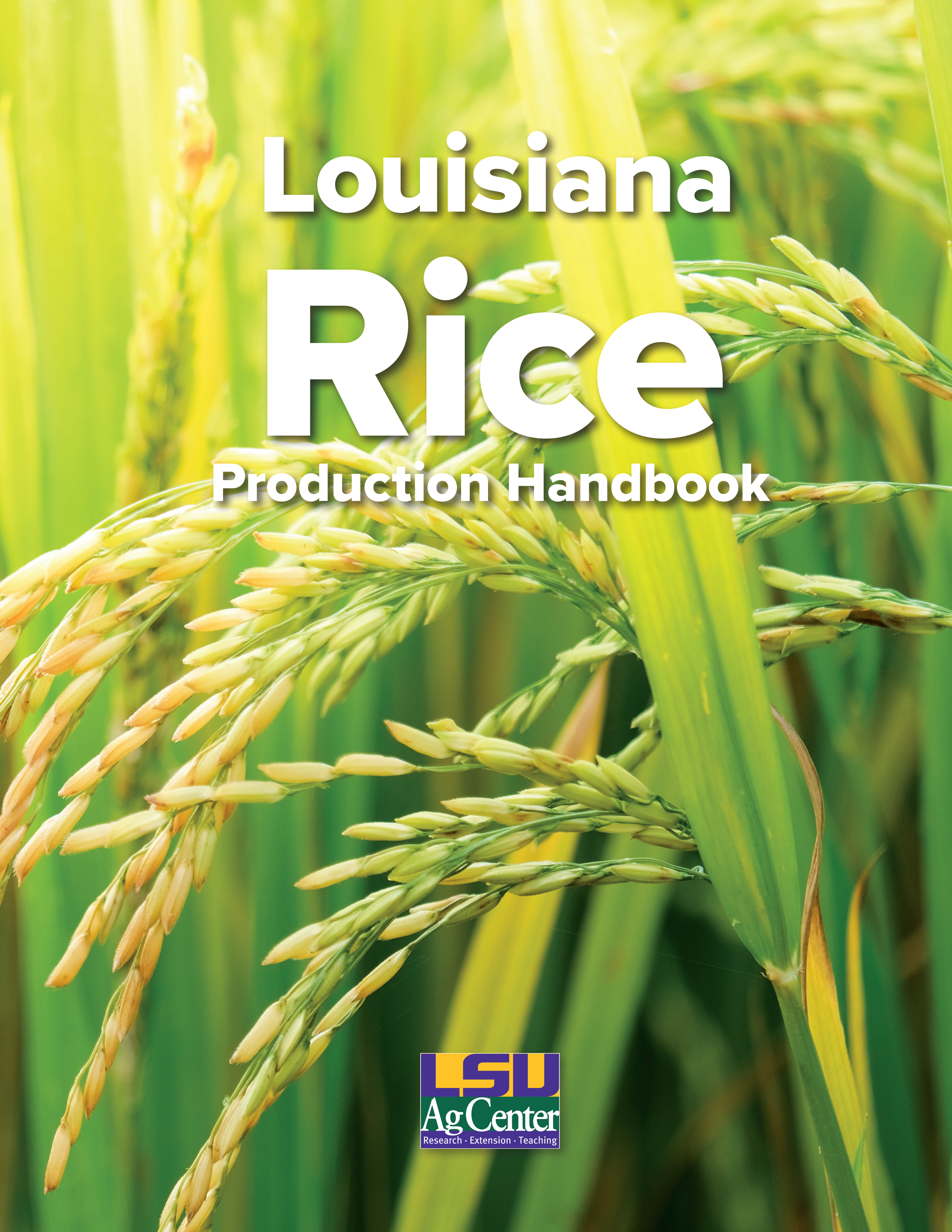

Louisiana Rice Production Handbook

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Louisiana Rice Production Handbook

Forward

Rice is one of the world's most important cereal crops. Cereal crops are members of the grass family (Gramineae or Poaceae) grown for their edible starchy seeds. The term "cereal" is derived from the Greek goddess, Ceres or "giver of grain." Rice and wheat are two of the most important cereal crops and together make up the majority of the world's source of calories. They feed the world.

In the United States rice is grown on approximately 3 million acres in two distinct regions — California and several southern states: Arkansas, Louisiana, Mississippi, Missouri and Texas. A small amount is also grown in Florida and South Carolina. Rice has been grown in Louisiana for over 300 years and today is one of the most important crops grown here.

In 1987 the first Louisiana Rice Production Handbook was published with the intent of putting into one volume a comprehensive reference to all aspects of rice production in Louisiana. The handbook was revised in 1999 with extensive changes and again in 2014. The handbook has been so popular it became apparent that supplies of printed copies would be exhausted well before the anticipated 10-year revision anniversary would be reached. Rather than reprint that edition, the authors decided to update it with new information, better photographs and the latest research information. This edition retains the enduring information from the first, second and third editions, deletes dated product references and adds the latest in rice production information. Many of the earlier references to crop protection chemicals and specific rice varieties have been eliminated to avoid early obsolescence. That information is available in the annually revised publication 2270, "Rice Varieties and Management Tips."

This publication is a product of the cumulative efforts of numerous scientists of the LSU Agricultural Center at the Rice Research Station in Crowley and from the main campus in Baton Rouge. All errors and omissions are the responsibility of the editor.

Edited by Ronnie Levy

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General Agronomic Guidelines

Manoch Kongchum and Ronnie Levy

Site Selection and Land Forming

Rice is grown under flooded conditions; therefore, it is best produced on land that is nearly level. Level tracts of land minimize the number of water-retaining barriers or levees required per unit of area (Figure 1-1). Some slope is required, however, to facilitate adequate drainage even though the practice of growing rice on zero-grade (level) fields has gained in popularity (Figure 1-2). Generally, a slope of less than 1% is adequate for water management. Most of Louisiana's rice-growing areas are well suited for rice production with a minimum of land forming. Recent innovations using laser systems have made precision leveled or graded fields physically and economically feasible.

Figure 1-1. More slope requires more levees.

Figure 1-2. Zero-grade field.

Precision grading a field to a slope of 0.2-foot or less difference in elevation between levees is important in rice production for several reasons: (1) it permits uniform flood depth; (2) it may eliminate a large number of levees; (3) it facilitates rapid irrigation and drainage; (4) it can lead to the use of straight, parallel levees that will increase machine efficiency; (5) it eliminates hills and potholes that may cause delay of flood and/or less than optimum weed control; and (6) it reduces the total amount of water necessary for irrigation.

In the past, leveling land was done first by identifying the natural slope or contour in fields using standard surveying methods. Then, levees were constructed following contour lines with a 0.2-foot elevation interval. The development of laser-leveling equipment has drastically improved both accuracy and efficiency of land forming (Figure 1-3). A laser emitter is set up on a stationary platform. Tractor-drawn implements, ranging from a simple straight blade to massive dirt buckets, are equipped with laser receivers and a computer. The computer is programmed according to the needs of the grower and field. As the tractor travels over the field, the implement removes soil from the high areas and deposits it in low areas creating either a gradual slope or completely level field depending on the programming and intended farming practices. On silt loam soils with a distinct hard pan, the procedure may be done while the field is flooded. This is called water leveling (Figure 1-4).

Figure 1-3. Laser leveling.

Figure 1-4. Water leveling.

On soils with deep profiles, such as the heavy clay soils of Mississippi and Red River alluvium, drastic cuts are often made to land. Although this practice certainly facilitates water management, it often creates fertility or productivity problems. Some herbicides prohibit their use on recently leveled ground because of phytotoxicity to rice and/or ineffective weed control. Until the subsoil layers weather, production problems may occur. Recovery of these areas usually takes from two to several years, depending on severity of cut and soil properties.

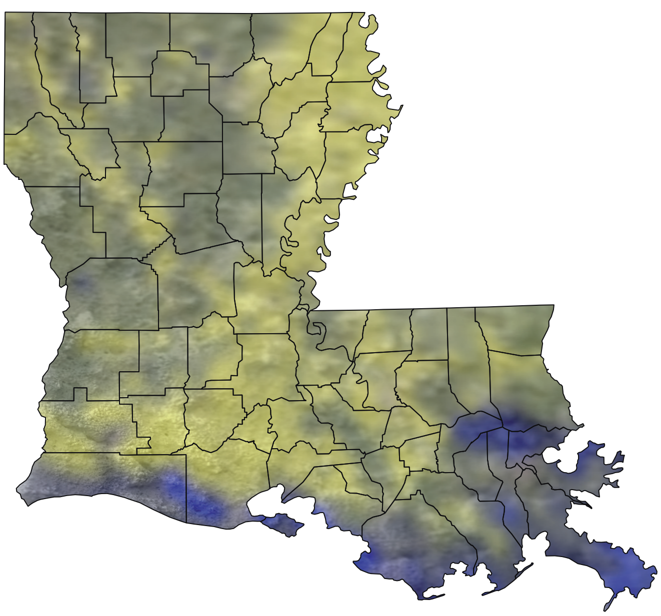


Figure 1-5. Louisiana soils map.

Soils

Rice can be grown successfully on many different soil textures throughout Louisiana. Most rice is grown on the silt loam soils derived from either loess or old alluvium that predominate the southwestern region and, to a lesser extent, the Macon Ridge area of northeast Louisiana. The clay soils in the northeastern and central areas derived from more recent alluvial deposits are also well adapted to rice culture (Figure 1-5). Deep, sandy soils are usually not suitable for rice production. The most important soil characteristic for lowland rice production is the presence of an impervious subsoil layer in the form of a fragipan, claypan or massive clay horizon that minimizes the percolation of irrigation water. Rice soils in Louisiana must be able to hold water in the paddies, which are, in a sense, small ponds.

Water Requirements

The ability to achieve optimum water management is essential in attempting to maximize rice yields. The single most important management practice is the ability to flood and drain rice fields in a timely manner. In general, pumping capabilities are adequate if a field can be flushed in two to four days, flooded in four to five days, and drained, dried and reflooded in two weeks. This is much easier to accomplish on fields that have been uniformly leveled to a slope of no more than a 0.2-foot fall between levees.

Sloped fields take advantage of gravity to flood and drain the fields. Usually, the top paddy is flooded and water overflows into the next paddy and so on continuing to the bottom of the field. Draining is accomplished using the same openings in levees until the end of the season when levees are opened mechanically, and the field is allowed to dry completely.

On zero-grade fields, flooding and drainage are accomplished by constructing the field so that at least two sides are bordered by deep trenches. Most often, these are on three sides of the field. The surface of the field then is crossed (in two directions if necessary) with shallow ditches. Water is pumped into the border ditches until it spreads through the shallow surface ditches, eventually overflowing them and spreading throughout the field. Drainage in these fields is the reverse of the process.

Figure 1-6. Using polypipe for irrigation.

The use of plastic (polyethylene) tubing, often called poly pipe, to flood multiple paddies simultaneously has gained in popularity in some of the rice-growing regions of the state (Figure 1-6). The plastic pipe is attached to the pump and water is pumped down one side of the field. Gates are installed in the tubing, or in some cases, the tubing is simply punctured to permit irrigation of all paddies at once. Size, shape and layout of the field all affect the economic efficiency of using this system.

Planting Dates

Some of the most important decisions that producers face are made prior to planting. Variety selection, planting date and appropriate seeding rate set the stage for the rest of the year, and good decisions here can translate into a better and more efficient harvest. Date-of-planting studies are conducted each year by LSU AgCenter researchers to adjust planting date recommendations. These studies include multiple varieties and planting dates and are designed to evaluate the optimum planting dates for new and popular varieties. Each year presents different environmental conditions, so there is not a single recommended date but rather a timeframe of about one month that is acceptable for planting.

LSU AgCenter recommendations for planting rice are from Feb. 25 to March 20 in southwest Louisiana and March 15 to April 15 in north Louisiana. On average, varieties planted during this time have the highest yield potential and milling quality and are generally easier to manage. Within this range is a lot of flexibility, and decisions should be based on specific field conditions. Average daily temperatures above 50 F, calculated by adding the daily high and low temperatures and dividing by 2, are critical in obtaining an acceptable stand. Also, sufficient seeding rates and a well-prepared seedbed that promotes good seed-to-soil contact are necessary when planting at the early end of this range.

Planting early is desirable for high-yield potential, good milling quality and the option to produce a second crop (in south Louisiana), but extremely early planting can be detrimental in some cases. Slow emergence and reduced seedling vigor in cold conditions can lead to seedling disease and stand reductions. Depredation due to birds is more common in early-planted rice, so higher seeding rates are necessary to compensate for potential stand loss. Many herbicides are less effective under cooler conditions often associated with very early seeding dates. On the other end of the spectrum, late-planted rice can also be challenging. In addition to lower yield potential and milling quality, most insect and disease pests are more damaging in late-planted rice. Yield loss due to high temperatures and a lower chance for a successful second crop are common in late-planted rice.

Seeding Rates

Planting date should always be a major consideration when determining seeding rates because of the impact of temperature on stand establishment and the relationship between uniform stands and yield. A number of factors, such as low germination percentage, poor seedbed conditions, cold weather damage, seedling disease and bird depredation, can result in stand loss; therefore, sufficient seeding rates are critical to compensate for potential yield reductions. Rice is naturally a compensatory crop because of its ability to produce tillers, which provide flexibility in plant stand without affecting yield, but stands outside of the recommended range and uneven stands can be difficult and costly to manage.

LSU AgCenter recommendations for rice varieties range from 50 to 80 pounds of seed per acre for drill seeding or dry broadcast seeding and 80 to 120 pounds of seed per acre for water-seeding rice to achieve a final plant stand of 10 to 15 plants per square foot. Typically, the lower end of these ranges should be used when conditions are ideal and the higher end when conditions are not conducive for good germination and plant establishment. Seeding rates for hybrid rice seed are much lower than for conventional varieties, and the hybrid seed representative should be consulted for recommendations. Stands that are too thin can result in increased weed competition, delayed maturity and decreased crop uniformity and quality. Conditions that justify a higher seeding rate include early planting, a poor seedbed, potential bird depredation, water seeding and any other factor that can cause stand loss and impede plant establishment.

Excessively high seeding rates should be avoided as well, as they are more costly and can increase disease pressure and lodging. Ultimately, the goal is to determine how much seed should be planted to ensure a plant stand of 10 to 15 plants per square foot given the current field, seedbed and weather (soil moisture, temperature, forecast, etc.) conditions.

Conventional rice varieties, varieties and hybrids with herbicide tolerant technology (Clearfield, Provisia, Max-Ace and FullPage), and conventional hybrid rice vary widely in seed costs, and reduced seeding rates are attractive economically requiring ideal planting conditions when reducing seeding rate or planting early. The money saved with a lower seeding rate or poor stand must be considered against potential additional expenses, such as replant costs, higher herbicide costs and other economic and agronomic factors.

Another important consideration is that seed size affects the recommended seeding rates in pounds per acre. For rice varieties, a final stand of 10 to 15 plants per square foot is optimal. In typical conditions, about 50% of planted seed produces a grain-bearing plant so a target seeding rate of 20 to 30 seeds per square foot is suggested to reach 10 to 15 plants per square foot. Seed size, and thus number of seeds per pound, varies among varieties, so a target seeding rate of 10 to 15 plants per square foot might require a different total seed weight per acre. For example, a medium-grain variety and a long-grain variety have 16,839 and 19,660 seeds per pound, respectively. Thus, a seeding rate for the medium-grain variety at 30 seeds per square foot would require 78 pounds of seeds per acre. The same seeding rate for the long-grain variety would require only 66 pounds to have the same number of seeds per acre.

Seeding rates of hybrid rice varieties are much lower than conventional rice varieties. Producers should consult the hybrid seed representative for guidelines and recommended seeding rates.

When water seeding or dry broadcasting, 40 to 60 seeds per square foot will be required to obtain a satisfactory stand. When drill seeding, 30 to 40 seeds per square foot will be required. Within each category is a range of seeding rates to allow for some adjustment. The higher seeding rates should be used when planting under less-than-optimal conditions.

Circumstances when the higher seeding rate should be used are as follows:

- When planting early in the season when the potential for unfavorably cool growing conditions exists. Cool conditions will favor water mold (seedling disease) in water-seeded rice, which can reduce stands. Varieties also differ in tolerance to cool growing conditions in the seedling stage.
- When planting into standing vegetation or after cover crop termination.
- Where seed depredation by blackbirds is potentially high.
- Where seedbed preparation is difficult and a less-than-optimal seedbed is prepared.
- If the seed source has a low germination percentage. Certified seed with high germination percentage should always be used, if possible.
- When water seeding into stale or no-till seedbeds with excessive vegetation.
- If any other factor (slow flushing capability, saltwater problems, etc.) exists that may cause stand establishment problems.
- If dry or nontreated seed are used in a water-seeded system. Water-seeding research has shown that the best plant populations are obtained when planting presprouted, fungicide-treated seed. Presprouted, nontreated and dry fungicide-treated seed produce somewhat lower plant populations. Dry, nontreated seed produce the lowest plant populations.

Dry Seeding

Fertilization Timing and Water Management

Dry seeding is the predominant seeding method used in the north Louisiana rice-growing areas. Dry seeding normally performs well on soils where a well-prepared seedbed is practical and/or red rice is not a severe problem. Rice can be dry seeded using a grain drill or by broadcasting (Figure 1-7).

Figure 1-7. Drilling seed into stale seedbed.

When rice is drill seeded, a well-prepared, weed-free seedbed is advantageous. A well-prepared seedbed will facilitate uniform seeding depth, which is important in establishing a uniform stand. Seeding depth is important with all varieties. It is especially critical with semidwarf varieties because these varieties are inherently slower in development during the seedling stage, and the mesocotyl length is shorter than conventional-height varieties. Therefore, semidwarf varieties should be seeded no deeper than 1 inch to maximize uniform stand establishment. Conventional-height varieties may be planted somewhat deeper, but seeding depths greater than 2 inches should be avoided with any variety.

Where soil moisture is adequate, a flush, or surface irrigation, following seeding may not be necessary. When soil moisture is insufficient and rainfall is not imminent, the field should be flushed within four days of seeding to ensure uniform seedling emergence. Therefore, levees should be constructed and butted at or soon after seeding.

Rice can be broadcast on a dry seedbed using either ground or aerial equipment. Seed should be covered using a harrow or similar implement. Uniformity of seeding depth is much more difficult to obtain when dry broadcasting. As with drill seeding, an immediate flush may facilitate uniform seedling emergence.

Fertilization timing and water management are similar for both drill seeded and dry broadcast-seeded rice. Phosphorus (P), potassium (K) and micronutrient fertilizers should be applied preplant and incorporated based on soil test results. The addition of 15 to 20 pounds of preplant nitrogen (N) is generally recommended to ensure against N deficiency in seedling rice. Application of large amounts of preplant N should be avoided in a dry-seeded system since wetting and drying cycles before the permanent flood is established can lead to the loss of much of this N.

The majority of the N fertilizer should be applied to a dry soil surface within three days prior to permanently flooding the field. The remainder of the N requirement should be applied midseason. In some cases, all of the N fertilizer can be applied ahead of the permanent flood if the precise N requirement for a field is known and if the permanent flood can be maintained throughout the season. If a field must be drained, however, for any unforeseen reason such as water weevil larva control or straighthead, appreciable amounts of N can be lost requiring reapplication of N. When the required N fertilizer rate is not known or the field will be drained before harvest for any reason, apply 60% to 70% of the estimated N fertilizer requirement prior to flood establishment. Additional N fertilizer should be applied at midseason at the beginning of reproductive growth between panicle initiation [(PI), green ring (Figure 5-10), or beginning internode elongation (IE)] and panicle differentiation (PD) (1/2 inch IE) (Figure 5-11).

Large amounts of N fertilizer should not be applied into the floodwater on seedling rice because it is subject to loss. With this system, the permanent flood should be established as soon as possible without submerging the rice plants. This will normally be at the four- to five-leaf rice stage in fairly level fields. Delaying permanent flood with the intention of reducing irrigation costs may increase other production costs, reduce yields and decrease profits. Additional information on fertilizer timing in relation to water management can be found in the Soils, Plant Nutrition and Fertilization section.

Row Rice/Furrow Irrigated Rice (FIR)

Row rice or furrow irrigated rice (FIR) has given Louisiana producers an alternative approach to rice production by giving producers the ability to use much of the same equipment used in soybean and corn production to grow a productive and potentially profitable rice crop. Every cropping system has its own set of advantages and disadvantages. Several factors to consider for FIR include choosing the right field, selecting appropriate varieties, managing fertility, controlling weeds and diseases, handling insect issues, and managing irrigation and water.

Field Selection

Just as not every field lends itself to traditional paddy rice, not every field will lend itself to FIR. A few considerations for field selection would be the row has little to no side fall and a row fall of 0.2 feet or less. If it is greater, water management in the field can become an issue as the water moves too quickly down the furrow and does not infiltrate the bed before reaching the end of the field. Depending on the soil type and infiltration rate, field setup can be done several ways. If beds are used, they need to be flat on top and short. Under this practice, planting depth will be much more uniform which will lead to even emergence. Row width for traditional beds or flats with a groove can range from 30 to 38 inches. Bed spacing wider than 38 inches depends on the soil's infiltration capability. In silt loam soils, water does not move sideways across the bed as well as it does in clay soils. In clay soils, 60- to 76-inch wide beds can be used. A more suitable description would be level ground with a furrow every 60 to 76 inches. A wide shallow bed helps the soil dry out uniformly for planting, in-season ground applications, irrigation and harvest.

There are two main types of planting equipment used in FIR – a grain drill or a vacuum row crop planter. The vacuum row crop planter is capable of much more uniform seed spacing and depth. Depending on rice row width (7-10 inches), planting equipment width and irrigation furrow width, it may be necessary to plant the rice at a slight angle to the row fall, so there is not a continual drill line down the bottom of the water path that might affect irrigation. When choosing a field for water management suitability, it's crucial to determine if the irrigation well can provide 1.5 to 2 acre-inches of water to the planted area within a 24-hour timeframe.

Variety Selection

The challenge with variety selection is that most trials are performed under a traditional paddy rice production system and will not provide a good predictive model of how a variety will perform in FIR. A major consideration when choosing a variety is blast resistance. Blast is a

significant disease risk in FIR which can cause tremendous damage and yield losses. This should be one of the first considerations when selecting a variety for FIR acres. Producers should look for a variety which has good stress tolerance along with good yield potential when considering what to plant.

Irrigation Management

FIR uses polypipe to deliver irrigation water to the fields. A computerized hole size software program should be used to determine the correct hole size for efficient irrigation. This helps minimize overwatering parts of a field while trying to make sure the entire field is irrigated. Sensors should also be used to monitor soil moisture and trigger irrigation. FIR draws most of its moisture needs from the top 6 inches of soil and the available level of moisture should be monitored carefully and irrigation applied as needed.

Fertility Management

In on-farm demonstrations and on research stations plots, a three-way split of nitrogen (N) has shown good results with 50% of the total applied at five- to six-leaf stage, then 25% applied seven to 10 days later, then 25% applied 10-14 days later. But each field can be different and what works in a field with a particular variety may not show the same results in a different location. A three-way split is a good starting place to customize applications moving forward. One valuable tool in evaluating any fertility program is the use of an N-rich strip. A N-rich strip is one strip through the field which has double the total amount of N applied. The N rich strip is used to monitor N levels during the growing season and determine if any additional N is needed to produce the crop. This observation can be done visually or through the use of a normalized difference vegetative index (NDVI). The LSU AgCenter has completed research that compares the NDVI readings in the N rich strip to the field readings and determines if additional N is needed.

Economics

A significant benefit of FIR to row crop producers is that it can use the same rows as the previous crop. FIR is a natural fit for a rotation with soybeans or other crops. Row crop producers usually have the equipment needed to grow FIR already in their operations. A major economic expense that is eliminated with FIR are internal levees and gates within the field. The savings in labor, fuel and wear on equipment to pull levees and install gates can be significant in both time and money. Without internal levees, applications of crop inputs, including fertilizer, herbicides, insecticides or fungicides, can be made by ground rigs instead of aerial methods between irrigation events.

The general expectation is that similar yields can be achieved as in flooded rice production, but growers should be prepared for a 10% yield reduction in row rice production depending on field conditions and management capabilities. The goal of this system is to achieve increased profit margins by reducing input costs in other areas that offset the potential yield loss.

Water Seeding

Fertilizer Timing and Water Management

Water seeding was once the predominant method of rice seeding used in Louisiana. It is still widely used in southwest Louisiana and, to a lesser extent, in the northern portion of the state.

The use of a water-seeded system can provide an excellent cultural method for red rice suppression, which is the primary reason for the popularity of water seeding in southwest Louisiana. Rice producers who raise crawfish in rice fields use water seeding because this planting method is easily adapted to rice-crawfish rotations. Other producers have adopted water seeding as a matter of custom, convenience or both. Water seeding is also an alternative planting method when excessive rainfall prevents dry seeding.

