice growers in the Sacramento Valley including revenue protection, revenue protection with harvest price exclusion and yield protection. Between 2011 and 2014, yield protection represented between 89 and 94 percent of total buy-up policies for rice growers in California. Depending on the crop insurance policy, the USDA RMA will subsidize between 38 and 67 percent of the grower premium cost, as of 2014. The grower is assumed to purchase a 75 percent yield protection policy, with an additional 55 percent PP coverage level, assumed to cost $18 per acre. For more information on crop insurance, visit the Risk Management Agency website: http://www.rma.usda.gov/, and for more information on prevented planting coverage, refer to the RMA Handbook: Prevented Planting Loss Adjustment Standards Handbook (FCIC-25370 [10-2006]).

Investment Repairs. Annual repairs on investments or capital recovery items that require maintenance are calculated as 2% of the purchase price. This includes repair on all investments (e.g. fuel tanks and pumps, backhoe, irrigation system, shop buildings, tools, etc.), except for land.

Non-Cash Overhead Costs

Non-cash overhead is calculated as the capital recovery cost for equipment and other farm investments.

Land. Rice land values range from $7,000 to $12,000 per acre. This study uses a value of $10,000 per acre. Environmentally important rice land is valued in excess of the amount that growers can profitably afford to pay because environmental associations or government agencies may be willing to pay more to acquire the land, however such land represents a small portion of total rice land. In this study, 10 acres of land is assumed to be owned by the grower.

Capital Recovery Costs. Capital recovery cost is the annual depreciation and interest costs for a capital investment. It is the amount of money required each year to recover the difference between the purchase prices and salvage value (unrecovered capital). It is equivalent to the annual payment on a loan for the investment with the down payment equal to the discounted salvage value. This is a more complex method of calculating ownership costs than straight-line depreciation and opportunity costs, but more accurately represents the annual costs of ownership because it takes the time value of money into account (Boehlje and Eidman). The formula for the calculation of the annual capital recovery costs is [(Purchase Price – Salvage Value) x Capital Recovery Factor] + (Salvage Value x Interest Rate).

Salvage Value. Salvage value is an estimate of the remaining value of an investment at the end of its useful life. For farm machinery (tractors and implements) the remaining value is a percentage of the new cost of the investment (Boehlje and Eidman). The percent remaining value is calculated from equations developed by the American Society of Agricultural Engineers (ASAE) based on equipment type and years of life. The life in years is estimated by dividing the wear out life, as given by ASAE by the annual hours of use in this operation. For other investments including irrigation systems, buildings, and miscellaneous equipment, the value at the end of its useful life is zero. The salvage value for land is the purchase price because land does not depreciate.

Capital Recovery Factor. Capital recovery factor is the amortization factor or annual payment whose present value at compound interest is 1. The amortization factor is a table value that corresponds to the interest rate used and the life of the machine.

Interest Rate. An interest rate of 4.75% is used to calculate capital recovery. The rate will vary depending upon loan amount and other lending agency conditions, but is the basic suggested rate by a farm lending agency as of January, 2015.

Irrigation System. The irrigation system in this study has the water delivered by a water district via canal and moved to the field by a portable PTO powered, low-lift pump. The grower is assumed to own two portable pumps. Many growers use well water to supplement surface water deliveries. In this study a 75 HP electric pump with a 500 foot deep well pumps water from an average depth of 135 feet.

Table Values. Due to rounding, the totals may be slightly different from the sum of the components.