Seedbed preparation is somewhat different when water seeding is used compared with dry seeding. With water seeding, the seedbed is left in a rougher condition than for dry seeding. This is accomplished by preparing a seedbed consisting primarily of large clods (approximately baseball-sized), which is often easier to attain with heavy-textured soils. A flood is established as soon as possible following tillage, and rice is seeded within three to four days. This will reduce potential weed problems and provide a more favorable oxygen situation at the soil/water interface. Low oxygen levels are often a problem where floodwater is held for a long time before seeding.

A preferable alternative to a rough seedbed is preparation of a smooth seedbed similar to that for drill seeding. Following smoothing, the seedbed is firmed with a grooving implement, resulting in a seedbed with grooves (1 to 2 inches deep) on 7- to 10-inch spacings. In some situations, a field cultivator can achieve the desired grooves. Some producers have constructed tools specifically for the purpose of establishing grooves, and these tools are based on similar tools used in California and on Louisiana ingenuity.

A rough seedbed will minimize seed drift following seeding and facilitate seedling anchorage and rapid seedling development. Seed and seedling drift is often quite severe, especially in large cuts common in precision-leveled fields. The large clods or shallow grooves provide

a niche into which the seed can fall and provide some protection from wave action in a flooded field.

Dragging a field while it is flooded should be avoided before seeding because dragging: (1) leaves an extremely slick seedbed, which will compound problems with seed drift; (2) increases the severity of crusting and curling of the surface during the initial drain; (3) may displace and unevenly distribute incorporated fertilizers and herbicides; and (4) increases soil loss during the initial drain.

Water seeding is by necessity accomplished with aircraft using either dry or presprouted seed (Figure 1-8). Presprouted seed offers the advantages of higher seed weight and initiation of germination because the seed has already imbibed water. Presprouting is accomplished by soaking seed for 24 to 36 hours followed by draining for 24 to 36 hours prior to seeding. These periods may need to be extended under cool conditions. A disadvantage to presprouting is that seed must be planted shortly after presprouting or deterioration will occur. Water management of water-seeded rice after seeding may be categorized as delayed flood, pinpoint flood or continuous flood.

Figure 1-8. Presprouted seeds.

Delayed Flood System

In a delayed flood system, fields are drained after water seeding for an extended period (usually three to four weeks) before the permanent flood is applied. This system is normally used in fields where red rice is not a problem because the delayed flood system provides no red rice suppression. Fertilizer application timings and water management after the initial drain are similar to those in dry-seeded systems.

Pinpoint Flood System

The most common water-seeding method is the pinpoint flood system. After seeding with presprouted seed, the field is drained briefly. The initial drain period is only long enough to allow the radicle to penetrate the soil (peg down) and anchor the seedling (Figure 1-9). A three- to five-day drain period is sufficient under normal conditions. The field then is permanently flooded until rice nears maturity (an exception is midseason drainage to alleviate straighthead). In this system, rice seedlings emerge through the floodwater, and seedlings must be above the water surface by at least the four-leaf rice stage. Before this stage, seedlings normally have sufficient stored food and available oxygen to survive. Atmospheric oxygen and other gases are then necessary for the plant to grow and develop. The pinpoint flood system is an excellent means of suppressing red rice emerging from seeds in the soil because oxygen necessary for red rice germination is not available as long as the field is maintained in a flooded or saturated condition.

Figure 1-9. Emerged seedlings ready for pinpoint flood.

Continuous Flood System

Use of a continuous flood system is limited in Louisiana. Although similar to the pinpoint flood system, the field is never drained after seeding. Of the three water-seeded systems, a continuous flood system is normally best for red rice suppression, but rice stand establishment is most difficult. Even the most vigorous variety may have problems becoming established under this system.

Fertilization timing is the same for both the pinpoint and continuous flood systems. Phosphorus, potassium, sulfur (S) and zinc (Zn) fertilizers are applied preplant incorporated as in the dry-seeded system. Once the field is flooded, the soil should not be allowed to dry.

If the N requirement of a particular field is known, all N fertilizer should be incorporated prior to flooding and seeding. Otherwise, one-half to two-thirds of the estimated N fertilizer requirement should be incorporated prior to flooding and seeding or during the brief drain period in a pinpoint flood system. Additional N fertilizer can be

applied at midseason at the beginning of reproductive growth between PI and PD. More information on fertilizer timing in relation to water management is in the Soils, Plant Nutrition, and Fertilization section.

Alternate Wetting and Drying (AWD)

Alternate wetting and drying (AWD) can be used for maximizing rainfall capture and reducing irrigation pumping. This practice can be integrated into the continuous flood or delayed flood system. The water level in AWD should not be too deep, which could allow it to subside naturally during the midseason. The reflooding indicator depends on soil type, which can be mud in a clay soil or dryer in a silt loam soil. Frequency and number of wetting and drying cycles depend on weather conditions and rice growth stage. This drying period can be maintained for five to seven days. However, the drying events should be avoided at the green ring and flowering stage, when rice is most sensitive to water stress. AWD is not only reducing irrigation pumping but also reducing methane emissions. Fertilizer management is similar to the dry seeding method. Flood water should be retained at least three weeks after N application before implementing a drying cycle for better nitrogen use efficiency.

Furrow Irrigated Rice (Row Rice) System

Furrow irrigated rice or row rice system has increased acreage in recent years, particularly in the northern part of Louisiana. In this water management system, the beds are made in fields to channel the flow of irrigation water in furrows down the slope in the field. The optimum spacing of the furrows depends on the soil type. Bed widths of 30 inches are acceptable, however, it can be increased to 36 or 40 inches in clay soil. Polypipe with multiple outlets is commonly used for irrigation. In this system, the planting practice is similar to dry seeding or delayed flood system with the planting direction parallel with the furrows. With the less water environment, rice cultivars for this system should be a blast resistance one. Nitrogen fertilizer can be managed in different options including (1) a single application preirrigation at the four- to five-leaf stage, (2) a two-way split with 50% preirrigation, and 50% 10-14 days later, or (3) a three-way split with one-third preirrigation, and another two times of one-third at seven to 10 days apart. Irrigation water should be maintained for adequate soil moisture (every five to seven days if no rainfall). Several reports indicated yield decrease between 10%-40% compared to flood rice system. This practice should be avoided if there is a high salt concentration in the irrigation water or the field has a history of salt contamination.

Ratoon (Second or Stubble) Crop Production in Rice

The climatic conditions of southwest Louisiana and the earliness of commonly grown rice varieties combine to create an opportunity for ratoon, or second/stubble, crop production. Ratooning is the practice of harvesting grain from tillers originating from the stubble of a previously harvested crop (main crop).

Weather during the fall will normally dictate the success of ratoon rice production. In southwest Louisiana where rice is ratooned, the growing season prior to the onset of unfavorable temperatures is not long enough in every year to allow maturation of the ratoon grain. A decline in temperature and day length as the ratoon crop is developing could produce negative impacts on pollination, grain filling, ratoon rice yield and milling quality. Furthermore, the months of September and October, when ratoon rice is developing, are also the months when the production area is most susceptible to tropical weather systems.

Mild temperatures will speed ratoon maturity and prevent excessive sterility (or blanking) associated with low temperatures at flowering. Average daily high and low temperatures are just as important in the development of ratoon rice as it is in the main crop. Later-than-normal first-frost dates will aid ratoon rice production, especially when the main crop is harvested later than Aug. 15. The main crop should be harvested by Aug. 15 to ensure adequate time for ratoon rice to develop. In years with an abnormally mild fall and a late first frost, ratoon rice can be produced when the main crop is harvested as late as the first week of September, but this is the exception rather than the rule.

While cooperation from the weather is essential for ratoon rice production, cultural practices play a critical role in maximizing ratoon rice yields. Cultural practices used in the main crop can have a major impact on ratoon rice production. Every management decision in the main crop will in some way impact the ratoon crop. Planting date, fertilization, and weed, disease and insect management in the main crop will all influence ratoon rice development and yield. Excessive nitrogen fertilizer applied to the main crop can delay regrowth of ratoon rice; therefore, overfertilization should be avoided even with a lodging-resistant variety. Severe disease pressure in the main crop may cause death of tillers and prevent regrowth from these plants, which will reduce ratoon rice production. Therefore, a foliar fungicide applied to the main crop can be beneficial to the ratoon crop.

Conditions at harvest for the main crop will influence whether a ratoon harvest should be attempted. If the main crop is harvested under muddy conditions and the field is excessively rutted, ratoon rice production will be difficult and is not recommended. Excessive red rice in the main crop will also limit ratoon rice yield and quality. Where red rice is severe, ratoon rice production should be avoided and efforts should be concentrated on encouraging germination of red rice seed followed by destroying the seedlings with fall tillage, which may decrease red rice populations in successive crops.

An application of N fertilizer is necessary for high ratoon rice yields. Nitrogen fertilizer applications should be made to a dry soil surface and a shallow flood established immediately after harvest. This procedure will facilitate rapid regrowth and efficient use of applied N fertilizer. Studies with N fertilization rates in the ratoon crop indicate that a rate of 75 to 90 pounds of N per acre is sufficient for most commonly used rice varieties when first crop is harvested before Aug. 15. Consult the annual LSU AgCenter publication 2270, Rice Varieties and Management Tips, when selecting varieties with the intention of producing ratoon rice.

The second (ratoon) rice crop has become an integral part of commercial rice production in southwest Louisiana. The ratoon crop will generally yield approximately one-third of that realized in the main crop. Although, ratoon yields are much less than that of the first crop, there is a definite economical advantage of growing the ratoon crop. It is economically productive because the input costs for producing the ratoon crop are kept at a minimal. Generally, the only costs associated with growing a ratoon crop are nitrogen fertilizer, irrigation, harvesting and grain drying. While growing a ratoon crop is economically favorable to a producer, having a successful ratoon crop is not guaranteed every year. Although traditional weather patterns in the southern rice growing region give us the opportunity to grow a ratoon crop, it is often weather that dictates the ultimate success of the endeavor. We cannot control the weather; however, there are several management strategies and decisions that we can use to improve our probability of success.

The first management decision begins before the main crop is even planted and that is to select an early maturing rice variety with a high ratoon potential. The second management decision is truly the "go" or "no" decision on attempting a ratoon crop. This decision should be made with information gathered from the main crop including an evaluation of disease pressure prior to harvest, the stubble conditions after harvesting and the date of harvest. Harvesting the first crop prior to Aug. 15 will generally give the ratoon crop enough days of warm weather to grow a ratoon crop. There have been many seasons in the past when a main crop harvested after Aug. 15 produced excellent ratoon yields; however, these were in years with mild fall temperatures and late first frosts. Unfortunately, there is no way of determining if any given year will be one of those years. The earlier the main crop is harvested the better the probability of success with the ratoon crop. We must also remember that all management practices that we apply towards the main crop will have a bearing on the ratoon crop. For example, less than optimum weed and disease control will not only reduce yield in the main crop but will also be detrimental to the ratoon crop. A clean first crop will improve second crop yield potential. Another example would be harvesting a main crop in muddy soil conditions. This will certainly lead to increased rutting of the field and reduced ratoon yields in the rutted areas. There are even times when we may want to make the decision not to grow a ratoon crop at all. For example, high disease pressure will almost certainly spell disaster in the ratoon crop. You also might want to consider not growing a ratoon crop in fields with a heavy infestation of red rice. Take the measures needed to control the red rice problem now before it becomes more of a problem in future crops.

The final major decision is to determine whether or not to use a stubble management practice. Stubble management practices, such as harvesting at a lower-than-normal harvest height, reducing the stubble height by postharvest flail mowing or bush hogging to around 8 inches, and rolling the stubble have all shown a yield benefit in studies conducted at the H. Rouse Caffey Rice Research Station in most years. The yield benefit can be up to several barrels per acre in some years. However, both harvesting the main crop at a lower-than-normal platform height, flail mowing, bush hogging and rolling the stubble will delay the maturity of the ratoon crop by approximately two weeks. So, if the main crop is harvested at a later than optimum date, further delaying the ratoon maturity by using one of these stubble management practices may not be the best decision. Interest in using a fungicide application in the ratoon crop has gained interest over the past several years. In a study at the Rice Station, application of a fungicide four weeks after harvest (coinciding with the first ratoon panicle emergence) did not reduce Cercospora incidence in the ratoon crop. On the other hand, lowering the ratoon stubble height by either flail mowing, bush hogging or harvesting lower did reduce Cercospora incidence.

The next true management decision is when and how much N fertilizer to use. Our past ratoon N studies have shown that 90 pounds of N applied on a dry soil just after the main crop is harvested and immediately followed by a very shallow flood is the best management strategy in almost every study across all varieties and hybrids. If you decide to attempt a ratoon crop when the main crop was

harvested after Aug. 15, you will need to reduce the N rate. This will reduce the time to maturity of the ratoon crop and also reduce your investment in the ratoon crop. Nitrogen fertilizer should not be applied to the ratoon crop if the first crop is harvested after Sept. 1.

Conservation Tillage Management

Enhancement of soil physical, chemical and biological properties is one of the major goals of sustainable agricultural production. Tillage practices are one way to impact soil properties and crop yields, hopefully with positive effects. Improvement of soil physical, chemical and biological properties is a technical factor. Tillage practices, however, are also directed by economic factors such as production costs, a producer's economic situation, commodity prices and credit availability. Therefore, a balance must be discovered that allows a producer to use sustainable production practices at economical levels.

Most rice in the United States is grown using conventional tillage; however, conservation tillage has gained acceptance in many rice-growing areas. No-till and reduced tillage systems, such as fall and spring stale seedbeds, have been shown to significantly improve the quality of floodwater being removed from rice fields by reducing sediment losses. Problems, however, are associated with producing rice in this manner. Previous research conducted at the LSU AgCenter Rice Research Station since 1987 has addressed issues related to varieties not adapted to conservation tillage systems and yield reductions related to numerous factors involving conservation tillage. This research has firmly established the advantages and disadvantages of reduced tillage rice production, and it has identified stand establishment and early-season plant density as critical components of managing a reduced tillage rice production system.

Preplant and/or early season vegetation management are vital elements in reduced tillage rice production systems. By minimizing the amount of preplant, vegetation present in the seedbed and competition between the vegetation and the establishing rice crop is reduced. Additionally, plant residue can increase immobilization and volatilization of N fertilizer applied during the seedling rice stage, so proper management of preplant and early season vegetation also may reduce the amount of N fertilizer lost due to immobilization and volatilization.

The following information on conservation tillage in rice is based in part on specific research results obtained from reduced tillage rice research studies. Some information is generalized based on observations from these studies and not necessarily scientific measurements.

The basic components of these alternative tillage practices are summarized emphasizing advantages and disadvantages. This information is intended as general guidelines, but it may not be applicable to every situation. Three alternative methods of seedbed preparation have been compared with conventionally prepared seedbeds in both water- and drill-seeded cultural systems. These methods are defined as follows:

Spring Stale Seedbed

Seedbeds are prepared three to six weeks prior to planting. Depending on temperature and rainfall, vegetation that emerges prior to planting is usually small and easily controlled with herbicides. Most producers find little cultural advantage with spring stale seedbed compared with spring seedbed preparation at the normal time under a conventional tillage system. The spring stale seedbed system, however, offers one important benefit: during dry springs, seedbeds can be worked earlier in the year and prepared for planting, which improves the likelihood of timely planting. Time, money and labor are conserved by controlling preplant vegetation with a burndown herbicide rather than waiting for the seedbed to dry for mechanical preparation if excessive rainfall occurs prior to planting.

Fall Stale Seedbed

Seedbeds are completely prepared in the fall prior to rice planting in the spring. Vegetation that emerges during the winter months is usually uniform, 8 to 10 inches in height and consists of winter annual grasses, clovers, vetches and other broadleaf weed species. The fall stale seedbed system is the most popular reduced tillage practice in southwest Louisiana. Better drying conditions and favorable weather in the fall allow more opportunity for field preparation.

No-till

Rice is planted directly into the residue of a previously harvested crop or native vegetation. In southwest Louisiana, soybean is the typical rotational crop. Cotton and soybean are options in north Louisiana. Preplant vegetation is usually not uniform in size and usually consists of larger, woody winter weeds that create problems when controlling preplant vegetation (Figure 1-10). Rice establishment practices used in conservation tillage systems are described below.

Figure 1-10. Drilling seed into standing vegetation.

Preplant vegetation control. Several herbicides are labeled for preplant burndown applications in rice. The herbicide label should be consulted for application rate and weed control spectrum. Application rate depends on type and size of weeds present, and herbicides should be applied according to label directions. Some rice is planted in a no-till system without termination of preplant vegetation, which is possible if weed growth is minimal and species include winter annuals that will eventually die in the spring or be killed by flooding. Significant yield reductions have occurred in studies where preplant vegetation was excessive and a burndown herbicide was not used. Choosing not to apply a burndown chemical is risky, and weed identification is critical.

Time of application in relation to planting. Best results in most burndown research have occurred with a seven- to 10-day preplant herbicide application timing. These results are especially true when residual herbicides are tank-mixed with burndown herbicides. Longer intervals between burndown and planting reduce the effectiveness of residual weed control in the planted rice crop. Plant back restrictions also exist for a number of burndown herbicides, and these restrictions for rice vary dramatically depending on the choice of burndown herbicide. Burndown herbicides must be applied according to label directions. See the section on Weed Management for more details on burndown herbicide materials and timing.

Planting practices. Presprouting seed when using a water-seeded system will speed stand establishment and minimize seedling problems associated with poor floodwater quality, low oxygen, seedling diseases and potential seed midge. Seed-to-soil contact is important and is a function of the amount of vegetation and, to some extent, the type of vegetation. When drill seeding, it is important to use planting equipment that places seed at a uniform depth and closes the seed furrow to conserve moisture. On some soils, no-till equipment may not be required. High quality, conventional grain drills perform well on well-prepared seedbeds. Heavy, no-till equipment is desirable where vegetation is excessive and seedbeds are compacted.

Water management. Inadequate stand establishment is a common problem in water-seeded, no-till rice, especially in a pinpoint flood system. Delaying permanent flood establishment for two to three weeks after water seeding and initial draining will improve stand establishment in some situations. Adequate moisture, however, must be available through rainfall or irrigation in delayed flood systems. Excessive drying of the seedbed during rooting also can cause stand reductions. Delayed flooding is not a desirable management practice when red rice is a problem, and control or suppression of red rice will be significantly lower when delayed flooding is practiced. Red rice suppression using water seeding is less consistent under conservation tillage compared with conventional tillage systems.

Stand establishment difficulties encountered when drill seeding are often associated with inadequate moisture. If moisture is inadequate at planting, the field should be flushed to encourage uniform emergence and stand establishment. Gibberellic acid seed treatment also may enhance emergence of some varieties. In water-seeded systems, seed-to-soil contact is often poor. Consequently, frequent flushing in delayed flood systems may be required. In a pinpoint flood system, draining a field multiple times may be required to encourage rooting.

Variety selection. Variety selection when using a no-till system is important. Good seedling vigor, tillering ability and yield potential are important characteristics. Under ideal conditions, any recommended commercial variety could be considered. Research supports the fact that no-till and weedy stale seedbeds are not ideal situations, and varieties that possess the characteristics listed above perform most consistently under conservation tillage systems. Seedling vigor in some semidwarf varieties is lower than in tall varieties, often causing stand establishment problems in no-till seedbeds, especially if water seeded. This problem may result in lower yields. Taller varieties or those that possess good seedling vigor have performed best under conservation tillage systems.

Fertilizer management. Plant nutrients can be surface applied in a no-till system. In stale seedbed systems, phosphorus and potassium can be incorporated at the time of land preparation or surface applied in the spring. Nitrogen management in the spring rice crop is much easier when P and K are applied in the fall. Fertilizer efficiency, however, is much higher when applied in the spring compared with fall applications, especially for K. In a no-till system where scumming may be a problem, P and K should be applied after rice stand establishment but before

the five-leaf rice stage. These nutrients can be applied into standing floodwater or before permanent flooding.

When not to no-till. Excessive vegetation, hard-to-control weeds, rutted fields, unlevel fields and fields where red rice is a problem are situations where a producer should consider conventional tillage practices. Heavy vegetation reduces seed-to-soil contact and increases problems establishing adequate stand. Weeds not controlled before planting will cause significant problems after planting. Rutted and unlevel fields impact both flooding and draining of rice fields.

U.S. Rice Sustainability Efforts

Steve Linscombe

Today's U.S. rice industry is building on past improvements and working in new ways to more sustainably feed a growing population. Rice farmers have an historic commitment to protect and conserve the natural resources that provide a healthy, environmentally beneficial, and economically stable food source while providing a sustainable livelihood for their families. Rice farmers and millers abide by a range of laws and regulations ensuring the safety of workers in the industry and environmental compliance as required. As consumers and the food industry demand more sustainable products and world population continues to rise, U.S. rice farmers and others in the industry are one step ahead – ever working to improve and forward facing to build the rice story for a sustainable future.

The U.S. rice industry recently published the U.S. Rice Sustainability Report which is available at https://www.usarice.com/sustainability/sustainability-report. This report, commissioned by The Rice Foundation, captures for the first time the sustainability story of U.S. rice and the remarkable progress made throughout the industry, focusing both on the significant environmental improvements as well as rounding out the story with the economic and societal benefits.

Over the past 40 years, improved sustainability practices have led to increased production and crop yields while also yielding some of the greatest environmental benefits.

- Crop yield per acre increased 62%.
- Rice production increased 32%.
- Land use decreased 39%.
- Water use decreased 52%.
- Energy use decreased 34%.
- Greenhouse Gas Emissions decreased 41%.
- Soil loss decreased 28% (on a per acre basis).

Enhancing Biodiversity

Rice conservation practices improve much more than water, soil and air. They improve and enhance vital wildlife habitat. Winter flooded rice fields provide a haven and play a critical role in supporting millions of waterbirds each year with both food and protection. Just beneath the surface of the water and the soil, flooded rice fields also give life to a complex web of crawfish, amphibians, fish, reptiles, microflora and microfauna.

- Winter flooded rice fields provide millions of acres of life-sustaining resources for wildlife and a haven for millions of waterbirds.
- Rice farmers manage and pay for approximately 700,000 acres of winter-flooded rice habitats.
- Rice wetlands provide roughly 35% of all food energy for migratory birds.
- Estimated cost of replacing the flooded rice habitats in rice-producing states is $3.4 billion.

Energy Use

Over the course of 36 years, energy use in U.S. rice production has decreased by 34% as shown by the linear trend analysis in Field to Market's 2016 National Indicators Report. While rice production increased, energy use decreased from 341,000 BTU per cwt in 1980 to 206,364 BTU per cwt in 2015. Rice farmers use a variety of energy-efficient practices to achieve energy and cost savings including:

- Improved farm equipment reducing diesel consumption, reduced aircraft passes and aircraft fuel consumption, and use of stripper heads to increase harvest speed.
- Practices such as conservation tillage saves fuel and reduces labor hours because of fewer tractor passes through the field, and alternate wetting and drying saves energy through optimized pump efficiencies.
- Mechanical improvements to pumps, motors, and engines increase the farmer's control over water application thus increasing energy efficiency.
- Irrigation flow meters to help farmers monitor energy as well as water use.
- Evaluating and optimizing irrigation pump efficiencies achieves energy and cost savings with studies showing savings of $16,000 per year if pumping systems are optimized.

Renewable Energy Production and Use

Renewable energy use is a growing practice in many agriculture commodities, especially in rice farming and production. Rice millers work with power facilities to change

a waste product (rice hulls) into a viable energy source, also contributing to the reduction in greenhouse gases.

- Some facilities provide enough power to supply surrounding small towns with electricity from burning rice hulls.
- Solar energy is being used throughout the rice industry value chain, with solar panels in use both on some rice farms and at mills.
- Solar power replaces purchased electricity or diesel fuel to run some irrigation systems.

Air Quality

U.S. rice greenhouse gas (GHG) emissions resource efficiencies improved with a 41% reduction in GHG emissions per cwt of rice produced over 36 years, according to the 2016 National Indicators Report. Rice conservation practices and innovation result not only in reduced energy use and potential renewable energy production but can also lead to improved air quality and a decrease in GHG emissions.

- Straw management strategies – incorporating straw into soil with active winter flooding, straw incorporation without active flooding, and harvesting the straw for other use – contribute to improved air quality.
- Use of urease inhibitors can reduce nitrate-N in the soil, decreasing losses of the greenhouse gas nitrous oxide.
- Studies have shown alternate wetting and drying (AWD) can reduce methane emissions between 39% with a single drain and 83% with multiple drains on average.
- Use of urease inhibitors can reduce nitrate-N in the soil, decreasing losses.

Land Use

U.S. rice farmers respect the land they work. They believe in conservation practices to maintain and improve their land for the next generation. Increasing demands on land use in the United States necessitate the most efficient use of land for any given purpose. The 2016 National Indicators Report measures land use by the amount of land required for a unit of production. The soil conservation indicator represents soil erosion from wind and water.

- In 2018, U.S. rice was grown on 2.8 million acres of land in six states: Arkansas, California, Louisiana, Mississippi, Missouri and Texas.
- Land use showed steady improvements with a 39% overall decrease in planted acres per cwt of rice produced from 1980 to 2015. In 2015, nearly 75 cwt of rice was produced per planted acre while that same acre only produced roughly 45 cwt in 1980.
- Soil conservation improved on a per acre basis with a 28% decrease in soil loss in the same 36-year period.

Water Use and Soil Conservation Practices

Precision land leveling uses GPS and laser-guided earthmoving equipment to create uniform grades and slopes within fields which:

- Facilitates surface drainage.
- More efficiently distributes irrigation water.
- Can produce greater crop yields, improve weed control, provide a larger farming area, and reduce transplant and seeding times.

Zero-grade farming uses precision-leveled fields without levees to:

- Provide for more efficient water use.
- Improve water use by 30-50% for some farms.

Conservation tillage is a practice where rice is planted with no or minimal tillage into previous crop residue or a stale seedbed which:

- Protects the soil from erosion, loss of nutrients and salinization.
- Improves soil health by keeping organic material in the field.
- Naturally saves energy and reduces carbon dioxide emissions with less tractor passes in the field.

Soil Erosion

Due in part to the unique nature of rice production practices, erosion hasn't historically been a major problem for rice. Heavy clay soils that are ill-suited to other crops retain water very well, making them perfect for rice. Because of rice cultivation practices such as land-leveling for flood irrigation and innovative water control structures, erosion continues to decline, and, according to the 2016 National Indicators Report, rice has one of the lowest soil erosion rates when compared to all major U.S. row crops.

U.S. rice farmers use a variety of management strategies to irrigate their fields. Groundwater from wells or surface water from rivers, streams, lakes, bayous and reservoirs is used to irrigate the land. Farmers strive to reclaim and recycle as much surface water as possible. This is better for the farmers' bottom line and better for the environment.

New innovative irrigation methods and other conservation practices significantly reduce water use and lead to improved water quality and other environmental benefits as reported in the 2016 National Indicators Report.

- Rice farmers reduced irrigation water use from 0.80 acre-inches per cwt of rice produced in 1980 to 0.46 acre-inches per cwt in 2015.
- Irrigation water use has decreased by an impressive 52% over the 36-year period from 1980 through 2015.

Water Use Practices

Farmers use a combination of water conservation methods to create a system best suited to their conditions.

- Continuous flooding: Facilitates weed control, reduces the need for herbicides and additional fertilizers, and improves water quality.
- Multiple-inlet rice irrigation (MIRI): Allows each area between the levees to be simultaneously irrigated, eliminating water flow from one levee to another, reducing the time for water to flow from one end of the field to the other, and allowing for greater control over water movement.
- Alternate wetting and drying (AWD): Saves water without negatively impacting crop yield, maximizes the use of captured rainfall, reduces total water use, and saves money with reduced pumping fuel costs.
- Furrow irrigation: Water flows efficiently down the furrows where the rice is planted and seeps vertically and horizontally to refill the soil reservoir.
- Tailwater recovery systems: Conserve irrigation water supplies through capture and reuse of run-off water.

On-Farm Efficiencies

Water use practices equate to several on-farm efficiencies, such as:

- MIRI reduces the cold-water effect on the first levee and has been found to reduce total water use by an average of 25%.
- On-farm trials have shown an 18% reduction in water cost using MIRI systems over straight levee production practices.
- AWD practices can reduce water use by up to 30% without hurting yields.
- Furrow-irrigated rice can save water, save energy, increase time efficiencies, improve the ability to rotate crops and improve seed distribution.
- Tailwater recovery systems save water, soil and money.

Water Quality

Growing rice is a natural filtration system removing sediments and nutrients thus producing cleaner water when leaving the field. Water management practices such as conservation tillage, land-leveling, filter strips and riparian buffers, integrated pest management (IPM) and 4R nutrient management may be used in conjunction with various irrigation methods which reduce runoff and make water cleaner and clearer.

- Studies show that when water leaves a rice field, the amount of suspended solids is five times less than when the surface water was pumped onto the field.
- Most U.S. rice farmers adhere to the 4R Nutrient Stewardship principles of applying fertilizer at the (1) right source, (2) at the right rate, (3) at the right time, (4) and in the right place.
- Filter strips and buffers act as natural nutrient managers, preventing soil erosion, filter runoff, and remove contaminants to improve water quality.
- Postharvest winter flooding practices increase straw decomposition, reduce winter weeds, and improve soil retention and water quality, while also providing wildlife habitat.
- Rice stubble maintained in the field can save on disking, herbicide administration and levee repairs, saving $20/acre or more.

As consumers and the food industry demand more sustainable products and world population continues to rise, U.S. rice farmers and others in the industry are one step ahead – ever working to improve and forward facing to build the rice story for a sustainable future.

Rice Varieties and Variety Improvement

Adam Famoso, Brijesh Angira and Rick Zaunbrecher

The development of superior rice varieties has played a vital role in enhancing rice production both in Louisiana and the United States as a whole. The introduction of these improved varieties through both public and private breeding programs, coupled with advancements in rice production technology, has led to a consistent increase in both the quantity and quality of rice produced. It is important to note that there is still significant genetic potential for further improving existing rice varieties. Furthermore, the importance of rice breeding initiatives will continue to grow as the severity and unpredictability of weather patterns increase. Therefore, continuous breeding efforts will be crucial in ensuring the long-term sustainability of the rice industry in both the U.S. and Louisiana.

Rice Varietal Improvement Program

Organized rice varietal improvement in the United States began in 1909 with the establishment of the Rice Research (Experiment) Station (RRS) in Crowley, Louisiana. The focus was on evaluating varietal introductions from around the world to determine the best performers for the local environment and production practices. Many of today's elite varieties and germplasm can trace their pedigree back to those initial introductions. The rice breeding activities were initially under the direction of U.S. Department of Agriculture scientists until the Louisiana Agricultural Experiment Station (LAES) took over in 1981. The Rice Research Station has a long history of developing new varieties that benefit the Louisiana rice industry. Since its inception, the program has formally released 65 improved rice varieties (Table 3-1). Variety development efforts require time, money, hard work, travel, specialized equipment and cooperation with producers and other research personnel.

Table 3-1. Varieties released by the H. Rouse Caffey Rice Research Station.

Year Released	Variety	Grain Type	Herbicide Type
1917	**Colusa**	Short	CN
1918	**Fortuna**	Long	CN
1918	**Acadia**	Short	CN
1918	**Delitus**	Long (A)	CN
1918	**Tokalon**	Long	CN
1918	**Evangeline**	Long	CN
1928	**Rexoro**	Long	CN
1932	**Nira**	Long	CN
1945	**Magnolia**	Medium	CN
1949	**Lacrosse**	Medium	CN
1953	**Sunbonnet**	Long	CN
1955	**Toro**	Long	CN
1956	**Nato**	Medium	CN
1964	**Saturn**	Medium	CN
1973	**Della**	Long (A)	CN
1973	**Vista**	Medium	CN
1979	**LA 110**	Medium	CN
1982	**Leah**	Long	CN
1984	**Toro-2**	Long	CN
1987	**Mercury**	Medium	CN
1991	**Lacassine**	Long	CN
1992	**Bengal**	Medium	CN
1992	**Cypress**	Long	CN
1994	**Jodon**	Long	CN
1995	**Dellrose**	Long (A)	CN
1996	**Lafitte**	Medium	CN
1998	**Cocodrie**	Long	CN
1999	**Dellmati**	Long (A)	CN
2000	**Earl**	Medium	CN
2001	**CL121**	Long	CL
2001	**CL141**	Long	CL
2002	**CL161**	Long	CL
2003	**Cheniere**	Long	CN
2003	**Pirogue**	Short	CN
2004	**Ecrevisse**	Short	CN
2005	**CL131**	Long	CL
2005	**Jupiter**	Medium	CN
2005	**Trenasse**	Long	CN
2008	**CL151**	Long	CL

Year Released	Variety	Grain Type	Herbicide Type
2008	**Catahoula**	Long	CN
2008	**Neptune**	Medium	CN
2009	**Jazzman**	Long (A)	CN
2010	**CL111**	Long	CL
2010	**CL261**	Medium	CL
2011	**CL152**	Long	CL
2011	**Caffey**	Medium	CN
2011	**Jazzman-2**	Long (A)	CN
2012	**Della-2**	Long (A)	CN
2012	**Mermentau**	Long	CN
2013	**CL271**	Medium	CL
2015	**CL153**	Long	CL
2015	**CL272**	Medium	CL
2015	**Frontière**	Long	CN
2017	**PVL01**	Long	PV
2018	**CLJ01**	Long (A)	CL
2019	**PVL02**	Long	PV
2020	**CLL17**	Long	CL
2021	**PVL03**	Long	PV
2022	**Addi Jo**	Long (HA)	CN
2022	**Avant**	Long	CN
2023	**CLL19**	Long	CL
2024	**CLHA03**	Long (HA)	CL
2024	**Fitzgerald**	Long (A)	CN

Abbreviations: A-Aromatic, HA-High Amylose, CN-Conventional, CL-Clearfield, PV-Provisia

Objectives and Market Segments

The breeding program is split into different segments based on grain quality (cooking and appearance) characteristics and herbicide tolerance classes. Long grain is the primary focus, accounting for approximately 80% of the breeding efforts, while medium grain accounts for the remaining 20%. The breeding program focuses on three main herbicide classes. The conventional herbicide class consists of rice varieties that are only tolerant to traditional rice herbicides. The advantage of this class is that the seed and production costs are typically lower for the producer, and there are sufficient options for weed control in the absence of weedy red rice. Clearfield, developed by the LSU AgCenter, was the first herbicide-tolerant rice production system. It revolutionized rice production in the southern U.S. by offering an effective method to control weedy red rice with pre- and postemergence herbicides with residual activity. This technology provided farmers with more flexibility and enabled more sustainable farming practices, including direct-drill seeding, no-till or minimum till practices, delayed flooding of the crop and reduced water usage. Over time, the Clearfield tolerance trait has outcrossed to weedy rice, leading to the development of Clearfield-resistant weedy rice populations. To complement the Clearfield system and control Clearfield-resistant weedy rice, BASF developed the Provisia Rice Production system. Provisia (PV) rice is resistant to the Group 1 herbicide quizalofop, an excellent grass herbicide that effectively controls weedy rice. The Provisia herbicide is a contact herbicide that controls existing weeds in the field but does not offer residual control.

Grain Quality

The three main components of grain quality are industrial, appearance and cooking. Industrial quality pertains to the milling attributes of the variety and includes the ease and uniformity of milling and milling yield in terms of the proportion of whole and broken kernels obtained from rough rice. The appearance quality of rice is largely determined based on the degree of chalk in the kernels and their shape. Chalk is an opaqueness in the endosperm caused by loosely packed starch granules. Grain shape is typically defined by the length and width of the grain and defines short-, medium- and long-grain market classes. Cooking quality largely pertains to the texture, consistency and aroma of cooked rice. Amylose content is the primary determinant of the cooking characteristics of rice, with lower amylose having a stickier texture and higher amylose having a nonsticky texture. Rice grains are primarily composed of amylose and amylopectin. Rice with higher amylose has lower amylopectin, and lines with lower amylose have higher amylopectin. Gelatinization temperature (gel temp) is the temperature at which starch is transformed from a semi-crystalline structure to an edible texture and is caused by the absorption of water and the bursting of the starch granules.

Long-grain rice accounts for approximately 85% of production, and medium-grain accounts for 15%. The LSU rice breeding program allocates a similar breakdown towards breeding efforts in long- and medium-grain. Traditional southern long-grain rice is intermediate amylose and high gel temp. In recent years, breeding efforts have begun for long-grain high amylose rice, which is desired for some processing processes and is highly preferred by some key rice export markets in Latin America. U.S. medium-grain is low amylose and low gel temp, resulting in a more sticky cooked texture. Specialty long-grain types include aromatic rice such as Jazzman (jasmine) and Della. In addition to aroma, Jazzman rice is characterized by low

amylose and low gel temp, while Della is characterized by intermediate amylose and high gel temp.

Trait Priorities

The two primary goals of the breeding program are to increase the profitability of the rice industry and the sustainability of farms and the environment. The profitability of our farms and industry is critical to ensuring an abundant and safe food supply. The U.S. rice industry has been a leader in sustainability and is continuously striving to improve on this front. Profitability is primarily driven by yield and quality. Sustainability is also driven by yield, as increased yield per acre also results in reduced water, energy and chemical usage per unit of rice produced. Increased environmental sustainability is also achieved by reducing soil runoff, increasing water quality and reducing reliance on fungicides and insecticides by breeding varieties with resistance to pests.

In addition, the breeding program also considers the ease or complexity of breeding for a trait, the probability of success, and the investment required for meaningful gains. Key factors include the heritability of the trait, which measures the extent to which genetics control the trait compared to the environment. Additionally, the program looks at the accuracy and scale at which the trait can be measured (phenotyped), as well as the genetic architecture of the trait. Simple traits are controlled by a single gene, while complex traits are controlled by many genes with small effects.

The primary traits targeted are yield and milling quality, both of which are complex traits influenced by the environment and cultural/management practices. Yield is evaluated in terms of potential and stability across different environments. The key quality components include milling yield, grain length and shape, chalkiness, whiteness and cooking chemistry. Various other traits are crucial for their impact on yield, quality and sustainability. Disease resistance is a major focus, specifically blast, Cercospora, sheath blight, bacterial panicle blight and kernel smut. Important agronomic traits include lodging resistance, vigor, tillering ability, height, early maturity and ratoon capacity.

Breeding Process and Stages

The breeding process involves a series of stages, and there are specific objectives and activities related to each stage. The overall process takes approximately seven to nine years from the initial cross to seed production and release. Each year, the process is started with new crosses, and there are materials and activities in each of the stages. Therefore, there is a continuous pipeline of materials being developed and evaluated. Each of the stages is outlined below with a description of the activities and objectives associated with each stage.

Population Development and Parent Selection

The first step of the breeding process is the selection of lines to be used as parents, and this is one of the most important steps in developing new commercial varieties. Parents are selected based on their performance and typically consist of the highest-performing advanced experimental lines and recently released varieties. In addition to choosing the highest-performing lines, it is important to maintain sufficient genetic diversity for the traits that are actively being improved. Each year, approximately 30 medium-grain lines and 50 long-grain lines are selected to be used as parents. Medium-grains are crossed among themselves, and long-grains are crossed among themselves. It is possible to cross across grain classes; however, in U.S. rice germplasm, it doesn't result in higher yields, and it introduces additional complexities in selecting for grain shape and cooking characteristics.

Figure 3-1. Sterilization of the male portion of the flower.

New populations are created by manually cross-pollinating two plants. Because the rice flower naturally self-pollinates, it is necessary to sterilize the male portion of the flower to prevent self-pollination. Sterilization can be accomplished by physically removing the anthers from each flower with forceps, which can be a time-consuming activity. The LSU rice breeding program utilizes the hot water treatment method that sterilizes the male pollen but does not damage the female portion of the flower (Figures 3-1 and 3-2). Panicles are selected for hot water sterilization after emergence and just prior to anthesis. At this stage, the female portion of the flower is receptive to pollination, but the pollen has yet to become viable. A typical crossed plant can produce zero to 100 seeds, with an average of 15 seeds, which is plenty for routine breeding activities. Over 500 new breeding crosses are

Figure 3-2. Seed resulting from successful breeding cross.

made each year for the routine breeding pipelines, but over 1,000 crosses are made each year when considering all breeding project activities.

Crosses are made in April/May of each year, and new crosses produce the seed of the F1 generation, which comprises 50% of each of the parents. Within a population, the F1 plants are theoretically identical to one another, assuming that the parents used are fixed inbred lines. In practice, the parents are not 100% fixed inbred lines, and thus the F1 plants within a population can slightly differ from each other. It takes approximately 30 days for the seeds of crosses to be ready for harvest. Eight F1 seeds of each cross are planted in the greenhouse in June and hand-transplanted to the field after two to three weeks. The plants of each individual cross (population) are self-pollinated and bulk harvested in September to generate the seed of the F2 generation.

Line Development

The main objectives of the line development stage are to increase uniformity of the line, select for traits that are not highly influenced by the environment (highly heritable traits) and increase seed quality needed for field plot testing. The F2 generation consists of single plants, and for any given population, each plant within the population is approximately 50% identical to the other plants in the population. Each individual plant has 50% of its genome fixed and 50% segregated. The proportion of the genome that is segregated is reduced by half with each generation of selfing, with the F3 containing 25% of the genome segregated, the F4 with 12.5% and the F5 with 6.25%. Thus, with each generation of selfing, the segregation and variation within a line are reduced. Selection in the line development stage is based on visual observations with a focus on traits that are not strongly influenced by the environment (highly heritable traits). These include maturity, plant height and architecture, grain shape and some disease resistance traits.

The F2 generation is immediately planted in late September/early October in the winter nursery in Lajas, Puerto Rico. Approximately 300 populations are planted across 25 rows/population, and single plant evaluations are conducted. Around 100 plants are selected from each population, and a single panicle is chosen from each selected plant. The selected panicles are then planted as F3 lines at the RRS in March, with approximately 100 lines per population (Figure 3-3). Visual evaluations are conducted, and about 50 lines are selected from each population, with a single panicle chosen from each row. The selected panicles are planted as F4 lines at the RRS the following year in March, with around 50 lines per population. Lines for the first year of testing are usually selected from the F4 nursery rows. On average, eight to

10 lines per population are chosen for testing, and which populations to advance to plot testing are determined based on the performance of the population's parents, the visual appearance of the population and the traits and characteristics present in the population.

Figure 3-3. Breeding nursery.

Testing and Characterization

The testing stages are defined by replicated evaluations on a plot level at multiple locations throughout Louisiana and neighboring states (Figure 3-4). Before a variety is released, it typically goes through four to five years of testing. Plots are drill seeded and managed throughout the season with specialized research field equipment. Fertilization is done using a small tractor with a gandy implement that spreads a precisely calibrated amount of fertilizer. Herbicide applications are done with an all-terrain vehicle that is outfitted with a spray unit and a 20-foot boom. The ATV can be operated on dry ground or in a flooded field. Plots are evaluated and rated for a range of traits throughout the season. Seedling vigor and plot stand ratings are conducted based on visual evaluations. Heading date is recorded and days to heading is calculated based on the emergence date of the test. Prior to harvest, plant heights are collected by measuring a representative plant from the ground to the tip of the panicle. Plots are harvested with a specialized research combine that measures the weight and moisture of each plot and preserves a 1 pound sample for milling and quality analysis. Upon harvest, samples are cleaned with an aspirator and a 100-gram sample is weighed for milling analysis. Milling is conducted with a laboratory mill to determine the whole and total milling yields. The whole-grain milling samples are then analyzed using image analysis to measure grain length, width and chalk.

The core breeding trials are split by herbicide type (Conventional, Clearfield and Provisia) to enable the experimental lines to be sprayed with the target herbicide. Conventional lines (non-CL or PV) are managed with typical rice herbicides. The variety test and precommercial tests are combinations of commercial lines and the most advanced experimental lines, and these trials are managed with a conventional herbicide program.

Figure 3-4. Breeding plots.

Testing is conducted throughout stages, with the best performing and most stable lines being advanced to the next stage of testing. The first stage of true testing of new lines occurs in the preliminary yield test (PYT), which typically takes place two to three years after the initial cross. The PYT is conducted in two environments at the H. Rouse Caffey Rice Research Station, with two planting dates. Between 1,500-2,000 new lines are tested each year across all segments. Approximately 180 of the best performing lines are advanced to the second year of testing in the regional yield test (RYT). These trials are conducted across four to five environments across Louisiana, with two replications per environment. Approximately 30 of the best performing lines are advanced to the advanced yield test (AYT), which is tested across eight environments with three replications at each. The lines that have commercial potential (approximately 10 per year) are selected and advanced to be repeated in the AYT the subsequent year. The five most prioritized lines are also tested in parallel in the precommercial test, which is conducted across 30 environments each year in collaboration with breeders, pathologists and agronomists at LSU, University of Arkansas, Nutrien Ag. and Horizon Ag. Additionally, a date of planting test is conducted across eight different planting dates at the Rice Research Station to better understand the performance of the lines across early and late planting dates.

Line Characterization

It is critical that a new variety has been characterized to provide producers recommendations on how best to manage the variety for agronomic practices and disease. These characterizations are conducted across multiple research projects at the RRS and with collaborators at other institutions.

Characterization of disease responses is conducted in the breeding program primarily using DNA markers for traits such as blast and narrow brown leaf spot, for which highly accurate and robust markers are available, and the traits are controlled by single genes. Disease characterization begins during the last two to three years of the variety development process. It consists of controlled screens and field evaluations conducted by the pathology project for sheath blight, bacterial panicle blight, Cercospora and blast. By the time a variety is released, the pathology program has multiple years of data to provide initial recommendations for disease management.

Agronomic characterization for seeding rates and nitrogen fertility is conducted by the agronomy program. It consists of testing the lines at different nitrogen rates under controlled conditions to determine the optimal fertility rates and provides useful information on the lodging potential of a line at high nitrogen rates. Seeding rate studies are conducted to determine the optimal seeding rate and to determine the seed number per pound, which is critical for planting calibrations. The weed science program characterizes advanced lines with herbicide tolerance under different rates of the target herbicide to determine the tolerance level and ensure suitable levels of tolerance under field conditions and conditions of herbicide overlap.

Line Purification and Foundation Seed

Purification of experimental lines begins after the first year of testing for lines advanced from the preliminary yield test. All experimental lines in the test are also grown in a separate field in a six-row increase, and lines selected for advancement have 20 panicles selected for plant increase rows the subsequent year. The six rows are then rogued to remove any off-type plants and bulk harvested to supply the seed for the RYT test. All entries in the RYT test have 24 increase rows planted, and lines selected for advancement from the RYT test have three rows selected for uniformity, and 20 panicles are selected. The remaining rows are rogued and bulk harvested to supply seed for the AYT testing stage. Similar purification steps are conducted at each subsequent stage of advancement.

Once a line is selected for potential release, 16 increase rows are selected based on uniformity, and 24 panicles are selected from each row for purity analysis and subsequent planting to generate breeder seed. Breeder seed is the first stage of the seed certification process, and each panicle is planted across two rows. The increase block is rogued for any segregation or off-types, and the field is bulk harvested. In addition, 24 rows are selected based on uniformity, and 12-24 panicles are selected from each row to serve as the source of future breeder seed increases. The bulked breeder seed is transferred to the Foundation Seed Program to plant a foundation seed field at the Rice Research Station. To ensure purity and mitigate the chances of volunteer rice, foundation seed fields are left fallow for two years between seed production, and during the fallow years, the fields are worked multiple times to stimulate germination of any seed present in the soil. A typical foundation seed field for a given variety is 2-10 acres, but in some special cases, foundation seed production of a variety can exceed this. The official seed certifying agency in Louisiana is the Louisiana Department of Agriculture and Forestry (LDAF). This agency establishes the guidelines for all aspects of the certification process. All levels of the certification process from breeder seed to certified seed are monitored, inspected, and tested by the LDAF. Inspectors from LDAF monitor and certify the field to ensure it is free of off-types and weeds. Once the foundation seed field is harvested, it is dried, and the seed is cleaned and bagged (50 pounds) at the Rice Research Station. A sample of seed is collected by LDAF and tested to ensure adequate germination and the absence of weed seeds and the presence of red/weedy rice. Foundation seed is ultimately sold to seed producers who use it to plant registered and certified seed that is then sold to rice farmers for the production of the rice crop.

DNA Markers

Tracking and characterizing rice plants by analyzing the DNA is valuable in plant breeding. A DNA marker is an assay that targets a precise location in the genome that contains differences between rice lines. These differences can be associated with a specific trait, such as disease resistance, or are regions that differ between lines and can be used to characterize similarities and differences between lines. Traits that are controlled by one or a few large effect genes are suitable for genetic discovery in which researchers can conduct genetic mapping to identify the specific gene underlying the trait. Once the gene is identified, DNA sequence information is compared between lines with the favorable and unfavorable versions of the gene to identify a specific DNA difference that can be developed into a DNA marker assay for future breeding applications. Examples of traits in which DNA markers have been effectively identified and deployed in the breeding process include blast and Cercospora resistance, PV and CL herbicide tolerance, semidwarf plant height, red grain pericarp, and grain quality traits of amylose content,

gelatinization temperature and aroma. DNA markers that are not associated with a specific trait are used to develop genetic fingerprint profiles of lines, enabling the differentiation of lines based on their DNA profile.