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UC COOPERATIVE EXTENSION

Table 1. COSTS PER ACRE TO PRODUCE RICE

SACRAMENTO VALLEY - 2015

Operation	Equipment Time (Hrs/A)	Cash and Labor Costs per Acre: Labor Cost	Fuel	Lube & Repairs	Material Cost	Custom/ Rent	Total Cost	YOUR COSTS
Cultural:								
Maintain Drains	0.10	3	2	1	0	0	5	
Maintain and Rework Levees	0.05	1	4	1	0	0	6	
Chisel 2X	0.17	4	13	3	0	16	36	
Stubble Disc	0.15	4	11	3	0	0	18	
Finish Disc 2X	0.28	7	21	6	0	0	34	
Triplane Fields - 1X/2yrs	0.07	2	5	1	0	0	8	
GPS Field Leveling - 1X/2yrs	0.00	0	0	0	0	20	20	
Fertilize-Zinc 50% Ac	0.00	0	0	0	7	5	12	
Fertilize - Aqua 130 Lbs. N/Ac	0.00	0	0	0	75	23	98	
Fertilize – Roll 12-23-20 @ 200 Lbs./Ac	0.07	2	5	1	44	0	52	
Irrigate	0.00	35	0	0	150	0	185	
Soak and Deliver Seed	0.00	0	0	0	53	5	58	
Plant @ 165 Lbs./Ac	0.00	0	0	0	0	14	14	
Weeds-Grass Spray	0.00	0	0	0	65	12	77	
Insects-Rice Weevil 15% Ac	0.00	0	0	0	2	2	4	
Pests-Shrimp/Algae 60% Ac	0.00	0	0	0	2	5	8	
Weeds-Broadleaf Spray	0.00	0	0	0	76	20	96	
Weeds-Cleanup 80% Ac	0.00	0	0	0	20	16	36	
Fertilize – Top dress 75% Ac	0.00	0	0	0	17	11	29	
Insects-Armyworms 5% Ac	0.00	0	0	0	1	1	1	
Disease-Fungus 80% Ac	0.00	0	0	0	22	9	31	
Pickup Truck 1/2 Ton	0.33	8	3	1	0	0	12	
Pickup Truck 3/4 Ton	0.33	8	3	1	0	0	12	
TOTAL CULTURAL COSTS	1.56	74	66	18	534	158	850	
Harvest:								
Combine Rice - Header 25'	0.39	10	29	17	0	0	55	
Grain Tub	0.21	5	15	3	0	0	24	
Haul Rice To Dryer	0.00	0	0	0	0	49	49	
Dry & Store Rice	0.00	0	0	0	0	159	159	
Rice Research Board Assessment	0.00	0	0	0	6	0	6	
California Rice Commission	0.00	0	0	0	6	0	6	
TOTAL HARVEST COSTS	0.59	15	44	20	12	208	299	
Post-Harvest:								
Burn Permit & Fees 8% Ac	0.00	10	0	0	0	0	11	
Flood & Roll 30% Ac	0.02	4	2	0	11	0	17	
Disc 30% Ac	0.05	1	3	1	0	0	5	
Chop 62% Ac	0.12	3	2	1	0	0	6	
Disc 62% Ac	0.10	2	7	2	0	0	11	
TOTAL POST-HARVEST COSTS	0.29	21	14	4	11	0	50	
Interest on Operating Capital at 5.75%							25	
TOTAL OPERATING COSTS/ACRE	2	110	125	42	557	366	1,225	

UC COOPERATIVE EXTENSION

Table 1. Continued

SACRAMENTO VALLEY - 2015

Operation	Equipment Time (Hrs/A)	Labor Cost	Fuel	Lube & Repairs	Material Cost	Custom/ Rent	Total Cost	YOUR COSTS
CASH OVERHEAD:								
Land Rent							425	
Liability Insurance							18	
Office Expense							50	
Compliance & Administration							25	
Crop Insurance							18	
Property Taxes							4	
Property Insurance							1	
Investment Repairs							3	
TOTAL CASH OVERHEAD COSTS/ACRE							544	
TOTAL CASH COSTS/ACRE							1,769	