DNA markers are used at nearly every stage of the breeding process. When parents are selected for crossing, DNA markers are used to characterize the favorable traits they contain and to accurately determine their breeding value. All new breeding populations are genotyped at the F1 generation to confirm a true cross and ensure the correct cross was made. This helps to prevent accidental self-pollination and mix-ups of parents during the crossing activities. In the line development stage, populations are prioritized for marker-assisted selection, where 96-384 plants from a population are genotyped and selected for the desired trait. Prior to field testing, 6,000-8,000 candidate lines are genotyped with 500 DNA markers across the genome. Genomic selection, also known as whole genome prediction, is used to predict the lines that are most likely to be the best performers for complex traits such as yield, milling, and chalk. Throughout the preliminary and advanced yield testing stages, each line is genotyped to identify the present traits, determine if any traits or genomic regions are still segregating, and ensure no mix-ups have occurred over the last year. DNA markers are also a key tool for purifying seed, minimizing heterogeneity and segregating off-types in a line during the initial stages of seed increase, and maintaining purity and uniformity of a line throughout its lifecycle.

Puerto Rico Winter Nursery

Since 1971, the LSU AgCenter rice breeding program has extensively utilized a winter nursery in Lajas, Puerto Rico. The University of Puerto Rico operates this research station, and the rice nursery operates as a collaboration between multiple U.S. universities and private companies conducting rice breeding activities. The station is fully equipped with all the necessary equipment and staff to conduct breeding nurseries, trials, seed increases and seed drying. The Puerto Rico nursery enables the breeding program to operate field activities year-round, cutting two to three years off the time it takes to develop and release a new variety. It also provides an additional opportunity to increase seed if necessary for testing the following season. Each year, the most promising advanced lines begin their initial purification in Puerto Rico to remove segregants and increase uniformity in potentially released lines. While the majority of these lines will not ultimately be released, those that are have an extra round of purification to minimize variation in the line and reduce the need for rouging. Each year, the new breeding populations are planted in Puerto Rico as part of the F2 generation in early October. The breeder visits the nursery in January to evaluate the materials and make plans for harvesting. In February, a crew from the RRS breeding program harvests the materials with the support of the Puerto Rico station staff. The harvested materials are then dried in Puerto Rico, inspected by the USDA, and shipped by air back to Louisiana. Once in Louisiana, the materials are immediately processed and prepared for planting.

When a variety is prioritized for release, breeder seed is often produced in Puerto Rico to generate the seed to plant and produce foundation seed. The amount of breeder seed produced in Puerto Rico typically ranges from as little as 200 head rows, generating approximately 100 pounds of seed, up to 7 acres that can produce 30,000 pounds of seed. In situations where there is an urgent release for a variety, the breeder seed from Puerto Rico can be downgraded to foundation seed and used to plant commercial seed production fields, reducing the time to commercial production by one year.

Soils, Plant Nutrition and Fertilization

Dustin Harrell and Manoch Kongchum

Rice requires an adequate supply of plant nutrients throughout the growing season. Four major nutrients – nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) – and one micronutrient, zinc (Zn), are critical for high-yielding rice in Louisiana. Nitrogen is required on all rice-producing soils, and N is the single most important nutrient necessary for maximizing yields. Rice also requires relatively large amounts of P and K on certain soils, especially the prairie and flatwoods soils of southwest Louisiana.

The alluvial soils (clay and clay loams) in central and northeast Louisiana are typically high in these nutrients and do not respond to P and K applications. Deficiencies in P and K can occur on alluvial soils where topsoil has been removed by land-forming operations. Sulfur is adequately supplied by most rice soils unless native fertility is inherently low (typical in coarse texture and low organic matter topsoil) or topsoil has been removed. Zinc is the only micronutrient known to be deficient on some Louisiana rice soils. Zinc deficiencies occur when native levels are low, where topsoil has been removed, pH is high or when cool weather retards root growth during the seedling stage.

Behavior of nutrients in rice is quite different from that of upland crops. Because rice is cultured under flooded conditions, the relationship between nutrient availability and flooded soils must be identified to manage these nutrients properly. It is important to understand the transformations of nutrients that occur in flooded soils to obtain maximum fertilizer efficiency. Soil reduction causes changes in the soil as a result of reactions between the soil and water and the biological and chemical processes set in motion as a result of flooding. Change is the conversion of the root zone of the rice plant from an aerobic (with oxygen) environment to an anaerobic (no oxygen) or near-anaerobic environment affects many nutrient transformations.

Nitrogen

The reducing conditions in a flooded soil govern nitrogen transformation processes. Inorganic N in the soil can be found in both the ammonium-N and nitrate-N forms. Rice plants are capable of using either form of N. Once a rice soil is flooded, the soil will change from an aerobic to an anaerobic state. Nitrate-N is unstable and can quickly be lost through denitrification under anaerobic, flooded conditions. On the other hand, ammonium-N is very stable under flooded (anaerobic) conditions and will remain available to plants as long as the flood is maintained. If a rice soil is drained, reoxygenated ammonium-N can be transformed to nitrate-N through a process called nitrification.

When the soil is reflooded, nitrate-N will be lost rapidly. Nitrogen fertilizer management for rice is important due to the high losses of fertilizer N. Research efforts have focused on the more efficient management of urea, such as improved rates and time of application, placement of N fertilizer, and the development of modified N fertilizer sources less prone to N loss. Therefore, only ammonium fertilizers (like ammonium sulfate) or ammonium forming fertilizers (like urea) should be used in rice production. Once the N fertilizer has been applied, the permanent flood should be established and maintained throughout the growing season to maximize nitrogen use efficiency.

Phosphorus

Soil P is present in both the organic and inorganic forms. As with all nutrients required by rice, organic forms are not immediately plant available. Since organic P is slowly converted to the inorganic form, P fertilizer applications are very important on soils deficient in this nutrient. Flooding a rice soil increases the availability of soil P to plants. However, alternating flooding and draining cycles have a significant impact on P availability. When the soil is drained and aerated, P availability to plants is often decreased. Reflooding on the other hand will enhance P release.

Potassium

Soil K is affected less by flooding than N or P. Availability of K changes very little with draining and flooding. In Louisiana soils, K is less often found limiting to growth and grain yield as compared with N and P. Potassium nutrition is closely associated with the rice plant's ability to resist disease, and more emphasis is being placed on the role it plays in overall rice plant nutrition.

Sulfur

Most of the S contained in the soil is in the organic form under flooded and nonflooded conditions. Inorganic S originates from the decomposition of organic matter, and the S status of a soil is related to the amount of organic matter present. Some S is also provided by rainfall and irrigation water.

Zinc

Zinc availability is affected by flooding, although the change in soil pH in response to flooding accounts for the fluctuation in available Zn. Zinc is more available when the soil pH is acidic. After soil is flooded, its pH will drift toward neutral, thus an acidic soil becomes more alkaline and an alkaline soil becomes more acidic. This means that when acidic soils are flooded, Zn will become less available, and when alkaline soils are flooded, it will become more available.

Other Nutrients

Many other nutrients play a role in rice plant nutrition, and flooding has differential effects on their availability. Availability of calcium and magnesium is not greatly affected by flooding. Iron (Fe), magnesium (Mg), boron (B), copper (Cu) and molybdenum (Mo) become more soluble under flooded conditions. While these nutrients are known to play a role in rice plant nutrition and critical levels in rice plant tissue have been established, documented deficiencies or toxicities have not been recognized in Louisiana.

Rice Plant Nutrition and Fertilization

The most frequently limiting plant nutrients in Louisiana rice in order of importance are N, P, K, Zn and S. Soil type, native soil fertility, cropping history and agronomic management practices determine when and to what extent deficiencies of these nutrients occur. A soil test is valuable in predicting nutrient deficiencies and the measures appropriate for correcting deficiencies. A sound fertility program is essential to maximize yields and efficient use of plant nutrients. Many nutrient deficiencies can be corrected in the field, but providing sufficient amounts of required nutrients to avoid deficiencies is the best approach to ensure maximum rice yields.

Proper fertilizer management is important to increase profitability, minimize inputs, improve nutrient efficiency and mitigate environmental concerns. Efficient fertilizer use requires: (1) proper water management in relation to fertilizer application; (2) selection of the proper fertilizer source; (3) timely application of fertilizers by methods that provide optimum rice growth, grain yield and crop quality and (4) application of the proper amount of fertilizer to ensure optimum grain yields and economic returns. The major plant nutrients required for rice production and their proper source, time of application and rate are discussed in the following sections.

Nitrogen Nutrition, Water Management, Source and Timing

Nitrogen is the most limiting plant nutrient in rice, and maximum yields depend on an adequate supply of N. Deficiency symptoms include yellowing of the older leaves, reduced tillering, browning of leaf tips and shorter plants (Figure 4-1). Efficiency of N fertilizer applications can be reduced due to losses from soil via nitrification-denitrification, volatilization and/or leaching. Research in the southern United States examining the influence of application timings and N management strategies commonly reported N recovery of 17% to 79% of the applied N at rice maturity.

Figure 4-1. Nitrogen deficiency.

Several environmental and cultural factors affect the uptake and use of N by rice. Depending on the N source, N could be lost before the rice plant even has a chance to begin absorbing it through the roots. Current rice varieties respond well to large amounts of N fertilizer, but these varieties are not totally immune to the problems in older varieties associated with over-fertilization. For example, excessive vegetative growth, lodging, disease damage, delayed maturity and reduced grain yields of lower quality can occur if N fertilizer applications are made at unnecessary rates or at the wrong growth stage. Because of the relation between N behavior and flooded soils,

the efficiency of N fertilizer applications in rice is greatly influenced by water management.

Rice is a semiaquatic plant that has been bred and adapted to flooded culture. Flooding rice soil eliminates moisture deficiency, increases the availability of most essential plant nutrients, minimizes weed competition and provides a more favorable and stable microclimate for plant growth and development.

A permanent flood of 2 to 4 inches should be established as soon as possible and maintained throughout the growing season. In dry-seeded rice, the permanent flood is established by the four- to five-leaf rice stage (20 to 35 days after planting). Uniform, level seedbeds allow earlier flooding, which improves nutrient availability and weed control. To avoid stand loss and reduced seedling vigor, dry-seeded rice should never be submerged by the floodwater. In water-seeded rice, a shallow flood is established before planting.

Rice seedlings either emerge through a permanent flood (continuous flood system) or the field is briefly drained to encourage seedling anchorage and uniform stand establishment (pinpoint flood system).

The field then is reflooded, and seedlings emerge through the floodwater as in the continuous flood system.

Draining rice fields after permanent flooding should be avoided unless extenuating circumstances exist. Removing the floodwater can result in loss of N, affects the availability of many other nutrients, encourages weed emergence and growth, and increases the incidence of some diseases. Situations that justify draining include soils conducive and/or varieties susceptible to straighthead, severe Zn deficiency is observed or expected, requirements for application of certain herbicides or the field is infested with rice water weevil larvae.

The development of herbicide tolerant rice systems, such as Clearfield, Provisia, Max-Ace and FullPage rice varieties, has added a new dimension to rice production in Louisiana.

This technology has prompted many rice producers in the state to change at least a portion of their acreage from the traditional water-seeded system to a drill-seeded system. Both the water- and drill-seeded systems place unique restrictions on N fertilizer management, but the essential components of a successful N management plan are the same for either system. In developing a successful N fertilizer management plan, the source of N fertilizer, the placement of fertilizer in the field, the application rate and application timing should all be carefully considered.

Ammonium sulfate and urea are the most common sources of N used in rice, and these two sources are equally effective when properly applied. Urea is the most common and best source of N for rice. Its relatively high N analysis (46%) compared with other N fertilizer sources also makes urea the most economical N source since less material is applied per unit of N. Urea is prone to losses through ammonia volatilization if applied to a moist soil or if left on the soil surface for an extended period (more than three to five days) after application.

Nitrogen fertilizer applied as urea is prone to loss through ammonia volatilization. Use of a urease inhibitor delays breakdown of urea, minimizing N loss associated with ammonia volatilization. This will improve N efficiency when urea is applied on a wet soil surface before permanent flood or when urea is applied to soil surface more than three days before permanent flood establishment. Results may vary with year and/or environment.

Ammonium sulfate contains 21% N, so more than twice the amount of fertilizer material is required per unit of N. However, it is a good choice if soil tests recommend S because it contains 24% S. If ammonium sulfate is used strictly as an N source, it is less desirable than urea because its price per pound of actual N is much higher than urea.

Research has shown that ammonium sulfate may be a slightly more effective N source than urea when N must be applied to saturated soils during the seedling stage because volatilization occurs at a much slower rate than urea. Nitrate-N should never be used in rice because of the potential for large losses of N caused by leaching and denitrification.

Another N source popular for rice in southwest Louisiana is a 50% blend of urea and ammonium sulfate, which has a N analysis of approximately 33%. This combination combines the positive traits of both sources. It is less prone to volatilization than urea and has a higher N analysis than ammonium sulfate. The mixture is still subject to ammonia volatilization at a slower rate; however, the mixture has 13% less total N than urea.

Ammonium-N is very stable in flooded soils and remains available throughout the season. Following N application and flooding, soil drying should be avoided or ammonium-N will be converted to nitrate-N. This conversion process results in loss of N through denitrification when the field is reflooded.

The proper application rate for N fertilizer depends on rice variety, stand density, previous crop, straw management, fertilizer source, application method, water management, soil texture, soil pH and tillage system. Therefore, a clear definition of N requirements for rice is difficult to formulate. Historically, total N requirements are determined by conducting statewide variety by N trials.

Current N recommendations in Louisiana are provided as a suggested rate range. For a given rice variety, the N rate range encompasses all soil types and environments. Previous knowledge of the productivity of a particular field should be used by the producer to fine tune the N recommendation within the range on a field-by-field basis. Most rice varieties grown in the United States require 120 to 180 pounds of N per acre to produce acceptable grain yields with good milling quality, and in some cases, 30 to 60 more pounds of N per acre will be required for a variety when grown on a clay soil than a silt loam soil. This information is updated annually in the LSU AgCenter publication 2270, Rice Varieties and Management Tips. In addition, N application in rice rotation with soybean crop should be avoided the maximum recommendation N rate to prevent lodging in some rice varieties.

Nitrogen fertilizer application timing depends on the cultural system used for rice production. A continuous, available supply of N must be maintained in the soil-plant system to maximize production. The relationship between N fertilizer application timing and water management impacts N retention, and N fertilizer recovery efficiency. The approaches to N management in a permanently flooded system (continuous or pinpoint) and a delayed flood system (dry seeded or water seeded with a delayed flood) are quite different. When N fertilizer is applied early in the growing season, the fertilizer must be placed where it is least prone to loss and most readily absorbed by the plant. Therefore, the N fertilizer must be incorporated into the soil. In a drill-seeded system, the majority of the N fertilizer should be applied to the soil surface and incorporated with the floodwater as the permanent flood is established. Regardless of whether rice is water seeded or drill seeded, the uptake of N early in the season is critical and affects uptake of N throughout the remainder of the season. So, for optimum growth and yield, the N supply should be adequate during the tillering stage of rice development.

In permanently flooded systems, all or most of the total N requirement should be incorporated into a dry soil 2 to 4 inches deep prior to flooding. Brief drainage following seeding to encourage seedling anchorage in a pinpoint flood system will not result in excessive N loss unless the soil is permitted to dry and aerate.

The majority of the N fertilizer could be applied during the initial drain period in a pinpoint flood system and incorporated with the floodwater following seedling anchorage. The seedbed must be maintained in complete saturation to conserve applied N fertilizer.

Regardless of the water management system, additional N fertilizer can be applied at midseason at the beginning of reproductive growth between panicle initiation [PI, green ring (Figure 5-10) or beginning internode elongation (IE)] and panicle differentiation (1/2-inch IE) (Figure 5-11) as needed unless the total requirement was applied preplant incorporated.

In the delayed flood systems (dry broadcast, drill seeded or water seeded), the permanent flood may not be established until three to four weeks after seeding. It is impractical to apply large amounts of N fertilizer at seeding in these systems since it cannot be stabilized or maintained before permanently flooding. Starter N fertilizer applications can be used in delayed flood rice production systems as a surface broadcast application and should be limited to 15 to 20 pounds of N per acre. The starter fertilizer N application encourages rapid growth and development of seedling rice and often results in rice which can be flooded a week earlier as compared with rice which does not receive a starter N application. This can be very beneficial in a weed control program. Research has shown that starter N applications in rice rarely result in increased yield at the end of the season. Surface broadcast applications of N fertilizers are inefficient and are subject to loss and should not be counted toward the total N requirement for the entire season. All or most of the required N fertilizer should be applied to a dry soil by the four- to five-leaf rice stage prior to permanent flood establishment. The floodwater solubilizes the N and moves it down into the soil where it is retained for plant use during the growing season. Additional N fertilizer can be applied at midseason at the beginning of reproductive growth between PI and PD as needed unless the total amount required was applied preflood.

One problem with preflood applications of urea is the potential for it to turn into ammonia (NH3) gas and simply float off the field if it is left exposed on the soil surface for an extended period of time. This process is called ammonia volatilization. Studies conducted in Louisiana have shown that when urea is left on the soil surface for 10 days, volatilization losses can range from 17% to 25%. Unfortunately, it may take 10 or more days for a flood to be established on large commercial rice fields. In this situation, a urease inhibitor containing the active ingredient N-(n-butyl) thiophosphoric triamide, or NBPT for short, is recommended. Urease inhibitors come in a liquid form and are applied on urea at the fertilizer distributor. The urease inhibitor basically slows down the breakdown of urea to the ammonium-N form. Because it temporarily delays the breakdown of urea, it also temporarily delays the potential for ammonia volatilization losses. The economic breakeven point for the use of a urease inhibitor product varies yearly due to the cost of the urease inhibitor, cost of urea and rate of volatilization. In general, the break-even point generally occurs between three and five days. The use of a urease inhibitor product will be economically

beneficial in most years when it takes longer than five days to flood a particular rice field. In order to maximize N use efficiency, it is imperative to make sure the urea is applied only on dry ground and then flooded. When urea is applied to damp ground the initial rate of volatilization is increased. The use of a urease inhibitor will help in this scenario; however, it is only half as effective as compared to dry-ground applications. A urease inhibitor will not be beneficial if the treated urea is applied into the flood water at the preflood fertilization timing.

In either a permanent or delayed flood system, an adjustment in N management is necessary when rice fields are drained for straighthead. Straighthead is a physiological disorder (Figure 4-2) that occurs on sandy soils, on soils where arsenical herbicides have been previously applied, on soils that have not been in rice production for several years and on soils where large amounts of plant residue have been incorporated prior to planting. Significant yield losses can result from straighthead if fields are not drained and completely aerated before PI. Draining detoxifies arsenical compounds and reduces the buildup of hydrogen sulfide. Since draining usually occurs during mid-tillering, no more than 60% to 70% of the required N fertilizer should be applied preplant or preflood, with the remainder applied before reflooding.

Figure 4-2. Straighthead symptoms.

Research indicates the total N fertilizer requirement can be applied preplant in a continuous flood system or preflood in a delayed flood system. Newer rice varieties can absorb enough N for high yields from a single application of the total N requirement applied; however, applying the entire amount of N in one application is not always feasible, i.e., aerial application. Uniform N fertilizer application, knowledge of the varietal N requirement, experience with a particular soil and proper water management are critical when using single preplant or preflood applications. This approach may not be practical commercially when (1) uniform application of large amounts of N fertilizer is difficult, (2) water management capabilities are inadequate, (3) the producer is unfamiliar with the variety or field history, (4) if the field has a history of straighthead and (5) the seedbed is saturated. Split applications may be required when any of these conditions exist.

Midseason N topdressing applications are used efficiently by rice if inadequate early season N fertilizer was applied. A single, midseason application is usually sufficient to maximize yield. Multiple applications of midseason N fertilizer may not be cost effective and could reduce yield if the basal N fertilizer application was inadequate. Unlike N fertilizer applications into the floodwater on seedling rice, N fertilizer applied into the floodwater at midseason is used efficiently by rice because of its large plant size and extensive root system.

Rice plant growth stages have been used to determine when to apply midseason N fertilizer. The green ring growth stage (internode elongation) traditionally has been used for timing midseason N fertilizer applications. Although this growth stage is a good indicator, the overall health of the rice crop before green ring formation must be considered.

Tissue analyses and visual assessment are excellent diagnostic tools to determine the N status of rice at midseason growth stages. Nitrogen deficiency should be avoided to minimize the potential for grain yield reductions. Midseason N fertilizer should be applied at the earliest indication of N deficiency, even if the green ring growth stage has not occurred.

Late-season N fertilizer applications also may be inefficient and could lead to grain yield reductions. Research indicates that grain yields are not improved when N fertilizer is applied later than 4 weeks following green ring.

Ratoon or second crop rice should be fertilized with 75 to 90 pounds of N per acre when main-crop harvest is before Aug. 15. When conditions are favorable for good ratoon rice production (minimal field rutting, little or no red rice, healthy stubble), the higher N fertilizer rate should be used. The N fertilizer should be applied and a shallow flood established within five days after harvest. Research has consistently shown that N fertilizer should be applied

and the field flooded as soon as possible after main-crop harvest to maximize ratoon rice yields. When main-crop harvest is after Aug. 15, the ratoon N fertilizer application rate should be reduced by approximately 5 pounds a day past Aug. 15.

Phosphorus Nutrition, Water Management, Source and Timing

Phosphorus deficiencies in rice occur infrequently compared with N deficiency. Stunting, reduced tillering, delayed maturity and yield reductions can occur when P is limiting (Figures 3-3 and 3-4). Unlike N, water management has little impact on P retention unless soil loss occurs through erosion or removal of floodwater containing high sediment concentrations. Phosphorus availability is influenced by fertilizer placement, soil factors (pH, Fe, aluminum, and calcium content), and wetting/drying cycles. Flooding increases P availability to rice, but alternating wetting and drying cycles can result in fixation of P in the soil and temporary deficiency.

Figure 4-3. Phosphorus deficiency.

Water soluble sources of P, such as triple superphosphate and diammonium phosphate, are effective in preventing and correcting mild P deficiency symptoms. Cost effectiveness and the requirement for other nutrients should be considered when choosing a P source. Factors to consider when determining the P application rate include soil type, cropping history, producer experience and soil and plant tissue analyses. Typical P application rates range from 20 to 60 pounds per acre.

Phosphorus is most available to rice when applied at planting as a band or broadcast and incorporated application in the spring prior to planting. If preplant applications are not possible, P should be applied prior to tillering. Since adequate P is essential for tiller formation, P deficiencies at this growth stage can reduce yield significantly. Research indicates that fertilizer applications to P-deficient soils are less effective after tillering has begun (four to five weeks after planting).

Figure 4-4. Left, normal plant. Right, phosphorus-deficient plant.

Potassium Nutrition, Water Management, Source and Timing

Rice plants deficient in K appear a lighter green than healthy plants, and the leaf edges contain rust-colored spots that give the plant a brown appearance (Figure 4-5). Plant height may be reduced. The role of K in plant nutrition is very important as it relates to disease resistance.

Potassium behavior in the soil is influenced little by water management. Potassium is a very soluble nutrient and is accumulated by the rice plant throughout the growing season. Preplant or early season K application in conjunction with N or P is recommended. Potassium chloride (KCl) and potassium sulfate (K_2SO_4) are common K sources to correct existing deficiencies. A single K application (20 to 60 pounds per acre) is usually sufficient

to maintain adequate K in rice plants. Split applications are not required unless the soil is very sandy and leaching occurs. Furthermore, since most rice soils, even those with a sandy plow layer, contain a clay hardpan that restricts water infiltration, split applications are seldom necessary.

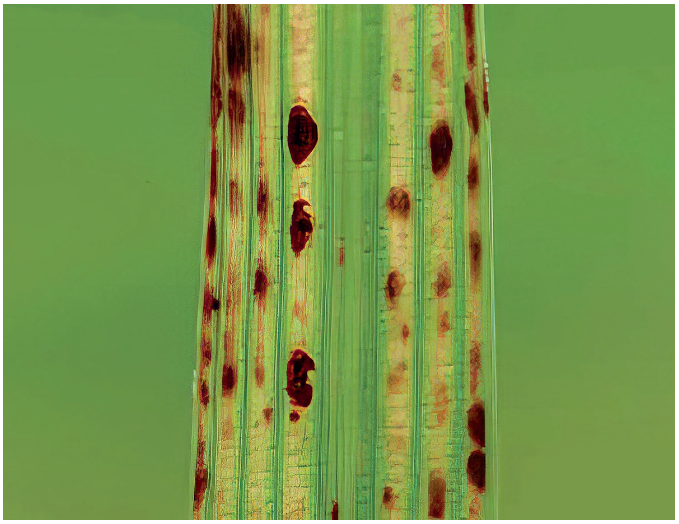


Figure 4-5. Potassium deficiency symptoms on leaf.