NON-CASH OVERHEAD:	Per Producing Acre	Annual Cost Capital Recovery	Total Cost	YOUR COSTS
Backhoe	24	3	3	
Fuel Tanks & Pumps	13	1	1	
2 - 550 gal Fuel Wagons	4	0	0	
Irrigation System	28	2	2	
Land - Rice	119	6	6	
Shop Building	54	4	4	
Shop Tools	16	1	1	
Tool Carrier	17	1	1	
Equipment	389	49	49	
TOTAL NON-CASH OVERHEAD COSTS	663	68	68	
TOTAL COSTS/ACRE			1,837	

UC COOPERATIVE EXTENSION

Table 2. COSTS AND RETURNS PER ACRE TO PRODUCE RICE

SACRAMENTO VALLEY – 2015

	Quantity/ Acre	Unit	Price or Cost/Unit	Value or Cost/Acre	YOUR COSTS
GROSS RETURNS					
Rice	85	Cwt	20.70	1,760	
TOTAL GROSS RETURNS	85	Cwt		1,760	
OPERATING COSTS					
Fertilizer:				**144**	
Zinc Sulfate 36%	15.00	Lb	0.48	7	
Aqua Ammonia	130.00	Lb N	0.58	75	
12-23-20	200.00	Lb	0.22	44	
21-0-0 Ammonia Sulfate	112.50	Lb	0.16	17	
Herbicides:				**135**	
Cerano	10.00	Lb	5.00	50	
Grandstand	4.80	FlOz	1.13	5	
Super Wham	4.80	Qt	12.38	59	
Regiment	0.33	Oz	60.00	20	
Insecticides:				**5**	
Warrior	0.77	FlOz	3.21	2	
Copper Sulfate-Fine	1.00	Lb	2.26	2	
Fungicides:				**22**	
Quadris	8.80	FlOz	2.53	22	
Adjuvants:				**26**	
Crop Oil	1.80	Gal	13.85	25	
Adjuvant	3.50	FlOz	0.22	1	
Seed:				**53**	
Seed - Rice	1.65	Cwt	32.25	53	
Custom:				**142**	
GPS Laser Leveling	0.50	Acre	40.00	20	
Air Application - Zinc Dry	0.50	Acre	9.00	5	
Fertilizer Rig - Aqua Ammonium	1.00	Acre	22.50	23	
Soaking (Chlorine) Seed	1.65	Cwt	2.25	4	
Delivery - Seed	1.65	Cwt	0.70	1	
Air Application - Seed	1.65	Cwt	8.55	14	
Air Application – Cerano	1.00	Acre	12.00	12	
Air Application - Warrior	0.15	Acre	11.50	2	
Air Application –Copper	0.60	Acre	9.00	5	
Ground Application – Super Wham/Grandstand	1.00	Acre	20.00	20	
Ground Application-Regiment	0.80	Acre	20.00	16	
Air Application - Dry Fertilizer	0.75	Acre	15.00	11	
Air Application - Warrior	0.05	Acre	10.75	1	
Air Application - Quadris	0.80	Acre	11.50	9	
Irrigation:				**161**	
Water - Irrigation	1.00	Acre	150.00	150	
Water - Straw Management	0.30	Acre	35.00	11	
Contract:				**208**	
Hauling	98.00	Cwt	0.50	49	
Drying Charge	98.00	Cwt	0.95	93	
Storage Charge	85.00	Cwt	0.78	66	
Assessment:				**12**	
California Rice Research Board	85.00	Cwt	0.07	6	
California Rice Commission	85.00	Cwt	0.07	6	
Burn Permit:				**0**	
Burning Fees	0.08	Acre	2.50	0	
Burn Permit	0.08	Acre	1.41	0	
Rent:				**16**	
Tractor 325 HP 4WD	0.20	Hour	80.00	16	
Labor				**110**	
Equipment Operator Labor	2.92	hrs	21.00	61	
Non-Machine Labor	0.50	hrs	20.55	10	
Irrigation Labor	1.10	hrs	35.00	39	
Machinery				**167**	
Fuel-Gas	1.33	gal	3.79	5	
Fuel-Diesel	30.83	gal	3.88	120	
Lube				19	
Machinery Repair				23	
Interest on Operating Capital @ 5.75%				26	
TOTAL OPERATING COSTS/ACRE				1,225	
TOTAL OPERATING COSTS/CWT				14	
NET RETURNS ABOVE OPERATING COSTS				534	