Sulfur Nutrition, Water Management, Source and Timing

Sulfur (S) deficiency is difficult to diagnose because it resembles N deficiency. Unlike N, S is less mobile in the rice plant. Rice plants deficient in S begin to yellow from the newest leaf to the oldest leaf, whereas N deficient plants begin to yellow from the oldest leaves to the newest leaf. Once the entire plant becomes yellow, it is very difficult to determine if the plant is deficient from S or N without plant analysis.

Inadequate S in the soil and removal of topsoil during land-forming operations contribute to S deficiencies. A soil test can aid in identifying soil areas where S deficiencies might occur. Ammonium sulfate (21-0-0-24S) is an excellent source of S for correcting existing deficiencies. An application of 100 pounds of ammonium sulfate per acre will supply 24 pounds of S, which is an adequate amount to avoid or correct S deficiency in an existing crop. Water management has no effect on S availability or retention in soil but may be important in relation to application of S-containing N fertilizers. Only S in the sulfate form should be used in rice production once S deficiency symptoms occur. Although, elemental sulfur fertilizer sources contain a higher amount of S per pound of fertilizer (generally 90% S) the S is not immediately plant available.

Zinc Nutrition, Water Management, Source and Timing

Zinc deficiency is a common micronutrient problem in rice. Early deficiency symptoms include chlorosis and weakened plants that tend to float on the floodwater surface (Figure 4-6). Dark brown spots develop on the leaves, and when deficiency is severe, stand loss occurs. Zinc deficiency is usually referred to as bronzing because of the rusty appearance that develops. Calcareous soils with an alkaline pH, inadequate Zn levels in the soil, removal of topsoil during land forming, excessive lime applications, deep water during seedling growth and cool weather that retards root growth during the seedling growth stage may all contribute to Zn deficiency. Deficiencies most often occur in early planted, water-seeded rice because of low temperatures and poor root growth. Since stand loss can occur when deficiency is severe, deficiency symptoms must be recognized early.

Figure 4-6. Typical zinc deficiency symptoms.

A soil test can identify soils prone to Zn deficiency. Inorganic Zn salts, such as Zn sulfate ($ZnSO_4$), may be applied with other required fertilizer nutrients at planting. In dry-seeded rice, Zn should be incorporated to a shallow depth. In water-seeded rice, Zn is more available when applied to the soil surface in close proximity to the developing root system.

Plant uptake of Zn is affected by temperature and root growth. Preplant Zn applications do not guarantee that deficiencies will not occur. If Zn deficiencies begin to develop in seedling rice, corrective applications need to be considered. Favorable growing conditions (high temperatures and sunlight) or removal of the floodwater may help correct mild Zn deficiencies. When Zn deficiency

is severe and the potential for stand loss exists, apply Zn fertilizer as a foliar application.

Either inorganic salts or chelated forms of Zn may be applied preplant. Inorganic forms, such as zinc sulfate, should be applied at a rate of 5 to 15 pounds of actual Zn per acre. Although, rice takes up less than one pound of Zn per acre, adequate distribution of Zn from granular fertilizers requires higher application rates. It is important that Zn fertilizer sources are at least 50% water soluble or higher rates of Zn will need to be applied. Zinc oxide forms should be avoided for in-season applications. Soil applied liquid Zn sources (greater than 50% water soluble) can be applied at rates of approximately one-half of that recommended for granular sources. Chelated Zn sources are preferred for soil applications. In-season, foliar Zn applications can be applied at a rate to deliver 1 to 2 pounds of actual Zn. If Zn deficiency occurs while the rice is flooded, it is best to drain the field and let the rice recover prior to foliar Zn application. Once applied, additional N may need to be applied to compensate the N that will be lost after flooding. Generally, ammonium sulfate ($(NH_4)_2SO_4$) is the preferred source in this situation. Granular applications of zinc sulfate are also equally as effective as foliar applications in this type of situation since it is 100% water soluble.

Fall Fertilizer Applications

Fertilizer nutrients are most efficiently used by rice when applied immediately before seeding and no later than permanent flooding. There are situations when a fall application of some nutrients may be a suitable alternative. These include: (1) no-till and stale seedbed rice production when soil incorporation at planting is not possible, (2) rice fields worked in the water prior to planting when there is concern of fertilizer movement and nonuniform redistribution after mudding in and (3) where scumming is a problem when fertilizer is applied into the floodwater on seedling rice. Advantages to fall application of P and K include more flexibility in early season N applications and more opportunity to apply these nutrients by ground application. Disadvantages include poor retention of K on sandy soils because of leaching and fixation of P on low pH soils containing high levels of Fe and aluminum. Never apply N and Zn in the fall.

Soil Testing

One of the key elements of a successful fertilization program for Louisiana-grown rice is the use of a soil test. Soil test data provide an estimate of plant-available nutrients that can be used to generate fertilizer recommendations. Soil test calibration studies are conducted annually by LSU AgCenter personnel to improve and validate soil test-based fertilizer recommendations. Currently, there is a calibrated soil test(s) for all major and minor plant essential nutrients with the exception of N. Nitrogen fertilizer recommendations for rice are variety based and can be found in the rice fertilization section of LSU AgCenter publication 2270, Rice Varieties and Management Tips.

A quality soil test begins with a representative soil sample. It is often said that a soil test is only as good as the sample that is sent to the soil testing laboratory. Soil samples should be grouped into areas with similar soil texture, organic matter content, elevation, etc. Other areas to pay particular attention to in a rice field include areas near water inlets, drains and areas where large amounts of topsoil have been removed and/or moved during the land leveling process. A soil test should never represent an area larger than 20 acres.

Once an area is defined, several cores are needed from that area to create a composite sample. To take a composite sample, simply take several soil cores using a soil test probe randomly throughout the designated area and mix them in a bucket or other container.

Cores in a rice field should be taken to depth of the plow layer and/or to the depth of the natural hardpan, which generally occurs from 4 to 6 inches. Once enough cores are taken to adequately represent the area, mix the soil thoroughly and pour approximately 1 pint of the soil into a complimentary soil test container or zipper-type storage bag. Soil test containers are available at your local extension office or directly from the LSU AgCenter Soil Testing and Plant Analysis Laboratory. A completed soil test form and a check for requested analyses should accompany all soil samples. Samples can be turned in to your extension office or mailed directly to the soil testing laboratory. All needed forms can be found online at the LSU Soil Testing and Plant Analysis Laboratory website at www.stpal.lsu.edu.

Soil samples should be taken and tested every two to three years during the fall. Sampling in the fall allows sufficient time for the laboratory to chemically analyze the soil and return the results to you in a timely fashion. This, in turn, gives you more time to plan the fertilization for your spring rice crop based on the recommendations provided by the laboratory.

The most important nutrients to pay attention to on your soil test report for a rice crop include P, K, S and Zn. The LSU AgCenter Soil Testing and Plant Analysis Laboratory provides fertilizer recommendations for these and other nutrients on their basic soil test recommendation sheet. Although the AgCenter recommends using its own soil testing laboratory, some producers may choose to use a private out-of-state soil testing laboratory. For this reason, the soil test-based fertilizer recommendation tables have

been included in this text. These tables can be used to generate fertilizer recommendations with soil test results from private laboratories. These tables were generated based on several years of fertilizer response trials on Louisiana rice soils. These tables are periodically updated based on new research results. It is important to check the online version of this manuscript to see if recent changes have occurred since the initial publication.

Prior to using one of these soil test-based fertilizer recommendation tables, it is important that you validate that the soil test extraction used by the private laboratory is the Mehlich-3 soil test. Other soil test extractions are not compatible with the following recommendation tables (Tables 4-1 to 4-4). Second, you must make sure that the soil test results are in parts per million (ppm). To change parts per million to pounds per acre, simply multiply by the number 2.

Table 4-1. Phosphorus (P) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich-3 soil analysis.

Mehlich-3 Extractable P	Fertilizer Recommendation (lb P_2O_5 / Acre)
Very low: <10 ppm	60
Low: 10-20 ppm	40
Medium: 21-35 ppm	20
High: >35 ppm	0

Table 4-2. Potassium (K) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich-3 soil test.

Soil Type	Texture	Very Low ppm	Low ppm	Medium ppm	High ppm	Very High ppm
Alluvial	clay, silty clay	<114	114 - 182	183 - 227	228 - 273	>273
	clay loam, silty clay loam	<91	91 - 136	137 - 182	183 - 205	>205
	loam and silt loam	<57	57 - 91	92 - 136	137 - 159	>159
	sandy loam	<45	45 - 80	81 - 114	115 - 136	>136
Upland	clay, silty clay	<114	114 - 182	183 - 227	228 - 250	>250
	clay loam, silty clay loam	<57	57 - 102	103 - 148	149 - 170	>170
	loam and silt loam	<57	57 - 91	92 - 136	137 - 159	>159
	sandy loam	<45	45 - 80	81 - 114	115 - 136	>136
	Fertilizer Recommendation	60 lb K_2O / Acre	40 lb K_2O / Acre	20 lb K_2O / Acre	0 lb K_2O / Acre	0 lb K_2O / Acre

Table 4-3. Zinc (Zn) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich-3 soil test.

Soil Test	≤ 1 ppm		1 - 1.5 ppm			1.6 - 2 ppm	
pH	≥ 7	< 7	≥ 7	6.9 - 6.0	< 6	≥ 7	< 7
Granular fertilizer recommendation	15 lb/A	10 lb/A	10 lb/A	5 lb/A‡	none	5 lb/A	none

† The granular zinc fertilizer source must be at least 50% water soluble or higher rates of zinc may be needed.

‡ Even distribution of most granular zinc fertilizer sources at rates of less than 10 pounds/A is difficult to achieve; however, it can be achieved when the zinc is premixed with a starter N application using 50-100 pounds ammonium sulfate.

Table 4-4. Sulfur (S) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich-3 soil test.

Soil Test Level	Soil Test Results	Fertilizer Recommendation
	ppm	lb S per acre
Low	<12	20 - 25*
Medium	12 - 16	5 - 15
High	>16	none

*Application of 100 pounds of ammonium sulfate will provide 21 pounds N and 24 pounds S.

Salinity in Rice Soils

Salinity is a measure of the amount of soluble salts in soil or water. A soluble salt is any compound that dissolves in water. Many salts can be found in soils, some of the more common salts are calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^+), sodium (Na^+), chloride (Cl^-), sulfate (SO_4^{-2}), carbonate (CO_3^-) and nitrate (NO_3^-). Not all salts are bad. Some fertilizers are salts and are necessary for healthy plant growth and development. Some salts, including both sodium and chloride, can become toxic when taken up at high levels.

Soils that accumulate high levels of sodium salts as a result of irrigation or coastal flooding are classified as saline, sodic or saline-sodic. Saline soils have a high concentration of total soluble salts. Sodic soils, on the other hand, have a high concentration of sodium (Na^+). Saline-sodic soils include both problems. The procedure described in this guide actually estimates total dissolved solids (TDS), or soluble salts, and is a measure of potential soil salinity problems. To measure potential sodic (sodium) soil problems requires more elaborate laboratory procedures and analytical equipment.

Salt Level, ppm	Interpretation
0-300	Very low
301-600	Low
601-1,000	Medium
1,001-1,500	High
>1,500	Very high

At very low salt levels, few if any crops will be damaged. At low levels, very sensitive crops may be damaged. The danger of salt damage increases if plants are very young or the soil becomes very dry.

Salt in the soil can be either precipitated on soil surfaces or dissolved in the soil solution. The soil solution occupies the spaces between the solid soil particles. When it completely fills these spaces, the soil is saturated. To measure soil salinity, all soluble salts must be dissolved. This is done by mixing the soil with water in specific amounts followed by separating the soil solids from the solution and analyzing the TDS in the solution.

Most meters used to measure salinity in water actually measure electrical conductivity (EC). The more salt the water contains the easier it is for electricity to flow through it. Higher salt content means a higher EC.

Electrical conductivity may be expressed several ways which sometimes causes confusion. It can be expressed as millimhos per centimeter (mmhos/cm), or millisiemens per centimeter (mS/cm) or decisiemens per meter (dS/m). All of these units are equivalent and express the ability of a solution to conduct electricity over a specific distance.

Soil salinity readings depend upon the relative amounts of soil and water added during analysis. This is another major source of confusion as some laboratories report results of 1 part soil to 2 parts water ($EC_{1:2}$). Others report results on a saturated paste basis (EC_{se}), the standard used in scientific literature to establish plant tolerances to salt. For the same soil sample, $EC_{1:2}$ values are about half those of EC_{se}. The LSU AgCenter's Soil and Plant Testing Lab reports salinity values on an EC_{se} basis.

To make interpretation easier, especially if measurements from different sources are to be compared, it is easier to convert them to parts per million (ppm). Some meters already have a scale that takes this into account and is expressed in ppm. To convert EC to ppm, multiply EC_{se} by 640 (or $EC_{1:2}$ by 1280) if the EC<5 or by 800 ($EC_{1:2}$ by 1600) if EC>5. 1 mmhos/cm = 1 mS/cm = 1 dS/m = 640 ppm (or 800 if EC>5). This is not an exact conversion, but will work in this case.

EC readings and expected crop responses.

Salinity, EC	Crop Responses
0-2	Mostly negligible
2-4	Yields affected in very sensitive crops
4-8	Yields affected in many crops
8-16	Only tolerant crops unaffected
>16	Only very tolerant crops unaffected

A few of the crops grown in Louisiana and their respective salt tolerance ratings (as seedlings) are shown below.

Crop	EC	ppm	Rating
Rice	3.0	1,920	S
Sugarcane	1.7	1,088	MS
Sorghum	6.8	4,352	MT
Soybeans	5.0	3,200	MT
Wheat	6.0	3,840	MT
Bermudagrass	6.9	3,840	T
Ryegrass	5.6	2,584	MT

Source: USDA-ARS salinity lab
Seedling stages are generally less tolerant than older stages.

Measuring salinity or EC alone will provide information on potential soil salinity problems. However, it does not provide a complete picture of soil sodicity (Na+). The ratio of the amount of exchangeable sodium to the amount of exchangeable calcium plus magnesium is often used to predict the potential of sodic (Na+) soil problems. This is called the sodium absorption ratio (SAR). A combination of EC and SAR is a better measure of the likelihood of both saline and sodic soil problems. The table below was developed by LSU AgCenter scientists to better interpret the effects of salt water on land to be used for rice production.

	Salts (ppm)		SAR	Effects
None	<500	And	<4	No effect on yield
Mild	500-1,000	Or	<4	Little to no effect on yield
Moderate	1,000-2,000	Or	<6	Some yield reduction possible
Severe	2,000-6,000	Or	<13	Substantial yield reduction w/o remediation
Very Severe	>6,000	Or	>13	Catastrophic crop failure

Using Salt Water to Irrigate Rice

Salt water can become a problem in rice production, especially in some areas in dry years. A small amount of salt water is not dangerous to rice at any stage of growth. Higher concentrations affect the existing crop and can cause a build-up of salt in the soil.

Rice grown on soils relatively free of salt is tolerant to salt water with 35 grains (600 parts per million) per gallon of sodium chloride. One flooding of 6 acre-inches of water containing 35 grains (600 ppm.) of salt would leave 800 pounds of salt per acre in the surface soil. Three such floodings would leave 2,400 pounds per acre, which is about all the crop would endure. Continued use of even this mount of salt will lead to trouble. Water containing more than 35 grains per gallon (600 ppm.) cannot be used continuously through the growing season and year after year without injury to both crop and soil.

Where sodium chloride or sodium carbonate has accumulated in the soil, less than 1,000 ppm. is not toxic to germination if there is normal soil moisture.

The following table can be used as a guide for tolerance of rice to salt water.

Commonly Accepted Tolerance of Rice to Salt Water
Concentrations of Salt as NaCl in water

Grains per Gallon	ppm	Stage of Growth
35	600	Tolerable at all stages, not harmful
75	1,300	Rarely harmful and only to seedlings after soil is dry enough to crack. Tolerable from tillering on to heading
100	1,700	Harmful before tillering, tolerable from jointing to heading
200	3,400	Harmful before booting, tolerable from booting to heading
300	5,100	Harmful to all stages of growth. This concentration stops growth and can only be used at the heading stage when soil is saturated with fresh water.

This information was taken from material compiled by M.B. Sturgis, LSU Department of Agronomy, and Lewis Hill, former extension rice specialist.

Poultry Litter Use in Louisiana Rice Production

A loss of production on recently precision-leveled rice fields and rice following crawfish in a rice-crawfish-rice rotation has become a common occurrence in commercial Louisiana rice production. This is especially true on mechanically altered silt loam soils of the coastal plains found in southwest Louisiana. The use of poultry litter on unproductive areas has provided an increase in productivity to levels above those realized prior to precision leveling in many cases. It has also been reported that the use of litter in conjunction with inorganic fertilizers provides improved yields above those found when using inorganic fertilizers alone.

Poultry litter is made up of the bedding material and manure from birds used in a commercial poultry facility. The most common litter material available in Louisiana is obtained from commercial broiler houses. The most common bedding materials used in commercial broiler houses include wood shavings, rice hulls and sawdust (Figure 4-7). As the bedding material is used it forms a hard layer on the surface often referred to as a cake. This cake can be removed (decaked) after one flock has been grown or can be removed after several flocks have been grown depending on the management practices of the producer. Therefore, nutritive value of litter is not constant between sources. The nutrient content can vary considerably depending on the bedding material used, number of flocks grown between decaking, feed source and feed efficiency, bird type, management practices and whether or not the litter has been composted or is fresh. This variability makes it imperative that every delivered batch of litter be tested to determine the nutrient and water content.

Nutrient Content

Poultry litter contains nitrogen, phosphorus and potassium, as well as several micronutrients and organic acids. Poultry litter on average contains N-P_2O_5-K_2O at a concentration around 60 pounds of each nutrient per ton of material on a dry basis. However, the actual content varies greatly between batches and must always be analyzed prior to determining an application rate.

Figure 4-7. Common commercial poultry litter.

There are multiple organic and inorganic forms of N contained in poultry litter. Rice takes up the inorganic forms of N including NH_4^+ and NO_3^- during the growth and development of the crop. Initially, the inorganic N content is only 10% or less of the total N content in the litter. Some of the inorganic N is mineralized during the first year and made available for uptake by rice. However, once the

rice crop is flooded and the soil converts to an anaerobic (without oxygen) condition, NO_3-N quickly is lost due to denitrification and will no longer be available for uptake by rice. This is one of the reasons that N use efficiency of poultry litter by rice is less efficient as compared to that of upland crops. Past research has shown the pre-flood urea-N equivalence for rice ranges from 25%-41% of the N content of the poultry litter. Therefore, a conservative estimate is that 25% of the N contained in the poultry litter will count towards the normal recommended preflood N rate for a particular rice cultivar and the rate of applied urea should be reduced to represent the litter N contribution. These estimates were developed from poultry litter applied the same day that rice was drill seeded. Application of litter several weeks before planting may further reduce N availability for drill-seeded rice. Research has not evaluated the urea-N equivalence of litter in water-seeded systems. However, it is expected that the urea equivalence of litter in a water-seeded system would be slightly greater than that of a drill-seeded, delayed flood production system since the litter would be in a saturated anaerobic condition at an earlier point in the season, which would limit the nitrification and subsequent denitrification of mineralized NH_4-N.

Total P_2O_5 and K_2O concentrations of litter are often very close in concentration to that of total N. Like N, the total P and K found in litter is made up of both organic and inorganic forms. The alternating flooded and draining (flushing) associated with early-season, drill-seeded rice management and the establishment of the permanent flood tends to accelerate the mineralization of organic bound nutrients into inorganic, plant available forms. Research comparing the uptake efficiency of P and K by rice between inorganic fertilizers and poultry litter when applied at equal concentrations of P_2O5 and K_2O has shown that the P and K applied from poultry litter is an equivalent source of these nutrients. Therefore, 100% of the P and K found in poultry litter can be applied towards the needs of the rice crop during the first year for a drill-seeded, delayed flood rice production system.

The P needs of rice are less than the N needs. It is estimated that a 7,000 pounds/A (43 barrels) rice yield will remove approximately 112, 60 and 168 pounds of N, P_2O_5 and K_2O from the soil, respectively. If poultry litter is applied based on the N needs of rice an over application of P will occur. The surplus P will buildup soil test P to excessive levels with repeated applications over several years and has the potential to cause environmental problems. This excess P can be lost through run off from fields can contribute to eutrophication of nearby surface waters. This is a problem often seen in pastures grown for forage in areas near poultry facilities where poultry litter has been used repeatedly in this fashion. Therefore, it is important that poultry litter only be applied based on the P needs of the rice crop as indicated from a current soil test.

Litter Sampling

Litter is generally delivered by 18-wheelers to field edges and stacked into piles prior to spreading (Figure 4-8). Physical and chemical variability of poultry litter between delivered batches are not uncommon (Figure 4-9). It is important to sample each delivered source to account for this variability. When sampling poultry litter for nutrient analysis, it is best to take multiple samples from all depths and sides of the litter pile. The samples can then be physically combined to create one composite sample. The composite sample will improve chemical analysis and will be more representative of the litter as a whole. Litter samples are generally analyzed on a wet, as is basis. Samples taken only from one location of the litter pile can alter analysis results. For example, litter stacked in the field waiting to be applied is often rained on prior to spreading. Simply taking a surface sample of the litter may result in a sample that has an elevated water content as compared with the litter pile as a whole. This, in turn, will subsequently alter the N, P_2O_5 and K_2O concentration of the litter. In cases where it is known that the litter will be stored for long periods of time before spreading, samples can be taken immediately after delivery to the field when the litter is the driest. Although, litter samples are generally analyzed on a moist basis, the results may be reported on a wet or dry basis depending on the laboratory used.

Figure 4-8. Litter delivered by 18-wheelers to field edges.

Litter Sources

Poultry litter can be purchased on a fresh, composted or in a pelletized form. The pelletized form is generally more expensive per unit of nutrient, has equivalent nutrient levels, and has lower water content. The pelletized form does improve handling, field application and equipment clean-up. Research has shown that nutrient availability between fresh, composted and pelletized litter is equivalent between the sources when applied at similar N, P_2O_5 and K_2O levels. The ease of use of the pelletized litter must be weighed against the increase in cost when making a litter source selection.

Figure 4-9. Litter piles prior to spreading.

General Recommendations

The use efficiency of nutrients in poultry litter is maximized when the litter is applied and incorporated immediately prior to drill seeding. An evaluation of the time of application of poultry litter indicated that the N-uptake by rice was reduced by 16% when the litter was applied 10 days prior to seeding as compared with application immediately prior to seeding. The urea-N equivalence of the litter during this study was 41%. Other yield-based research has also shown that litter applied in the fall results in lower yields as compared with litter applied in the spring prior to seeding. While not as efficient, litter can be surface applied in a reduced tillage system. Due to the alkaline nature of poultry litter, volatilization losses can be excessive on surface applied litter. Surface losses of P and K can also be expected from run-off events associated with field flushing.

Other general observations of the use of poultry litter in a rice production system include:

- The responses of litter applied on precision leveled clay soils are generally not as great as compared with precision leveled silt loam soils.
- Consultants and producers have noted that even distribution of litter at rates less than one ton per acre are difficult. The cake and clods of the litter and the use of poor application equipment are the main culprits of the distribution problem. For this reason, rates of less than one ton are rarely used. The use of properly calibrated spreading equipment in good operating condition should always be used to maximize even distribution.
- Producers and consultants have also noted an increase in weed seed germination as a result of the use of poultry litter. While not substantiated, the increase of weed incidence seen when using poultry litter is most likely a derivative of the organic acids enhancing weed germination and the additional nutrients enhancing weed growth. It is highly unlikely that the increased weed pressure is caused by weed seed being introduced by the litter itself.
- Continued use of litter can increase organic matter, soil structure and CEC. However, a significant increase in these soil properties should not be expected from one-time or sporadic use.

Best Management Guidelines for the Use of Poultry Litter

1. Obtain a soil test on precision leveled and problem areas of fields separate from productive areas.
2. Obtain a composite poultry litter sample and send off for N-P-K and water content analysis. Generally, one to two weeks are needed for chemical analysis.
3. Determine litter rate based on P_2O_5 recommendations provided by a soil test.
4. Determine supplemental K needs, if any, based on soil test results.
5. Apply poultry litter and K as close to planting as possible using calibrated equipment and incorporate.
6. Determine supplemental preflood N needs based on a 25% urea equivalence.
7. Resample precision leveled and problem areas in subsequent years to monitor nutrient changes.