UC COOPERATIVE EXTENSION

Table 2. Continued

SACRAMENTO VALLEY - 2015

	Quantity/ Acre	Unit	Price or Cost/Unit	Value or Cost/Acre	Your Cost
CASH OVERHEAD COSTS					
Land Rent				425	
Liability Insurance				18	
Office Expense				50	
Compliance & Administration				25	
Crop Insurance				18	
Property Taxes				4	
Property Insurance				1	
Investment Repairs				3	
TOTAL CASH OVERHEAD COSTS/ACRE				544	
TOTAL CASH OVERHEAD COSTS/CWT				6	
TOTAL CASH COSTS/ACRE				1,769	
TOTAL CASH COSTS/CWT				21	
NET RETURNS ABOVE CASH COSTS				-9	
NON-CASH OVERHEAD COSTS (Capital Recovery)					
Backhoe				3	
Fuel Tanks & Pumps				1	
2 - 550 gal Fuel Wagons				0	
Irrigation System				2	
Land - Rice				6	
Shop Building				4	
Shop Tools				1	
Tool Carrier				1	
Equipment				49	
TOTAL NON-CASH OVERHEAD COSTS/ACRE				68	
TOTAL NON-CASH OVERHEAD COSTS/CWT				1	
TOTAL COST/ACRE				1,837	
TOTAL COST/CWT				22	
NET RETURNS ABOVE TOTAL COST				-78	

UC COOPERATIVE EXTENSION

Table 3. MONTHLY CASH COSTS PER ACRE TO PRODUCE RICE

SACRAMENTO VALLEY - 2015

	FEB 15	MAR 15	APR 15	MAY 15	JUN 15	JUL 15	AUG 15	SEP 15	OCT 15	Total
Cultural :										
Maintain Drains	5									5
Maintain and Rework Levees			6							6
Chisel 2X			36							36
Stubble Disc			18							18
Finish Disc 2X			34							34
Triplane Fields - 1X/2yrs			8							8
GPS Field Leveling - 1X/2yrs			20							20
Fertilize-Zinc 50% Ac			12							12
Fertilize - Aqua 130 Lbs. N/Ac			98							98
Fertilize - 12-23-20 @ 200 Lbs./Ac			52							52
Irrigate				37	37	37	37	37		185
Soak and Deliver Seed				58						58
Plant @ 165 Lbs./Ac				14						14
Weeds-Grass Spray				77						77
Insects-Rice Weevil 15 % Ac				4						4
Pests-Shrimp/Algae 60% Ac				8						8
Weeds-Broadleaf Spray					96					96
Weeds-Cleanup 80% Ac					36					36
Fertilize – Top dress 75% Ac						29				29
Insects-Armyworms 5% Ac						1				1
Disease-Fungus 80% Ac						31				31
Pickup Truck 1/2 Ton	1	1	1	1	1	1	1	1	1	12
Pickup Truck 3/4 Ton	1	1	1	1	1	1	1	1	1	12
TOTAL CULTURAL COSTS	8	3	286	200	171	101	40	40	3	850
Harvest:										
Combine Rice - Header 25'								55		55
Grain Tub								24		24
Haul Rice To Dryer								49		49
Dry & Store Rice									159	159
Rice Research Board Assessment									6	6
California Rice Commission									6	6
TOTAL HARVEST COSTS	0	0	0	0	0	0	0	128	171	299
Post-Harvest:										
Burn Permit & Fees 8% Ac									11	11
Flood & Roll 30% Ac									17	17
Disc 30% Ac									5	5
Chop 62% Ac									6	6
Disc 62% Ac									11	11
TOTAL POST-HARVEST COSTS	0	0	0	0	0	0	0	0	50	50
Interest on Operating Capital @5.75%	0	0	1	2	3	4	4	5	6	25
TOTAL OPERATING COSTS/ACRE	8	3	288	202	175	105	44	172	230	1,225