Example of Poultry Litter Rate Determinations

A soil test of a precision leveled area indicated that 40 pounds of P_2O_5 and 60 pounds of K_2O are required to grow a rice crop. Poultry litter analysis indicated that the litter contains 2.5% N, 3.2% P_2O_5, 2.7% K_2O and 40% moisture. Litter analysis is reported on an “as is” wet basis.

1. Determine how much total litter will be needed to supply 40 pounds of P_2O_5. Calculate nutrients based on dry basis first then adjust to wet (as applied) basis.
   a) Divide total pounds needed by percent P_2O_5 in litter.
      i) 40 pounds P_2O_5 divided by 3.2% = 40/0.032 = 1,250
   b) Convert to as applied (wet) basis.
      i) Need 1,250 pounds dry
      ii) Litter is 40% water
      iii) 100% - 40% = 60% dry matter
      iv) 1,250 pounds dry litter / 0.60 dry matter = 2,083 pounds as is (wet) litter needed
2. Determine how much additional K from potash is needed.
   a) Determine amount of K_2O supplied by litter
      i) 2,083 pounds (wet) applied * 0.60 dry matter = 1,250 pounds dry litter
      ii) Litter contains 2.7% K_2O
      iii) 2.7% of 1,250 pounds = 0.027 * 1250 = 33.7 pounds K_2O
   b) Determine additional K_2O needed from potash (0-0-60). A total of 60 pounds K_2O is needed based on the soil test.
      i) 60 pounds needed – 33.7 pounds supplied by litter = 26.3 pounds K_2O needed
   c) Determine potash rate
      i) K_2O fertilizer (0-0-60) is 60% K_2O
      ii) 26.3 pounds K_2O needed / 0.60 pounds K_2O per pound of 0-0-60 = 43.8 pounds of 0-0-60
3. Determine how much preflood N is supplied by litter and how much additional urea is needed based on a 90 pounds/A preflood N rate.
   a) Determine N supplied by litter. Assume that the litter will provide a 25% urea equivalent.
      i) 2,083 pounds (wet) applied * 0.60 dry matter = 1,250 pounds dry litter
      ii) Litter contains 2.5% Nitrogen
      iii) 2.5% of 1,250 pounds = 0.025 * 1,250 = 31.2 pounds of N
      iv) N in litter is only 25% of the value of urea
      v) 25% of 31.2 = 0.025 N in litter * 0.25 urea equivalent = 7.8 pounds N supplied by litter
   b) Determine additional preflood N needed.
      i) 90 pounds needed - 7.8 pounds N supplied = 82.2 pounds N needed
   c) Convert to pounds of urea
      i) Urea (46-0-0) is 46% N
      ii) 82.2 pounds N / 0.46 = 178.7 pounds urea needed to supply 82.2 pounds nitrogen

Poultry litter from different sources can contain differing amounts of N, P_2O_5 and K_2O. It is important to individually test each poultry litter load.

Rice Growth and Development

Richard Dunand, Manoch Kongchum and Ronnie Levy

First (Main) Crop

Growth and development of the rice plant involve continuous change. This means important growth events occur in the rice plant at all times. Therefore, the overall daily health of the rice plant is important. If the plant is unhealthy during any state of growth, the overall growth, development and grain yield of the plant are limited. It is important to understand the growth and development of the plant.

The ability to identify growth stages is important for proper management of the rice crop. Because management practices are tied to the growth and development of the rice plant, an understanding of the growth of rice is essential for management of a healthy crop. The timing of agronomic practices associated with water management, fertility, pest control and plant growth regulation is the most important aspect of rice management. Understanding the growth and development of the rice plant enables the grower to properly time recommended practices.

Growth and Development

Growth and development of rice grown as an annual from seed begin with the germination of seed and end with the formation of grain. During that period, growth and development of the rice plant can be divided into two phases: vegetative and reproductive. These two phases deal with growth and development of different plant parts. It is important to remember growth and development of rice are continuous processes rather than a series of distinct events. They are discussed as separate events for convenience.

The vegetative phase deals primarily with the growth and development of the plant from germination to the beginning of panicle development inside the main stem. The reproductive phase deals mainly with the growth and development of the plant from the end of the vegetative phase to grain maturity. Both phases are important in the life of the rice plant. They complement each other to produce a plant that can absorb sunlight and convert that energy into food in the form of grain.

The vegetative and reproductive phases of growth are subdivided into groups of growth stages. In the vegetative phase of growth there are four stages: (1) emergence, (2) seedling development, (3) tillering and (4) internode elongation. Similarly, the reproductive phase of growth is subdivided into five stages: (1) prebooting, (2) booting, (3) heading, (4) grain filling and (5) maturity.

Growth Stages in the Vegetative Phase

Emergence

When the seed is exposed to moisture, oxygen and temperatures above 50 F, the process of germination begins. The seed is mostly carbohydrates stored in the tissue called the endosperm. The embryo makes up most of the rest of the seed. Germination begins with the imbibition of water. The seed swells, gains weight, begins to convert carbohydrates to sugars and the embryo is activated.

Nutrition from the endosperm can supply the growing embryo for about three weeks. In the embryo, two primary structures grow and elongate: the radicle (first root) and coleoptile (protective covering enveloping the shoot). As the radicle and coleoptile grow, they apply pressure to the inside of the hull. Eventually, the hull weakens under the pressure, and the pointed, slender radicle and coleoptile emerge.

Appearance of the radicle and coleoptile loosely defines the completion of germination.

After germination, the radicle and coleoptile continue to grow and develop primarily by elongation (or lengthening) (Figure 5-1). The coleoptile elongates until it encounters light. If further elongation is required (for example, if the seeds are planted or covered too deeply), the region of the shoot below the coleoptile begins to elongate. This region is called the mesocotyl. Usually, it does not develop in water-seeded rice. The mesocotyl originates from the embryo area and merges with the coleoptile. The mesocotyl and coleoptile can elongate at the same time. They are sometimes difficult to tell apart. Usually, the mesocotyl is white, and the coleoptile is off-white and slightly yellowish. Shortly after the coleoptile is exposed to light, usually at the soil surface, it stops elongation. The appearance of the coleoptile signals emergence. From a production perspective, emergence is called when eight to 10 seedlings 3/4 inch tall are visible per square foot in water-seeded rice or four to seven plants break the soil surface per foot for drill-seeded rice, depending on drill spacing (Figure 5-2).

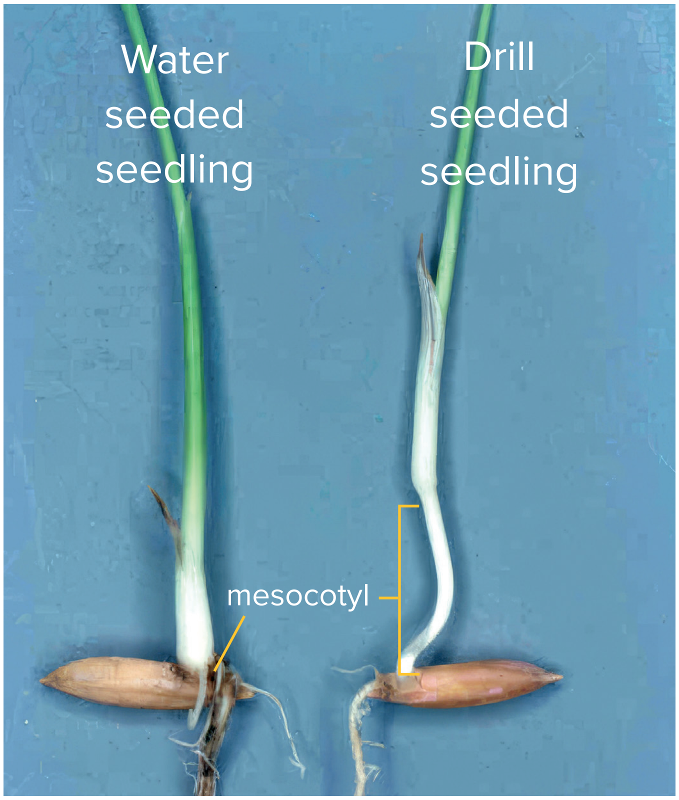


Figure 5-1. Left, water-seeded seedling. Right, drill-seeded seedling.

Figure 5-2. Emergence, water-seeded rice.

Seedling Development

Seedling development begins when the primary leaf appears shortly after the coleoptile is exposed to light and splits open at the end. The primary leaf elongates through and above the coleoptile (Figure 5-3). The primary leaf is not a typical leaf blade and is usually 1 inch or less in length. The primary leaf acts as a protective covering for the next developing leaf. As the seedling grows, the next leaf elongates through and past the tip of the primary leaf. Continuing to grow and develop, the leaf differentiates into three distinct parts: the sheath, collar and blade (Figure 5-4). A leaf that is differentiated into a sheath, collar and blade is considered complete; thus, the first leaf

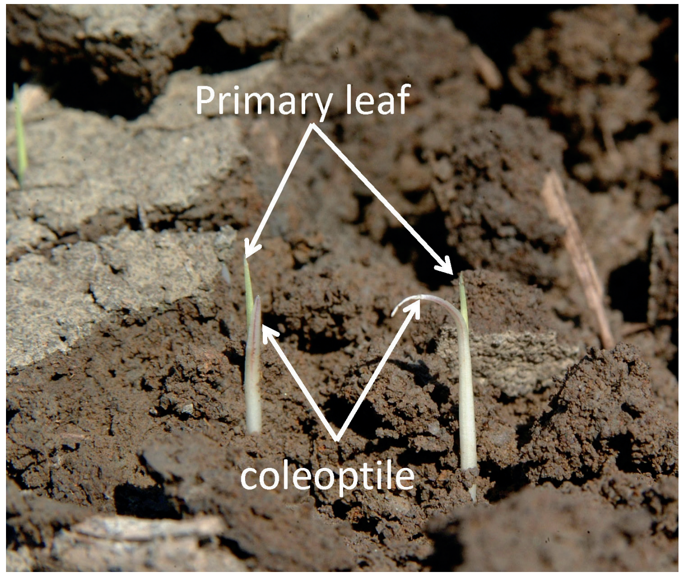


Figure 5-3. Emergence, drill-seeded rice.

Figure 5-4. One-leaf seedling.

to develop after the primary leaf is the first complete leaf. The one-leaf stage of growth rice has a primary leaf and a completely developed leaf.

All subsequent leaves after the first leaf are complete leaves. The sheath is the bottom-most part of a complete leaf. Initially, all leaves appear to originate from a common

point. The area is actually a compressed stem with each leaf originating from a separate node.

Throughout the vegetative growth period, there is no true stem (culm) development. The stem of rice, as with all grasses, is called the culm. Leaf blades are held up by the tightly wrapped leaf sheaths.

This provides support much like tightly rolling up several sheets of paper to form a column. Without this mechanism, the leaves would lay flat on the soil surface.

The collar is the part of the leaf where the sheath and blade join (Figure 5-5). It is composed of strong cells that form a semicircle that clasps the leaf sheath during vegetative development and the stem during reproductive development. It is marked by the presence of membranous tissue on its inner surface called the ligule. Rice also has two slender, hairy structures on each end of the collar called auricles.

Figure 5-5. Collar of rice leaf.

The blade or lamina is the part of the leaf where most photosynthesis occurs. Photosynthesis is the process by which plants in the presence of light and chlorophyll convert sunlight, water and carbon dioxide into glucose (a sugar), water and oxygen. It contains more chlorophyll than any other part of the leaf. Chlorophyll is the green pigment in leaves that absorbs sunlight. The absence of chlorophyll is called chlorosis. The blade is the first part of a complete leaf to appear as a leaf grows and develops. It is followed in order by the appearance of the collar at the base of the blade then the sheath below the collar. During the vegetative phase of growth, the collar and blade of each complete leaf become fully visible. Only the oldest leaf sheath is completely visible, since the younger leaf sheaths remain covered by sheaths of leaves whose development preceded them. Each new leaf originates from within the previous leaf so that the oldest leaves are both the outermost leaves and have the lowest point of origin.

Since growth and development are continuous, by the time the first complete leaf blade has expanded, the tip of the second complete leaf blade is usually already protruding through the top of the sheath of the first complete leaf. The second leaf grows and develops in the same manner as the first. When the second collar is visible above the collar of the first leaf, it is called two-leaf rice (Figure 5-6). Subsequent leaves develop in the same manner, with the number of fully developed leaves being used to describe the seedling stage of growth.

Figure 5-6. Two-leaf seedlings.

When the second complete leaf matures, the sheath and blade are each longer and wider than their counterparts on the first complete leaf. This trend is noted for each subsequent leaf until about the ninth complete leaf, after which leaf size either remains constant or decreases. Although a rice plant can produce many (about 15) leaves, as new leaves are produced, older leaves senesce (die and drop off), resulting in a somewhat constant four to five green leaves per shoot at nearly all times in the life of the plant. Each additional leaf develops higher on the shoot and on the opposite side of the previous leaf producing an arrangement referred to as alternate, two-ranked and in a single plane. Seedling growth continues in this

manner through the third to fourth leaf, clearly denoting plant establishment.

Root system development is simultaneous to shoot development. In addition to the radicle, other fibrous roots develop from the seed area and, with the radicle, form the primary root system (Figure 5-7). The primary root system grows into a shallow, highly branched mass limited in its growth to the immediate environment of the seed. The primary root system is temporary, serving mainly to provide nutrients and moisture to the emerging plant and young seedling. In contrast, the secondary root system is more permanent and originates from the base of the coleoptile.

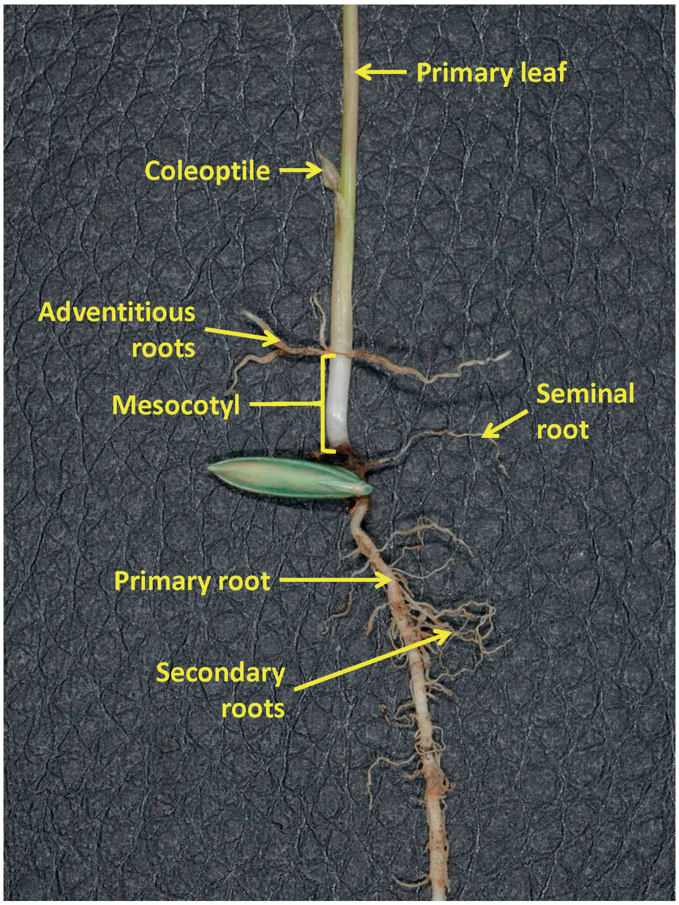


Figure 5-7. Rice seedling root system.

In water-seeded rice (or any time seeds are left on the soil surface), the primary and secondary root systems appear to originate from a common point. When seed are covered with soil as in drill seeding, the primary root system originates at or near the seed, while the secondary root system starts in a zone above the seed originating from the base of the coleoptile. These differences can have an impact on some management practices.

During the seedling stages, the secondary root system, composed of adventitious roots, is not highly developed and appears primarily as several nonbranched roots spreading in all directions from the base of the coleoptile in a plane roughly parallel to the soil surface. The secondary root system provides the bulk of the water and nutrient requirements of the plant for the remainder of the vegetative phase and into the reproductive phase.

During the seedling stages, the plant has clearly defined shoot and root parts. Above the soil surface, the shoot is composed of one or more completely developed leaves at the base of which are the primary leaf and upper portions of the coleoptile. Below the soil surface, the root system is composed of the primary root system originating from the seed and the secondary root system originating from the base of the coleoptile. Plants originating from seed placed deep below the soil surface will have extensive mesocotyl and coleoptile elongation compared with plants originating from seed placed on or near the soil surface (Figure 5-1). Seed placement on the soil surface usually results in no mesocotyl development and little coleoptile elongation. In general, the presence of primary and secondary roots and a shoot, which consists of leaf parts from several leaves, is the basic structure of the rice plant during the seedling stages of growth.

Tillering

Tillers (stools) first appear as the tips of leaf blades emerging from the tops of sheaths of completely developed leaves on the main shoot. This gives the appearance of a complete leaf that is producing more than one blade (Figure 5-8). This occurs because tillers originate inside the sheath of a leaf just above the point where the sheath attaches at the base of the plant. If the leaf sheath is removed, the bud of a beginning tiller will appear as a small green triangular growth at the base of the leaf. This bud is called an axillary bud. Tillers that originate on the main shoot in this manner are primary tillers. When the first complete leaf of the first primary tiller is visually fully differentiated (blade, collar and sheath apparent), the seedling is in the first tiller stage of growth.

The first primary tiller usually emerges from the sheath of the first complete leaf before the fifth leaf. If a second tiller appears, it usually emerges from the sheath of the second complete leaf and so on.

Consequently, tillers develop on the main shoot in an alternate fashion like the leaves. When the second primary tiller appears, it is called two-tiller rice. The appearance of tillers in this manner usually continues through about fourth or fifth primary tiller. If plant populations are very low (fewer than 10 plants per square foot), tillers may originate from primary tillers much in the same manner as primary tillers originate from the main shoot. Tillers originating from primary tillers are considered secondary tillers. When this occurs, the stage of growth of the plant is secondary tillering.

Tillers grow and develop in much the same manner as the main shoot, but they lag behind the main shoot in their development. This lag is directly related to the time a tiller first appears. It usually results in tillers producing fewer leaves and having less height and maturing slightly later than the main shoot.

Figure 5-8. One-tiller rice seedling.

During tillering (stooling), at the base of the main shoot, crown development becomes noticeable. The crown is the region of a plant where shoots and secondary roots join. Inside a crown, nodes form at the same time as the development of each leaf. The nodes appear as white bands about 1/16 inch thick and running across the crown, usually parallel with the soil surface. Initially, the plant tissue between nodes is solid, but with age, the tissue disintegrates, leaving a hollow cavity between nodes. With time, the nodes become separate and distinct, with spaces (internodes) about 1/4 inch or less in length between them.

In addition to crown development, leaf and root development continue on the main shoot. An additional five to six complete leaves form with as many additional nodes forming above the older nodes in the main shoot crown. On the main shoot, some of the older leaves turn yellow and brown. The changes in color begin at the tip of a leaf blade and gradually move to the base. This process is called senescence. The lowest leaves senesce first with the process continuing from the bottom up or from oldest to youngest leaves. From this point on, there is simultaneous senescence of older leaves and production of new leaves. The result is that there are never more than four or five fully functional leaves on a shoot at one time.

In addition to changes in leaves, the main shoot crown area expands. Some of the older internodes at the base of the crown crowd together and become indiscernible by the unaided eye. Usually, no more than seven or eight crown internodes are clearly observable in a dissected crown. Sometimes, the uppermost internode in a crown elongates 1/2 to 1 inch. This can occur if depth of planting, depth of flood, plant population, N fertility and other factors that tend to promote elongation in rice are excessive. During tillering, tiller crowns develop. Along with growth of the main shoot and tiller shoot crowns, more secondary roots form, arising from the expanding surface of the crowns. These roots grow larger than those that formed during the seedling stages. They are wider and longer as they mature. A vegetatively mature rice plant will be composed of a fully developed main shoot, several tillers in varying degrees of maturity, healthy green leaves, yellow senescing leaves and an actively developing secondary root system.

Internode Elongation and Stem Development

Each stem or culm is composed of nodes and internodes. The node is the swollen area of the stem where the base of the leaf sheath is attached. It is also an area where a great deal of growth activity occurs. This area is one of several meristematic regions. Growth of the stem is the consequence of the production of new cells along with the increase in size, especially length, of these cells. The area between each node is the internode. The combination of node and internode is commonly called a “joint.”

The formation and expansion of hollow internodes above a crown are the process that produces a stem, determines stem length and contributes to a marked increase in plant height. Internode formation above a crown begins with the formation of a stem node similar to that of the crown nodes (Figure 5-9). The stem node forms above the uppermost crown node, and a stem internode begins to form between the two nodes. As the stem internode begins to form, chlorophyll accumulates in the tissue below the stem node.

This produces green color in that tissue. Cutting the stem lengthwise usually reveals this chlorophyll accumulation as a band or ring. This is commonly called “green ring” and indicates the onset of internode elongation (Figure 5-10). It also signals a change in the plant from vegetative to the reproductive stage of development (Figure 5-11).

Figure 5-9. Plant with three distinct crown nodes and a fourth developing.

Figure 5-10. Green ring-internode elongation.

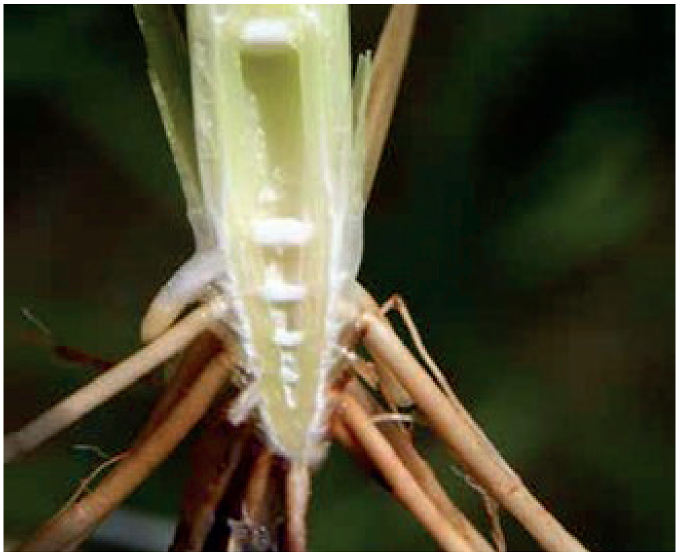


Figure 5-11. Half-inch internode.

Subsequent nodes and internodes develop above each other. Growth of the stem can be compared to the extension of a telescope with the basal sections extending first and the top last. As the newly formed nodes on the main stem become clearly separated by internodes, the stages of growth of the plant progress from first internode, to second internode, to third internode, etc. With the formation and elongation of each stem internode, the length of the stem and the height of the plant increase. Internode elongation occurs in all stems. The main stem is usually the first to form an internode and is also the first stem in which internode formation ends. In tillers, internode formation lags behind the main stem and usually begins in the older tillers first.

During the internode formation stages, each newly formed internode on a stem is longer and slenderer than the preceding one. The first internode formed is the basal most internode. It is the shortest and thickest internode of a stem. The basal internode is located directly above the crown. Sometimes, if the uppermost crown internode is elongated, it can be confused with the first internode of the main stem. One difference between these two internodes is the presence of roots. Sometimes, especially late in the development of the plant, the node at the top of the uppermost crown internode will have secondary roots associated with it. The upper node of the first stem internode will usually have no roots at that time. If roots are present, they will be short and fibrous. The last or uppermost internode that forms is the longest and slenderest internode and is directly connected to the base of the panicle. The elongation of the uppermost internodes causes the panicle to be exserted from the sheath of the uppermost or "flag leaf." This constitutes heading. This process is covered in detail in the booting and heading sections.

Internode length varies, depending on variety and management practices. In general, internode lengths vary from 1 inch (basal internode) to 10 inches (uppermost internode) in semidwarf varieties and from 2 inches to 15 inches in tall varieties. These values, as well as internode elongation in general, can be influenced by planting date, plant population, soil fertility, depth of flood, weed competition and so on.

The number of internodes that forms in the main stem is relatively constant for a variety. Varieties now being grown have five to six internodes above the crown in the main stem. In tillers, fewer internodes may form than in the main stem. The number is highly variable and depends on how much the tiller lags behind the main stem in growth and development.

The time between seeding and internode formation depends primarily on the maturity of the variety, which

is normally controlled by heat unit exposure (see DD-50 Rice Management Program section). It also can be influenced by planting date, plant population, soil fertility, flood depth and weed competition. In general, varieties classified as very early season maturity (head 75 to 79 days after planting) reach first internode about six weeks after planting. Varieties classified as early season maturity (head 80 to 84 days after planting) reach first internode about seven weeks after planting, and varieties classified as midseason maturity (head 85 to 90 days after planting) reach first internode about eight weeks after planting.