UC COOPERATIVE EXTENSION

Table 3. Continued

SACRAMENTO VALLEY – 2015

	FEB 15	MAR 15	APR 15	MAY 15	JUN 15	JUL 15	AUG 15	SEP 15	OCT 15	Total
CASH OVERHEAD										
Land Rent									425	425
Office Expense	6	6	6	6	6	6	6	6	6	50
Liability Insurance									18	18
Compliance & Administration	3	3	3	3	3	3	3	3	3	25
Crop Insurance									18	18
Property Taxes	2					2				4
Property Insurance	1									1
Investment Repairs	0	0	0	0	0	0	0	0	0	3
TOTAL CASH OVERHEAD	12	9	9	9	9	11	9	9	470	544
TOTAL CASH COSTS/ACRE	19	11	296	211	183	115	52	181	700	1,769

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Table 4. RANGING ANALYSIS

SACRAMENTO VALLEY – 2015

COSTS PER ACRE AT VARYING YIELDS TO PRODUCE RICE

	YIELD (CWT)						
	70.00	75.00	80.00	85.00	90.00	95.00	100.00
OPERATING COSTS/ACRE:							
Cultural	850	850	850	850	850	850	850
Harvest	260	273	286	299	312	325	338
Post-Harvest	50	50	50	50	50	50	50
Interest on Operating Capital @ 5.75%	24.83	24.91	24.99	25.06	25.14	25.21	25.29
TOTAL OPERATING COSTS/ACRE	1,186	1,199	1,212	1,225	1,238	1,251	1,264
TOTAL OPERATING COSTS/CWT	16.94	15.99	15.15	14.41	13.76	13.17	12.64
CASH OVERHEAD COSTS/ACRE	544	544	544	544	544	544	544
TOTAL CASH COSTS/ACRE	1,730	1,743	1,756	1,769	1,782	1,795	1,808
TOTAL CASH COSTS/CWT	24.71	23.24	21.95	20.81	19.80	18.89	18.08
NON-CASH OVERHEAD COSTS/ACRE	68	68	68	68	68	68	68
TOTAL COSTS/ACRE	1,798	1,811	1,824	1,837	1,850	1,863	1,876
TOTAL COSTS/CWT	25.69	24.15	22.80	21.61	20.56	19.61	18.76

These are the new tables-(2016 amended).

Net Return per Acre above Operating Costs for Rice

PRICE ($/cwt)	YIELD (Cwt/acre)						
Rice	70.00	75.00	80.00	85.00	90.00	95.00	100.00
14.70	-157	-97	-36	24	85	145	206
16.70	-17	53	124	194	265	335	406
18.70	123	203	284	364	445	525	606
20.70	263	353	444	534	625	715	806
22.70	403	503	604	704	805	905	1,006
24.70	543	653	764	874	985	1,095	1,206
26.70	683	803	924	1,044	1,165	1,285	1,406

Net Return per Acre above Cash Costs for Rice

PRICE ($/cwt)	YIELD (Cwt/acre)						
Rice	70.00	75.00	80.00	85.00	90.00	95.00	100.00
14.70	-701	-640	-580	-519	-459	-398	-338
16.70	-561	-490	-420	-349	-279	-208	-138
18.70	-421	-340	-260	-179	-99	-18	62
20.70	-281	-190	-100	-9	81	172	262
22.70	-141	-40	60	161	261	362	462
24.70	-1	110	220	331	441	552	662
26.70	139	260	380	501	621	742	862

Net Return per Acre above Total Costs for Rice

PRICE ($/cwt)	YIELD (Cwt/acre)						
Rice	70.00	75.00	80.00	85.00	90.00	95.00	100.00
14.70	-769	-709	-648	-588	-527	-467	-406
16.70	-629	-559	-488	-418	-347	-277	-206
18.70	-489	-409	-328	-248	-167	-87	-6
20.70	-349	-259	-168	-78	13	103	194
22.70	-209	-109	-8	92	193	293	394
24.70	-69	41	152	262	373	483	594
26.70	71	191	312	432	553	673	794

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Table 5. WHOLE FARM ANNUAL EQUIPMENT, INVESTMENT, AND OVERHEAD COSTS

SACRAMENTO VALLEY – 2015

ANNUAL EQUIPMENT COSTS

						Cash Overhead		
Yr.	Description	Price	Yrs. Life	Salvage Value	Capital Recovery	Insurance	Taxes	Total
15	Chisel - 21'	21,000	10	3,714	2,388	10	124	2,522
15	Combine - No Header	420,000	7	114,296	57,783	225	2,671	60,680
15	Disc - Offset 21'	42,500	8	9,596	5,495	22	260	5,778
15	Disc - Stubble 14'	28,000	8	6,322	3,621	14	172	3,807
15	Disc Ridger - 12'	12,000	10	2,122	1,365	6	71	1,441
15	Mower - Flail 15'	13,500	10	2,387	1,535	7	79	1,621
15	Pickup - 1/2 Ton	30,000	7	11,380	3,729	17	207	3,954
15	Pickup - 3/4 Ton	45,000	7	17,070	5,594	26	310	5,931
15	V Ditcher	5,000	20	261	385	2	26	413
15	Header - 25'	78,000	6	23,985	11,696	43	510	12,249
15	Grain Tub	35,000	10	6,189	3,980	17	206	4,203
15	95 HP 4WD Utility Tractor	75,000	16	13,433	6,218	37	442	6,698
15	300 HP 4WD Tractor	250,000	10	73,846	26,044	137	1,619	27,800
15	Triplane 24'X40'	35,000	10	6,189	3,980	17	206	4,203
15	Roller Rice 24' + Dry Box	40,000	10	7,074	4,548	20	235	4,804
	TOTAL	1,130,000	-	297,865	138,362	602	7,139	146,103
	40% of New Cost*	452,000	-	119,146	55,345	241	2,856	58,441

*Used to reflect a mix of new and used equipment

ANNUAL INVESTMENT COSTS

					Cash Overhead			
Description	Price	Yrs. Life	Salvage Value	Capital Recovery	Insurance	Taxes	Repairs	Total
INVESTMENT								
Backhoe	20,000	10	0	2,559	50	100	400	3,109
Fuel Tanks & Pumps	10,500	20	0	825	37	53	210	1,125
2 – 550 Gal Fuel Wagons	3,478	10	349	417	14	19	70	520
Irrigation System	22,500	20	0	1,767	80	113	450	2,410
Land - Rice	100,000	40	100,000	4,750	0	1,000	0	5,750
Shop Building	45,338	20	0	3,561	162	227	906	4,856
Shop Tools	13,087	20	1,309	987	51	72	262	1,373
Tool Carrier	14,418	20	1,442	1,088	7	79	120	1,294
TOTAL INVESTMENT	229,321	-	103,100	15,954	401	1,662	2,418	20,436

ANNUAL BUSINESS OVERHEAD COSTS

Description	Units/ Farm	Unit	Price/ Unit	Total Cost
Land Rent	830	Acre	425	357,000
Liability Insurance	840	Acre	17.85	14,994
Office Expense	800	Acre	50	42,000
Compliance & Administration	800	Acre	25	21,000
Crop Insurance	800	Acre	18	15,120

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Table 6. HOURLY EQUIPMENT COSTS