The appearance of nodes above the crown marks a change in the role of the node as the point of origin of several plant parts. Before stem internode formation begins above the crown, all leaves, tillers and secondary roots formed during that time originate from crown nodes. But after internode formation begins above the crown, the stem nodes serve mainly as the point of origin of all subsequent leaves.

Because stem nodes become separated significantly by internode development, the leaves that originate at these nodes are more separate and distinct than leaves formed before internode formation. The separation of these leaves increases as the length of the internodes increases. More complete leaf structure does not become apparent until the last two leaves to form have all or most of all three parts (sheath, collar and blade) completely visible. In varieties now in use, no more than six new complete leaves are produced on the main shoot after stem internode elongation begins. The last of these leaves to form is the flag leaf. It is the uppermost leaf on a mature stem. The sheath of the flag leaf, the boot, encloses the panicle during the elongation of the last two internodes. Not only is the flag leaf the last formed and uppermost leaf on a mature stem, it is also considered to be the most important leaf because the products of photosynthesis from it are most responsible for grain development.

Root growth approaches a maximum as internode formation above the crown begins. At this time, the secondary root system has developed extensively in all directions below the crown and has become highly branched. Newly formed roots are white; older roots are brown and black. A matted root system forms in addition to the secondary root system. It is composed of fibrous roots, which interweave and form a mat of roots near the soil surface.

Tiller formation usually ceases, and tiller senescence begins during internode elongation. With adequate soil fertility, more tillers are produced during tillering than will survive to maturity. Tiller senescence begins as the crown becomes fully differentiated and continues until the last internode forms above the crown of the main stem.

Tiller senescence can be recognized by the smaller size of a tiller in comparison to other tillers on a plant. It appears significantly shorter than other tillers, has fewer complete leaves and fails to have significant internode development above the crown. Eventually, most leaves on a senescing tiller lose coloration while most leaves on other tillers remain green. The leaves and stems of senescing tillers turn brown and gray and, in most instances, disappear before the plant reaches maturity.

Internode elongation signals the end of vegetative growth. As stem internodes develop, reproductive growth begins.

Growth Stages During the Reproductive Phase

Prebooting

Prebooting refers to the interval after the onset of internode elongation and before flag leaf formation is complete. During prebooting, the remaining leaves of the plant develop, internode elongation and stem formation continue, and panicle formation begins.

When cells first begin actively dividing in the growing point or apical meristem, the process is called panicle initiation (PI). This occurs during the fifth week before heading. Although it can be positively identified only by microscopic techniques, it is closely associated with certain vegetative stages of growth.

The growth stages that coincide closely with PI differ depending on the maturity of a variety. In very early season varieties, PI and internode elongation (green ring) occur at about the same time. In early season varieties, PI and second internode elongation occur almost simultaneously, and in midseason varieties, PI and third internode elongation are closely concurrent.

About seven to 10 days after the beginning of active cell division at the growing point, an immature panicle about 1/8 inch long and 1/16 inch in diameter can be seen. At this point, the panicle can be seen inside the stem, resembling a small tuft of fuzz. This is referred to as panicle differentiation (PD) or panicle 2-mm (Figure 5-12). The panicle, although small, already has begun to differentiate into distinct parts. Under a microscope or good hand lens, the beginnings of panicle branches and florets are recognizable. As the panicle develops, structures differentiate into a main axis and panicle branches (Figure 5-13). The growing points of these branches differentiate into florets. Florets form at the uppermost branches first and progress downward. Because there are several panicle branches, development of florets within the panicle overlaps. Florets at the tip of a lower branch might be more advanced in their development than florets near the base of an upper panicle branch.

From a management standpoint, panicle length defines plant development during this phase. A fungicide label,

for example, might prescribe its application "from a 2- to 4-inch panicle." By the time the panicle is about 4 inches long, individual florets can be easily recognized on the most mature panicle branches.

Figure 5-12. Immature panicle, PD or panicle 2-mm.

Figure 5-13. Half-inch panicle.

Booting

Booting is the period during which growth and development of a panicle and its constituent parts are completed inside the sheath of the flag leaf. The sheath of the flag leaf is the boot. Booting stages are classified according to visible development of the panicle without dissection. For convenience, it is divided into three stages: early, middle and late boot. It is based on the amount of flag leaf sheath exposed above the collar of the leaf from which it emerges, the penultimate (second to last) leaf. Early boot (Figure 5-14) is recognized when the collar of the flag leaf first appears above the collar of the penultimate leaf on the main stem and lasts until the collar of the flag leaf is about 2 inches above the collar of the penultimate leaf. Middle boot occurs when the collar of the flag leaf is 2 to 5 inches above the collar of the penultimate leaf and late boot when the collar of the flag leaf is 5 or more inches above the collar of the penultimate leaf. By late boot, the increasing panicle development causes the boot to swell, giving rise to the term "swollen boot." The boot becomes spindle shaped; it is wider in the middle tapering to a smaller diameter at each end.

Figure 5-14. Early boot, flag leaf first appears above collar.

Heading

Heading refers to the extension of the panicle through the sheath of the flag leaf on the main stem. This process is brought about mainly by the gradual and continuous elongation of the uppermost internode. When elongation of the uppermost internode of a main stem pushes the panicle out of the sheath of the flag leaf exposing the tip of the panicle, that stem has headed. The uppermost internode continues to elongate, revealing more of the panicle above the sheath of the flag leaf. Once the uppermost internode completes elongation, the full length of the panicle and a portion of the uppermost internode are exposed above the collar of the flag leaf. This stem is now fully headed.

The main stem of each plant heads before its tillers. In a field of rice, there is considerable variation in the heading stage of growth. For example, some main stems, as well as tillers of other plants, may be fully headed while other plants may have just begun to head. Some management practices are based on the percentage of headed plants within a field. This should not be confused with the degree to which a single panicle has emerged from the boot or with the number of completely headed stems. Fifty percent heading means half of the stems in a sample have a range from barely extended to completely exposed panicles. It is not the degree of exposure of each panicle but the percentage of stems with any panicle exposure that is important.

Each floret or flower is enclosed by protective structures called the lemma and palea. These become the hulls of mature grain. These hulls protect the delicate reproductive structures. The female reproductive organ is the pistil. At the tip of the pistil are two purplish feathery structures called stigmas. They are visible when the hulls open during flowering. More obvious are the male or pollen-bearing stamens. Each rice floret has a single pistil and six stamens. Pollen is produced and stored in anthers, tiny sacks at the tip of each stamen.

Figure 5-15. Open floret with floral parts showing.

As heading progresses, flowering begins. During the middle hours of the day, mature florets open, exposing both the stigmas and anthers to air (Figure 5-15).

Pollen is shed as the anthers dry, split open and spill the pollen. The pollen then is carried by wind to the stigmas of the same or nearby plants. Special cells of the pollen grain join special cells within the pistil, completing fertilization and initiating grain formation.

Figure 5-16. Milk stage.

Figure 5-17. Soft dough stage.

Grain Filling

During grain filling, florets on the main stem become immature grains of rice. Formation of grain results mainly from accumulation of carbohydrates in the pistils of the florets. The primary source of the carbohydrate is from photosynthesis occurring in the uppermost three to four leaves and the stem. The carbohydrate that accumulates in grain is stored in the form of starch. The starchy portion of the grain is the endosperm. Initially, the starch is white and milky in consistency. When this milky accumulation is first noticeable inside florets on the main stem, the stage is milk stage (Figure 5-16).

Prior to pollination, the panicle in most varieties is green, relatively compact and erect. During milk stage, the accumulation of carbohydrate increases floret weight. Since the florets that accumulate carbohydrate first are located near the tip of the panicle, the panicle begins to

lean and eventually will turn down. The milky consistency of the starch in the endosperm changes as it loses moisture. When the texture of the carbohydrate of the first florets pollinated on the main stem is like bread dough or firmer, this stage of growth is referred to as the dough stage (Figure 5-17).

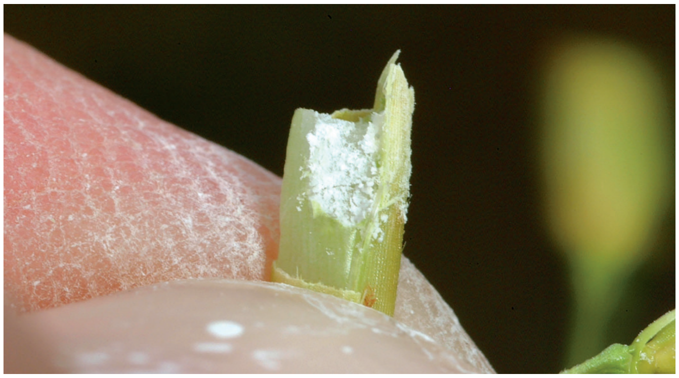


Figure 5-18. Hard dough stage.

As the carbohydrate in these florets continues to solidify during the dough stage, the endosperm becomes firm and has a chalky texture. Grains capable of being dented without breaking are in the soft dough stage. As more moisture is lost, grains become chalky and brittle. These grains are in the hard dough stage (Figure 5-18).

During the grain filling stages, the florets develop and mature unevenly because pollination and subsequently grain filling occur unevenly. In the dough stage, only the florets on the main stem, which pollinated first, have an endosperm with the texture of bread dough. At the same time, the florets which pollinated later, including those on the tillers, may be in the milk stage. These are the last florets to accumulate carbohydrate. As more and more florets fill with carbohydrate, the translocation of carbohydrate to the panicle starts to decline, and the final phases of grain filling occur.

The panicle changes in color and form as the florets develop and mature. For most varieties of rice, the panicle changes from a uniform light green at the milk stage to a mixture of shades of brown and green during the dough stage. As the color changes so does the grain shape as a consequence of carbohydrate accumulation in the florets. The weight of the carbohydrate causes the panicle to bend over and the panicle branches to be less compact around the panicle axis. At the end of the grain filling stages, the panicle on the main culm has a bent and slightly open shape and is various shades of brown and green. The bent and slightly open configuration of the panicle remains unchanged from dough to maturity.

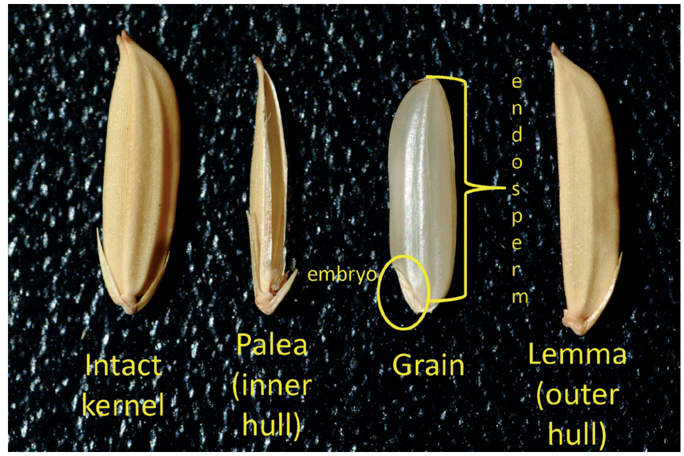


Figure 5-19. Mature grain, intact and dissected.

Maturity

Maturity occurs when carbohydrate is no longer translocated to the panicle. The moisture content of the grain is high after grain filling, and the primary process, which occurs in the panicle during the maturity stages, is the loss of moisture from the grain. The moisture content of the grain is used as the basis for judging degree of maturity. When the physiological processes associated with grain filling cease and the collective moisture content of the grain on the main stem is 25% to 30%, the plant has reached physiological maturity (Figure 5-19).

Figure 5-20. Left panicles are two-thirds ripe. Right panicles are half ripe.

At this stage, the endosperm of all grains on the panicle of a main stem is firm. Most grains are some shade of brown and the grains in the lower quarter of the panicle are the only ones with a greenish tint (Figure 5-20). As maturity progresses and moisture is lost, the greenish tint of the hulls fades and the endosperm of all grains becomes uniformly hard and translucent. Once the average moisture content of the grains on the main stem is 15% to 18% (crop grain moisture, 18% to 21%), the plant has reached harvest maturity.

Second (Ratoon) Crop

Second crop stems originate from small axillary buds at the crown and stem nodes of the stubble remaining after harvest of the first crop (Figure 5-21). At each node just above the area of attachment of the leaf sheath to the stem is a bud called an axillary bud.

Figure 5-21. Axillary bud on stem.

The leaf sheath is wrapped around the stem keeping it hidden unless the leaf itself is damaged or the bud begins to grow. As long as the apical bud, the one that eventually becomes the panicle, remains intact, axillary buds are suppressed. Removal of the panicle through harvesting or injury removes the suppressive effect, called apical dominance, permitting axillary buds to grow. In the crown, buds are difficult to detect (Figure 5-22). At the stem nodes on first crop stubble they appear as a small (1/8 inch), mostly white, fleshy, triangular shaped structure. Buds that appear necrotic (have dark or dead tissue) and are associated with nodes that also appear necrotic usually do not develop into second crop growth.

There is one bud per node. Because each bud is associated with a single leaf, bud development on a stem follows the same pattern of leaf development.

Depending on stubble height, as many as three nodes can be on a stem of stubble with the potential to produce second crop growth. Once a bud on a stem above the crown develops, it usually inhibits the development of other similar buds. Buds on the crown usually are not suppressed. Five to six shoots can appear from the crown of a single plant. Second crop panicles can be produced from both axillary stem buds and from the crown. Shoots and stems originating from the crown usually produce larger panicles with higher quality grain than those originating from axillary buds on the stem; however, panicles originating from the crown mature later than those originating from axillary buds.

Figure 5-22. Crown or axillary buds at base of stem.

These buds are easily observed by pulling back the leaf sheath from the stem. This is particularly true of buds located at stem nodes. As axillary buds grow, they elongate within the cover of sheaths of first crop leaves. Depending on the node and integrity of the attached sheath, buds can elongate several inches before emerging from the sheaths. Once a developing bud senses sunlight, it differentiates into a green leaf. Leaf formation can occur before ratoon growth emerges from a first crop leaf sheath.

Second crop growth first appears as leaves originating from the crown or a leaf emerging through the sheath of a leaf from the first crop that remains attached to stubble. This usually occurs within five days after harvest, depending on first crop maturity at harvest.

Generally, the second crop begins to initiate when the first crop approaches harvest moisture (18% to 21%). It is not uncommon to see second crop growth initiated prior to harvest of the first crop.

Shoots develop in the second crop as they do in the first crop. New leaves emerge through sheaths of leaves on the first crop stubble; eventually, internode formation occurs, followed by panicle initiation (PI) and panicle differentiation (PD), booting, heading, grain filling and maturity. Development of buds on the crown is essentially

the same process of tillering without the presence of a distinct primary shoot.

Second crop growth is small and much more variable in all aspects compared with the first crop. There are fewer leaves and internodes per stem, a shorter maturation period (time from bud initiation to heading) and shorter mature plant height. There are fewer panicles per acre and per plant and fewer grains per panicle. Second crop yields are generally less than 40% of first crop yields.

Second crop growth and development are limited by declining day length and falling temperatures at the end of summer and during the fall, which is opposite from the first crop that experiences mostly increasing day length and temperatures from planting to heading during the spring and early summer. The reduction in total sunlight translates to lower photosynthesis, which accounts in part for the lower yields. Reduced input costs often make ratoon cropping profitable despite lower yields.

Weed Management

Connor Webster and Eric Webster

Weeds are some of the most troublesome pests in rice production in the United States and throughout the world. Weeds compete with rice for water, nutrients, space and light. Direct losses from weed competition are measurable and can be great. Indirect losses such as increased costs of harvesting and drying, reduced quality and dockage at the mill and reduced harvest efficiency are not readily measured but can reduce profits. Therefore, weed control measures should encompass broad spectrum activity under different production practices and systems.

Numerous grasses, broadleaf weeds and sedges can be economically damaging in rice. It is estimated that more than 80 species belonging to more than 40 genera can be problem weeds in U.S. rice production. Rice weeds can grow and thrive in aquatic, semiaquatic and terrestrial environments. Some of the major weed problems, such as barnyardgrass, broadleaf signalgrass, red rice, hemp sesbania, alligatorweed, dayflower, jointvetch species and annual and perennial sedges, can thrive in both aquatic and dryland situations. Neally's sprangletop and rice cutgrass are grass weeds that have become more widespread over the past few years. These weeds and several other perennial grass species tend to be more common in reduced tillage areas or growing along levees.

In south Louisiana, a rice-crawfish rotation is a common practice, causing several weeds to become major problems as a result of the year-round aquatic environment associated with these production systems. Ducksalad, grassy arrowhead, common arrowhead, creeping burhead, pickerelweed and roundleaf mud-plantain require high moisture to germinate and are much more aggressive in aquatic situations. Perennial grasses, such as perennial barnyardgrass, knotgrass, brook paspalum and water paspalum, are becoming more of a problem in Louisiana rice production due to a rice-crawfish rotation and in areas of reduced tillage.

Although weeds vary in their ability to compete with rice, most fields contain a complex of weeds that will reduce yield and quality if an appropriate weed management strategy is not implemented. Rice weed control is best accomplished by using a combination of cultural, mechanical and chemical management practices. Relying on a single control practice seldom provides adequate weed management. A thorough knowledge of weeds present in each field is critical in developing appropriate management strategies.

Red Rice Management

The No. 1 weed problem in Louisiana rice production is red rice. Red rice has been spread largely by planting commercial seed that is contaminated with red rice and movement of equipment from infested fields to clean fields. Red rice is similar to commercial rice and is considered by many to be in the same genus and species. Commercial rice and red rice can readily cross, producing a wide phenotypic set of offspring. Besides reducing commercial rice yields, the red pericarp of this noxious plant can contaminate milled commercial rice. Additional milling can help remove the red discoloration but often will lead to reduced head rice yields through breakage of kernels. Cooking attributes of rice can be altered if significant amounts of red rice are present in milled rice.

The presence of red rice dictates production systems and weed control options and decreases flexibility. Rotating rice with other crops can reduce future weed problems. Successful rotations with soybean, corn, sorghum or cotton have reduced levels of red rice. In 2002, the development of Clearfield rice gave producers an option to plant rice that is resistant to the imidazolinone family of herbicides. Following the release of Clearfield rice, imidazolinone resistant hybrid rice was released and is now sold under the tradename FullPage. Imazethapyr (Newpath) was the first herbicide labeled for use in the Clearfield production system. This herbicide provides residual and postemergence activity on red rice and other grass and broadleaf weeds. Later the herbicide imazamox (Beyond) received a label for use as a late-season herbicide choice to control late emerging red rice and red rice plants that may have escaped an earlier imazethapyr application. In the FullPage production system, imazethapyr is sold under the tradename Preface, and imazamox is sold under the tradename Postscript.

As mentioned previously, red rice often crosses with commercial rice due to being in the same genus and species. Numerous populations of red rice throughout Louisiana have been confirmed to have crossed with imidazolinone resistant rice lines and have become resistant to imidazolinone herbicides themselves. In addition to outcrossing, hybrid imidazolinone resistant rice has an inherent seed dormancy characteristic with a high degree of seed shattering, and later generations often have weedy characteristic and are resistant to imidazolinone herbicides. In response to imidazolinone

resistant red rice populations, Provisia rice was developed with resistance to quizalofop (Provisia) which belongs to the aryloxyphenoxypropionate family. Quizalofop only provides postemergence activity of grass species, including red rice populations that are resistant to imidazolinone herbicides. Since the release of Provisia rice, an additional quizalofop resistant rice production system has been released under the tradename Max-Ace.

Herbicide Selection and Application

The most important factor in herbicide use is the selection of the proper herbicide. Producers should have a basic understanding and knowledge of the weeds present in production fields. Keeping visual and written records of each field from year to year is very important.

Six basic herbicide application timings should be considered when choosing a herbicide: (1) burndown prior to planting, (2) preplant incorporated, (3) preemergence prior to planting, (4) preemergence after planting, (5) delayed preemergence (drill seeded only) and (6) postemergence.

When selecting a herbicide, it is very important to understand the basic activity of the herbicide. If a herbicide has contact activity, it must be applied to weeds that have emerged above the soil surface and, in most cases, above the flood level. Most herbicides that require foliage contact should have at least 75% of the plant above the water line. A herbicide with soil activity should be applied when the soil surface is exposed. Herbicides like pendimethalin provide little to no benefit if applied to a flooded field. Many herbicides labeled for use in rice have both residual and postemergence activity. It is very important to take advantage of the entire package the herbicides can deliver.

Burndown Herbicide Application

Based on LSU AgCenter recommendations, burndown herbicides should be applied no earlier than six to eight weeks prior to planting and no later than three to four weeks prior to planting. If burndown herbicides are applied too early, weeds may be present at planting. Waiting too long before applying burndown herbicides may not allow enough time for herbicides to work properly prior to planting. This is a timing that is often missed in Louisiana because it is often made within one to two weeks prior to planting. Several herbicides are available for use as a burndown choice, and most options are applied based around glyphosate. Price is often factored in when selecting a burndown herbicide program, but in many cases, the cheapest option may not be the best for a given situation.

Preplant Incorporated Herbicide Application

The use of preplant incorporated (PPI) herbicides requires the application of a herbicide to the soil surface prior to planting followed by herbicide incorporation with a disk or a field cultivator. It is important for the field to be relatively free of vegetation and or large soil clods to allow for uniform herbicide application. Vegetation or soil clods can intercept the herbicide spray and prevent uniform application. It is important to apply the herbicide with adequate spray volume to insure a uniform application. When incorporating herbicides, the implement should be passed over the area twice, with the second pass running perpendicular or at an angle to the previous pass. When a highly water-soluble herbicide is used, incorporation can be achieved with water; however, incorporating with water can be inconsistent.

The number of acres receiving a PPI herbicide application in Louisiana has dropped drastically in recent years. This was an accepted practice for the management of red rice in south Louisiana. With the introduction of Clearfield/FullPage and Provisia/Max-Ace rice, the use of PPI treatments has been drastically reduced. The Clearfield and FullPage rice systems do have the option of a PPI application of imazethapyr (Newpath/Preface). When fuel costs are high and flushing is required to activate a PPI herbicide, the benefit of the PPI herbicide may be offset. In many cases, a PPI treatment provides better overall weed control, but with the additional costs, the added benefit is often unprofitable.

Preemergence Herbicide Application Prior to Planting

This practice is used on a regular basis throughout Louisiana, especially in water-seeded rice production in south Louisiana. The herbicide is applied prior to planting as a surface application frequently in conjunction with a burndown herbicide program. When applied in a burndown program, the preemergence herbicide works best if existing vegetation is small or the field area is sparsely vegetated.

In south Louisiana, producers often impregnate starter fertilizer with a herbicide with preemergence activity. The field is flooded for seeding; starter fertilizer is impregnated with the herbicide and then is either applied to the flooded field or to the field after seeding and draining. Herbicides with high water solubility wash off the fertilizer granule and make soil contact, thereby providing preemergence herbicidal activity.

Preemergence Herbicide Application Following Planting

This practice is used most often in drill-seeded rice. Immediately after rice is planted, a herbicide is applied to the soil surface. Within a 24- to 48-hour period after herbicide

application, adequate rainfall (1 inch or more) must occur or the field must be flushed for herbicide activation. Many producers attempt to avoid flushing by waiting on rainfall to save money; however, to receive optimum benefit from the herbicide, it must be activated by moisture. Efficacy is reduced the longer a herbicide remains on the soil surface without activation. Poor weed control is a common side effect of waiting for rainfall because weeds continue to grow during the waiting period.

A preemergence application can allow a rice crop to emerge and gain a competitive advantage on many weeds present in a given field. Producers should consider using preemergence applications on the majority of their farm to allow for more time before postemergence applications are needed and to potentially reduce the number of postemergence applications. If the producer has a basic knowledge of the history of weed pressure in a rice field, the grower can select fields most likely to benefit from a preemergence program.

Delayed Preemergence Herbicide Application

This herbicide application timing is primarily, if not exclusively, used in a drill-seeded rice production system. The rice crop is planted, and four to seven days after planting, the herbicide is applied. This delay after planting allows the rice seed to begin the germination process, allowing the young seedling to get an initial growth advantage prior to herbicide application. This application usually follows a surface irrigation or rainfall within the four- to seven-day interval after planting.

Postemergence Herbicide Application

Postemergence herbicide applications are those made any time after crop emergence. These applications include timings from very early postemergence on one- to two-leaf rice to salvage treatments applied late in the season to aid in harvest efficiency.

Postemergence herbicide applications are the most common timings for weed management in rice. Some postemergence herbicides have only contact activity, while others have both preemergence and postemergence activity. It is very important to understand the activity of the herbicide when selecting a postemergence herbicide. Postemergence herbicides almost always are most effective when applied to small actively growing weeds. The larger a weed the more difficult it is to manage with herbicides. A one- to two-leaf Texasweed is easier to control than a Texasweed with five to six leaves. When applying herbicides postemergence, it is important to avoid applications to weeds under any form of stress, especially moisture stress. Weeds that are not under moisture stress and are actively growing are controlled more easily than stressed weeds. This can also be true when temperatures are low enough to reduce plant activity or high enough to cause heat stress.