SACRAMENTO VALLEY – 2015

		Rice	Total		Cash Overhead		Operating			
Yr.	Description	Hours Used	Hours Used	Capital Recovery	Insurance	Taxes	Lube & Repairs	Fuel	Total Oper	Total Costs/Hr.
15	Chisel - 21'	133	200	4.78	0.02	0.25	2.98	0.00	2.98	8.03
15	Combine - No Header	340	428	54.00	0.21	2.50	31.34	67.55	98.89	155.60
15	Disc - Offset 21'	224	250	8.79	0.04	0.42	4.74	0.00	4.74	13.98
15	Disc - Stubble 14'	236	250	5.79	0.02	0.27	3.12	0.00	3.12	9.21
15	Disc Ridger - 12'	40	200	2.73	0.01	0.14	1.32	0.00	1.32	4.20
15	Mower - Flail 15'	136	200	3.07	0.01	0.16	3.79	0.00	3.79	7.04
15	Pickup - 1/2 Ton	267	285	5.23	0.02	0.29	2.62	7.58	10.20	15.74
15	Pickup - 3/4 Ton	267	285	7.85	0.04	0.44	3.35	7.58	10.93	19.26
15	V Ditcher	80	100	1.54	0.01	0.11	0.88	0.00	0.88	2.53
15	Header - 25'	309	333	14.05	0.05	0.61	8.72	0.00	8.72	23.43
15	Grain Tub	181	300	5.31	0.02	0.27	0.00	0.00	0.00	5.60
15	95 HP 4WD Utility Tractor	238	750	3.32	0.02	0.24	4.78	17.15	21.93	25.50
15	Rented 325 HP 4WD Tractor	73	250	0.00	0.00	0.00	10.98	73.18	84.16	84.16
15	300 HP 4WD Tractor	1013	1600	6.51	0.03	0.40	14.57	67.55	82.12	89.07
15	Triplane 24' X 40'	53	300	5.31	0.02	0.27	3.59	0.00	3.59	9.19
15	Roller Rice 24' + Dry Box	135	200	9.10	0.04	0.47	3.06	0.00	3.06	12.66

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Table 7. OPERATIONS WITH EQUIPMENT & MATERIALS

SACRAMENTO VALLEY – 2015

Operation	Operation Month	Tractor	Implement	Labor Type/ Material	Rate/ acre	Unit
Maintain Drains	Feb	95 HP 4WD Utl Trac	V Ditcher	Non-Machine Labor		
Maintain and Rework	Apr	300 HP 4WD Tractor	Disc Ridger - 12'	Equipment Operator Labor	0.06	hour
Chisel 2X	Apr	Rented 325 HP 4WD	Chisel - 21'	Equipment Operator Labor	0.10	hour
				Tractor 325 HP 4WD	0.20	Hour
	Apr	300 HP 4WD Tractor	Chisel - 21'	Equipment Operator Labor	0.10	hour
Stubble Disc	Apr	300 HP 4WD Tractor	Disc - Stubble 14'	Equipment Operator Labor	0.18	hour
Finish Disc 2X	Apr	300 HP 4WD Tractor	Disc - Offset 21'	Equipment Operator Labor	0.34	hour
Triplane Fields - 1X	Apr	300 HP 4WD Tractor	Triplane 24'X40'	Equipment Operator Labor	0.08	hour
GPS Field Leveling	Apr			GPS Laser Leveling	0.50	Acre
Fertilize-Zinc 50% Ac	Apr			Zinc Sulfate 36%	15.00	Lb
				Air Application - Zinc Dry	0.50	Acre
Fertilize - Aqua	Apr			Aqua Ammonia	130.00	Lb N
				Fertilizer Rig - Aqua Ammonium	1.00	Acre
Fertilize - 12-23-20	Apr	300 HP 4WD Tractor	Roller Rice 24' + Dry Box	Equipment Operator Labor	0.09	hour
				12-23-20	200.00	Lb
Irrigate	May			Irrigation Labor	0.20	hour
				Water - Irrigation	0.20	Acre
	June			Irrigation Labor	0.20	hour
				Water - Irrigation	0.20	Acre
	July			Irrigation Labor	0.20	hour
				Water - Irrigation	0.20	Acre
	Aug			Irrigation Labor	0.20	hour
				Water - Irrigation	0.20	Acre
	Sept			Irrigation Labor	0.20	hour
				Water - Irrigation	0.20	Acre
Soak and Deliver Seed	May			Seed - Rice	1.65	Cwt
				Soaking (Chlorine) Seed	1.65	Cwt
				Delivery - Seed	1.65	Cwt
Plant @ 165 Lbs./Ac	May			Air Application - Seed	1.65	Cwt
Weeds-Grass Spray	May			Cerano	10.00	Lb
				Crop Oil	1.00	Gal
				Adjuvant	3.50	FlOz
				Air Application - Cerano/Bolero	1.00	Acre
Insects-Rice Weevil	May			Warrior	0.58	FlOz
				Air Application - Warrior	0.15	Acre
Pests-Shrimp/Algae	May			Copper Sulfate Fine	1.00	Lb
				Air Application -Copper	0.60	Acre
Weeds-Broadleaf Spray	June			Grandstand	4.80	FlOz
				Crop Oil	0.80	Gal
				Super Wham	4.80	Qt
				Ground Application - Prop/Grand	1.00	Acre
Weeds-Cleanup 80% Ac	June			Regiment	0.33	Oz
				Ground Application-Regiment	0.80	Acre
Fertilize – Top dress	July			21-0-0 Ammonia Sulfate	112.50	Lb
				Air Appl - Dry Fertilizer	0.75	Acre
Insects-Armyworms 5% Ac	July			Warrior	0.19	FlOz
				Air Appl - Warrior	0.05	Acre
Disease-Fungus 80% Ac	July			Quadris	8.80	FlOz
				Air Appl - Quadris	0.80	Acre
Pickup Truck 1/2 Ton	July		Pickup - 1/2 Ton	Equipment Operator Labor	0.40	hour
Pickup Truck 3/4 Ton	July		Pickup - 3/4 Ton	Equipment Operator Labor	0.40	hour
Combine Rice – Header	Sept		Combine - No Head	Equipment Operator Labor	0.46	hour
			Header - Conv. 25'			
Grain Tub	Sept	300 HP 4WD Tractor	Grain Tub	Equipment Operator Labor	0.25	hour
Haul Rice To Dryer	Sept			Hauling	98.00	Cwt
Dry & Store Rice	Oct			Drying Charge	98.00	Cwt
				Storage Charge	85.00	Cwt
Rice Research Board	Oct			California Rice Research Board	85.00	Cwt
California Rice Comm	Oct			California Rice Commission	85.00	Cwt
Burn Permit & Fees	Oct			Non-Machine Labor	0.50	hour
				Burning Fees	0.08	Acre
				Burn Permit	0.08	Acre
Flood & Roll 30% Ac	Oct	300 HP 4WD Tractor	Roller Rice 24' + Dry Box	Irrigation Labor	0.10	hour
				Water - Straw Management	0.30	Acre
Disc 30% Ac	Oct	300 HP 4WD Tractor	Disc - Stubble 14'	Equipment Operator Labor	0.06	hour
Chop 62% Ac	Oct	95 HP 4WD Utl Trac	Mower - Flail 15'	Equipment Operator Labor	0.15	hour
Disc 62% Ac	Oct	300 HP 4WD Tractor	Disc - Stubble 14'	Equipment Operator Labor	0.11	hour

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On-line Resources

UC Pest Management Guidelines - Pests of Rice

- www.ipm.ucanr.edu/PMG/selectnewpest.rice.html

Uiversity of California Rice On-line

- www.rice.ucanr.edu