Weed Management Through Cultural Practices

Producers have several options available for managing weeds with cultural practices. These practices include conventional or reduced tillage, fallow versus crop rotation, rice cultivar selection, purchasing weed-free seed, water management, water- or drill-seeded rice planting systems, proper herbicide selection, timing of herbicide applications, herbicide application carrier volume and aerial versus ground herbicide application. While the use of herbicides to control weeds is not normally considered a cultural practice, the interaction of cultural practices with herbicide use must be considered.

Tillage and Rotation

In Louisiana, a strict no-tillage production system is rare; however, producers throughout the state practice both conventional tillage and reduced tillage or stale seedbed systems on their farms. Often, a producer will use a combination of these practices. Good records can determine which tillage practice should be used to manage each weed situation. Red rice can be managed through the use of stale seedbed or reduced tillage systems. Following harvest of a rice crop infested with red rice, not tilling the field will allow some red rice seed to decompose while lying on the soil surface. It also exposes the seed to depredation by wildlife. If the field is tilled, red rice seed will be buried and become dormant. The following spring a burndown herbicide may be employed once red rice has emerged.

In south Louisiana, the rice-crawfish rotation has caused changes in weed management strategies. Tillage is often used on a very limited basis in this type of rotation. In severe cases, this lack of tillage has caused the weed spectrum in these fields to shift from annual grasses and broadleaf weeds to perennial aquatic weeds. To manage some of these difficult-to-control aquatic weeds, the area must be tilled and be fallowed or rotated to another crop, such as soybean, to take advantage of conventional tillage and herbicide rotation.

Cultivar Selection, Planting Rates and Row Spacing

The most important aspect of cultivar selection from a weed management standpoint is selection of weed- free seed. Cultivar selection can also impact competition between rice and weeds.

Research has indicated some rice cultivars are more competitive with weeds than others. This is especially true of the once popular taller cultivars. Semidwarf varieties are

less competitive than conventional tall varieties. Cultivars that produce large numbers of tillers also tend to be more competitive.

All rice cultivars have an optimum seeding rate that varies, depending on growth characteristics. Research conducted in Louisiana indicates that cultivars planted at the optimum seeding rate tend to be more competitive with weeds than when planted at low seeding rates. High seeding rates can be competitive with weeds, but intra-specific competition occurs at excessive seeding rates and yields are reduced. Establishing a good stand of rice and providing an environment that promotes rapid growth helps to minimize weed interference. Optimum plant populations and adequate fertility, insect, disease and water management contribute to the ability of rice plants to compete with weeds.

Water Management

Proper water management is a key component in controlling weeds. Several different water management schemes have evolved in Louisiana, and two major planting systems dictate the basic water management strategies used by producers. Historically, a majority of Louisiana's rice is in southwest Louisiana and most of this acreage was planted using a water-seeded system prior to the commercialization of Clearfield rice. The introduction of Clearfield herbicide resistant rice has caused a shift from water-seeded to dry-seeded rice in southwest Louisiana. The remaining acreage is grown in northeast Louisiana where dry-seeding methods are more common.

Water-seeded rice. In general, weed spectrum changes from a predominantly annual grass problem in drill-seeded rice to more aquatic weed problems in a water-seeded system. If a water-seeded system is used for several years, it may cause a shift in the weed spectrum from terrestrial to aquatic weeds. The predominant weeds found in this production system are ducksalad, grassy arrowhead, common arrowhead, creeping burhead, pickerelweed and roundleaf mudplantain.

Three types of water management systems are used by producers: (1) continuous flood, (2) pinpoint flood and (3) delayed flood. See the General Agronomic Guidelines section for more information on water management systems.

Water seeding is strongly tied to weed management. Weed seeds have the same requirements for germination as rice – proper temperature, water and oxygen. By flooding a rice field before temperatures have risen to levels sufficient for germination, two of the requirements are at least minimized because over time the flooded soil will become saturated. Saturated soils have little dissolved oxygen in them; thereby reducing weed seed germination and emergence.

In a continuous flood system, aquatic weeds become a problem earlier in the season. For example, it is not unusual for ducksalad to emerge along with planted rice in a continuous flood system. When a pinpoint flood system is employed, the area is drained for a short period of time after planting, and aquatic weeds can be a problem. Red rice and annual grasses can begin to emerge if the drain period is long enough to allow oxygen to reach weed seeds. The object of a pinpoint flood is to allow for rice seedling establishment before the soil dries. If soil is allowed to dry, annual grasses and other terrestrial weeds can and will emerge. Annual grass weeds are less of a problem in continuous and pinpoint flood systems, but producers must manage a pinpoint system closely to prevent soils from drying.

The third water management system is a delayed flood in a water-seeded system. From a weed control standpoint, this is not as practical if producers intend to manage weeds by flooding. In most instances, aquatic weeds create fewer problems in this type of flood management. With the development of Clearfield rice, this flooding practice has become more common because producers now have the ability to use herbicides to control red rice and other annual grasses.

When a water-seeded system is used, herbicide applications are generally applied postemergence. Prior to the development of Clearfield rice, the herbicides thiobencarb and molinate were the only available herbicides that could be incorporated prior to planting. The development of herbicide-resistant rice, introduction of new herbicides and the loss of molinate have nearly eliminated the preplant incorporated applications. It is very important to apply postemergence applications in a timely manner, choose the correct herbicide and apply it at proper rates.

Dry-seeded rice – delayed flood. In this system, four to six weeks may elapse between planting and permanent flood establishment. Controlling weeds during this period is critical for maximizing yields. Annual grasses, such as barnyardgrass, broadleaf signalgrass and sprangletop species, and broadleaf weeds, such as Texasweed, eclipta, Indian jointvetch and hemp sesbania, can become established. Timely herbicide applications made to small weeds; surface irrigations, often referred to as flushes, to activate herbicides; and establishment and maintenance of a permanent flood as soon as possible will improve weed control. In south Louisiana, permanent floods are generally established on two- to three-leaf rice. In northeast Louisiana, permanent flood may not be established until rice is in the four-leaf to one-tiller stage.

In dry-seeded systems, constructing levees as soon as possible after planting can improve weed control by allowing fields to be surface irrigated and flooded in a timely manner. Without levees, using water as a management tool is impossible. On coarse textured, silt loam soils, establishing levees is much easier than on finer-textured, clay soils. Although rainfall shortly after planting is beneficial for establishing a stand of rice and reducing the need for surface irrigation, excessive rainfall can prevent levee construction on clay soils. Establishing levees as soon as the rice is planted, when the soil is still relatively dry, can prevent or reduce problems encountered in preparing levees on wet soils.

Management of weeds is critical for optimum rice production in both water- and dry-seeded systems. Although herbicide options and management strategies differ under these systems, managing herbicides and water in a timely manner is critical.

Dry-seeded rice – furrow-irrigated/row rice. In recent years producers in the northeast portion of Louisiana have started utilizing the furrows left behind from a previous crop such as cotton, soybeans, corn, etc. to irrigate rice, hence the name furrow-irrigated or row rice. This practice is primarily utilized to simplify crop rotations and has also become popular in Arkansas, Mississippi and Missouri. The benefits of using this production practice include reduced tillage, reduced levee construction, increased ground rig applications, increased harvest efficiency, and allows for rice to be grown on steeper grades. The disadvantages of this production system include increased weed control costs due to the need for more frequent herbicide applications because of the lack of cultural weed control from a permanent flood, higher risks of blast and bill bug infestations and oftentimes lower yields.

The biggest challenge from a weed management standpoint is the shift in the weed control spectrum. In furrow-irrigated or row rice the primary weed species that are observed tend to be weeds more commonly observed in row crop production such as Palmer amaranth, prickly side, crabgrass, goosegrass and Johnsongrass. Overall, producers should budget for at least one additional, if not two, herbicide applications and to be prepared to incorporate a residual herbicide with every application. The frequent flushes required in this production system promote weed germination and growth, so a proactive approach is needed to keep fields manageable.

Dry-seeded rice – alternate wetting and drying. In a typical rice production system, once the permanent flood is established, the flood is held continuously until the field is drained prior to harvest maturity. However, alternate wetting and drying has been shown to be effective in reducing methane gas emissions from rice fields. When this practice is correctly implemented there have been no yield reductions while greenhouse gas emissions have been reduced by as much as 50%.

Weed control programs must be considered where alternate wetting and drying will be utilized. Alternate wetting and drying of the soil can promote weed seed germination, whereas a permanent flood provides weed suppression.

Adjuvants and Spray Additives

Technology advances have brought about many changes in adjuvants. The standard adjuvants like nonionic surfactants (NIS) and crop oil concentrates (COC) have been around for years with little change in formulations. New surfactants, such as organo-silicone and methylated seed oils, and the addition of fertilizers, like urea, to NIS to improve herbicide uptake have made a major impact on herbicide application. Many herbicides depend on certain adjuvants to maximize activity, and producers and applicators should be familiar with the importance of proper adjuvant selection.

Postemergence herbicide performance can be greatly influenced by adjuvants. Adjuvant cost is much lower than the cost of a herbicide application, especially when several herbicides are applied as a mixture. Not using an adjuvant or selecting a poor-quality adjuvant can reduce weed control. Consult the herbicide label for recommendations of the proper type and rate of the adjuvant to use.

Weed Resistance to Herbicides

Some weeds have developed resistance to herbicides in Louisiana. In situations where weeds are not controlled with labeled rates of herbicides applied under environmental conditions that are favorable for herbicide activity, these weeds may be resistant. Repeated use of propanil has resulted in the development of biotypes throughout the Midsouth that are resistant to the herbicide. Aquatic weeds, such as ducksalad, have developed resistance to herbicides in all rice-growing states.

Changing herbicides and crops and applying herbicide mixtures with different modes of action may prevent or delay development of resistance in Louisiana. Rice producers in Louisiana have been fairly successful at keeping resistance problems to a minimum because of the lack of a standard program across the state. Production systems vary widely in Louisiana compared with other states, and this helps keep herbicide resistance manageable in Louisiana rice.

Rotating rice with soybean or other crops will allow use of soil-applied herbicides or postemergence grass herbicides that can control troublesome weeds. These herbicides have mechanisms of action that often differ from most

rice herbicides. If weed resistance is suspected, contact your LSU AgCenter Extension agent so that an alternative herbicide program can be developed, and resistance can be monitored. In addition to developing potential weed resistance, repeated use of a single herbicide will exploit the weakness of the herbicide and may shift the weed spectrum to weeds that may be more difficult to control. An example of this is the continued use of Facet (quinclorac)-only weed management program, resulting in a shift from barnyardgrass to sprangletop species as the primary annual grass weed.

Weed species found in Louisiana rice

Grasses

Annual

Amazon sprangletop (*Leptochloa panicoides*)
Barnyardgrass (*Echinochloa crus-galli*)
Broadleaf signalgrass (*Urochloa platyphlla*)
Fall panicum (*Panicum dichotomiflorum*)
Large crabgrass (*Digitaria sanguinalis*)
Junglerice (*Echinochloa colona*)
Nealley's sprangletop (*Leptochloa nealleyi*)
Red rice (*Oryza sativa*)

Perennials

Brook crowngrass/Brook paspalum (*Paspalum acuminatum*)
Creeping rivergrass (*Echinochloa polystachya*)
Knotgrass (*Paspalum distichum*)
Rice cutgrass (*Leersia oryzoides*)
Southern watergrass (*Luziola fluitans*)
Water paspalum (*Paspalum hydrophilum*)
Waxy mannagrass (*Glyceria declinata*)

Broadleaf

Annual

Cutleaf groundcherry (*Physalis angulata*)
Eclipta (*Eclipa prostrata*)
False pimpernel (*Lindernia* spp.)
Gooseweed (*Sphenolcea zeylanica*)
Hedge hyssop (*Gratiola* spp.)
Hemp sesbania (*Sesbania herbacea*)
Indian/rough jointvetch (*Aeschynomene indica*)
Indian toothcup (*Rotala indica*)
Ladysthumb (*Polygonum persicaria*)
Pennsylvania smartweed (*Polygonum pensylvanicum*)
Purple ammannia (*Ammannia coccinea*)
Redweed (*Melochia corchorifloia*)
Spreading dayflower (*Commelina diffusa*)
Texasweed (*Caperonia palustris*)

Aquatics

Alligatorweed (*Alternathera philoxeroides*)
Common arrowhead (*Sagittaria latifolia*)
Creeping burhead (*Echinodrous cordifolius*)
Ducksalad (*Heteranthera limosa*)
Grassy arrowhead (*Sagittaria lancifolia*)
Pickerelweed (*Pontederia cordata*)
Red ludwigia/March seedbox (*Ludwigia palustris*)
Roundleaf mudplantain (*Heteranthera reniformis*)

Sedges and Rushes

Bog bulrush (*Schoenoplectus mucronatus*)
Fimbristylis (*Fimbristylis littoralis)*
Rice flatsedge (*Cyperus iria*)
Spikerush (*Eleocharis* spp.)
White-margin sedge (*Cyperus flavicomus)*
Yellow nutsedge (*Cyperus esculentus*)

Amazon sprangletop

Leptochloa panicoides

Keys to Identification: Tufted summer annual; no hairs on leaf blade, keeled leaf sheath, long membranous ligule; seedhead is a long, narrow panicle.

Distribution: All Louisiana parishes. Native of Brazil.

Barnyardgrass

Echinochloa crus-galli

Keys to Identification: Smooth leaf and leaf sheath with no ligule; tuffed erect summer annual grass with fibrous root; seed often awned.

Distribution: All Louisiana parishes. Introduced from the Old World.

Broadleaf signalgrass

Urochloa platyphylla

Summer annual

Keys to Identification: Spreading growth habit; stem bent at nodes; hairy leaf blades on lower leaves; leaf sheath hairy along margin; membranous ligule fringed with hairs; seedhead two to six long racemes, distinctive.

Distribution: All Louisiana parishes. Native to southeast U.S.




Fall panicum

Panicum dichotomiflorum

Erect summer annual

Keys to Identification: Bent and branched nodes; leaf blade may be hairy on upper surface; membranous ligule; large panicle seedlhead.

Distribution: All Louisiana parishes.




Large crabgrass

Digitaria sanguinalis

Tufted summer annual

Keys to Identification: Dense hairs on leaf blades and sheaths; membranous ligule; prostrate stems with spreading habit and rooting at nodes.

Distribution: All Louisiana parishes.

Junglerice

Echinochloa colona

Keys to Identification: Smooth leaf and leaf sheath with no ligule; purple bands on leaf tufted erect summer annual grass with fibrous root; seed awnless.

Distribution: All Louisiana parishes.

Nealley's sprangletop

Leptochloa nealleyi

Keys to Identification: Erect annual 3-5 feet tall; small hairs on leaf sheath up to four-leaf stage, older plants smooth to slightly hairy on leaf sheath, keeled leaf sheath, short membranous ligule; tall and narrow seedhead, 10-20 inches long 1-1.5 inches wide.

Distribution: Southwest and southeast Louisiana parishes.





Red rice

Oryza sativa

Keys to Identification: Tufted summer annual; leaves long and rough; large triangular ligule; seedhead a loose erect panicle.

Distribution: All Louisiana parishes.




Brook crowngrass, brook paspalum

Paspalum acuminatum

Perennial grass

Keys to Identification: Solid stem; lacks hair, leaf blades wide in proportion to stem; membranous ligule; seedhead winged rachis.

Distribution: South Louisiana parishes.

Creeping rivergrass

Echinochloa polystachya

Aquatic perennial grass

Keys to Identification: Solid stem; leaf blades narrow in proportion to stem; ligule fringe of hairs; hairy nodes; seedhead loose panicle.

Distribution: Southern Louisiana parishes.

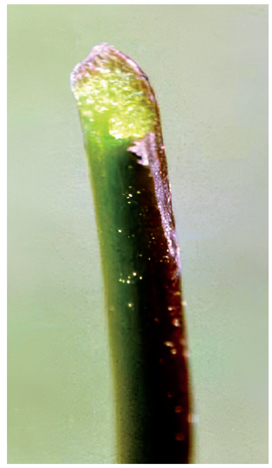
Knotgrass

Paspalum distichum

Perennial grass

Keys to Identification: Solid stem; leaf midvein not prominent; hairy nodes; leaf blade narrow in proportion to stem; membranous ligule with hair at collar region.

Distribution: All Louisiana parishes.



Rice cutgrass

Leersia oryzoides

Perennial

Keys to Identification: Long membranus ligule; upright growth pattern; pubescent (hairy) nodes; long course leaves; short stiff hairs growing downward on stem.

Distribution: All Louisiana parishes.

Southern watergrass

Luziola fluitans

Aquatic perennial grass

Keys to Identification: Floating slender stems; roots at nodes; short light green leaves less than 3 inches; membranus ligule.

Distribution: All Louisiana parishes.

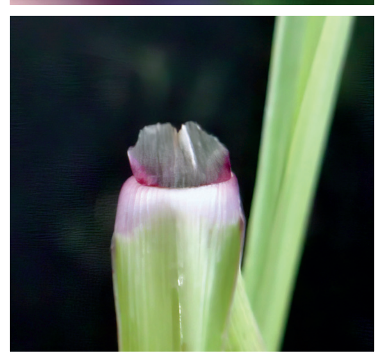
Water paspalum

Paspalum hydrophilum

Perennial grass

Keys to Identification: Hollow stem; prominent white leaf midvein; lacks hair at nodes; leaf blade wide in proportion to stem; membranous ligule.

Distribution: Southern Louisiana parishes.



Waxy mannagrass

Glyceria declinata

Perennial grass

Keys to Identification: Found in wet areas; tufted plant with upright growth; long membranus ligule.

Distribution: South Louisiana parishes.

Cutleaf groundcherry

Physalis angulata

Annual

Keys to Identification: Leaves alternate, lanceolate to ovate, edges coarsely irregular; berry fruit enclosed in an enlarged rounded calyx.

Distribution: All Louisiana parishes.




Eclipta

Eclipa prostrata

Annual

Keys to Identification: Erect to spreading; spatulate cotyledons; opposite, elliptic leaves, hairy on lower leaf surface, leaf margins slightly toothed; flowers are two solitary heads.

Distribution: All Louisiana parishes.





False pimpernel

Lindernia spp.

Annual

Keys to Identification: Mat-forming; leaves opposite, elliptic to ovate, sometimes pubescent; stems creeping, sometimes rooting at nodes.

Distribution: All Louisiana parishes, wetlands and flooded rice fields.

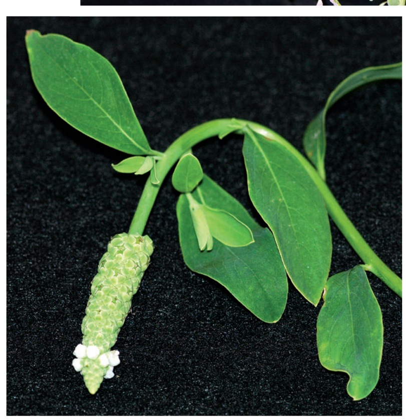
Gooseweed

Sphenoclea zeylanica

Annual

Keys to Identification: Erect, branching annual; leaves elliptic with smooth margins and varying in size; stems often contain a milky, watery sap and terminate in a dense spike with many small white flowers.

Distribution: All Louisiana parishes.



Hedge hyssop

Gratiola spp.

Annual

Keys to Identification: Erect, branching, herbaceous; leaves elliptic to ovate, sometimes finely serrated; stems often rooting at nodes.

Usually occurring in spring in rice field left flooded during the winter.

Distribution: All Louisiana parishes.

Hemp sesbania

Sesbania herbacea

Annual

Keys to Identification: Lance shaped cotyledons; first true leaf is simple; alternate, pinnately compound leaves with stipules; yellow petals on flower; distinctive curved seedpod.

Distribution: All Louisiana parishes.

Broadleaf Weeds

Indian/rough jointvetch

Aeschynomene indica

Annual

Keys to Identification: Ovate cotyledons; first true leaf pinnately compound; alternate pinnately compound leaves with lance shaped stipules; yellowish to reddish-purple flower petals; seedpod compressed, oblong and breaks into segments easily.

Distribution: All Louisiana parishes.

Indian toothcup

Rotala indica

Annual

Keys to Identification: Erect and branching; leaves opposite, lanceolate to spatulate; stems round to square.

Distribution: All Louisiana parishes in wetlands, ditches and flooded rice fields.

Ladysthumb

Polygonum persicaria

Annual

Keys to Identification: Erect or prostrate; lance-shaped cotyledons; leaves are lance shaped with pointed tips; stems are round and smooth with swollen nodes, ocrea surrounding nodes is fringed with hair-like bristles.

Distribution: All Louisiana parishes.

Pennsylvania smartweed

Polygonum pensylvanicum

Annual

Keys to Identification: Erect or prostrate; lance-shaped cotyledons; leaves are lance-shaped with pointed tips, usually with a purple watermark in the center of the leaf; stems are round and smooth with swollen nodes; ocrea lacks hair-like bristles.

Distribution: All Louisiana parishes.

Purple ammannia

Ammannia coccinea

Annual

Keys to Identification: Erect, herbaceous annual; reddish glabrous linear to linear-lanceolate cotyledons; leaves opposite, similar shaped, sometimes clasping; stems are square, slightly winged.

Distribution: All Louisiana parishes.

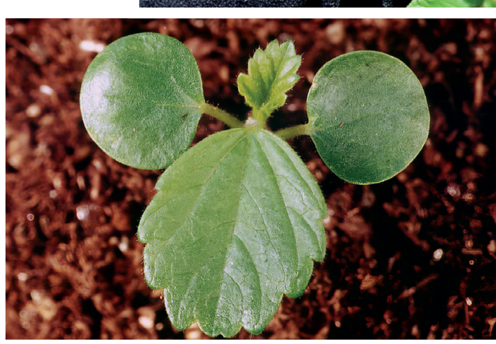
Redweed

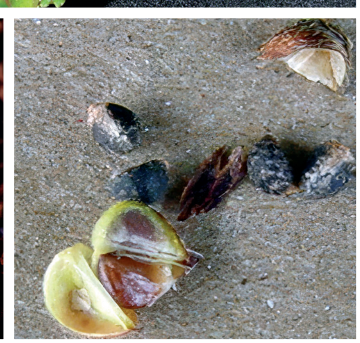
Melochia corchorifolia

Annual

Keys to Identification: Herbaceous; round cotyledons; ovate to lanceolate leaves with serrated margins; hairy stem; flower in compact head-like cymes.

Distribution: All Louisiana parishes.





Spreading dayflower

Commelina diffusa

Annual

Keys to Identification: Diffusely branching herbaceous annual; seedling unbranched, glabrous, grass-like; leaves glabrous, lanceolate, acuminate or acute; stems glabrous.

Distribution: All Louisiana parishes.

Texasweed

Caperonia palustris

Annual

Keys to Identification: Herbaceous annual, with smooth cotyledons and coarse hairy stems and petioles; alternate lanceolate leaves with serrated margins; monoecious plants (separate male and female flowers).

Distribution: All Louisiana parishes.

Alligatorweed

Alternanthera philoxeroides

Aquatic annual

Keys to Identification: Erect or prostrate; lance-shaped cotyledons; leaves are lance-shaped with pointed tips, usually with a purple watermark in the center of the leaf; stems are round and smooth with swollen nodes.

Distribution: All Louisiana parishes.

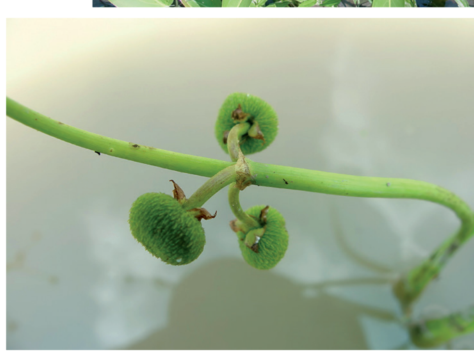
Bulltongue arrowhead

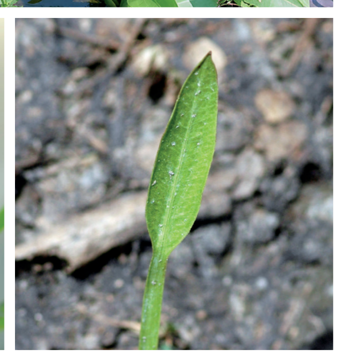
Sagittaria lancifolia

Aquatic annual

Keys to Identification: Erect aquatic perennial; leaves on long, spongy petioles, broadly elliptic to oblong-elliptic; flowers unisexual, with three white petals

Distribution: All Louisiana parishes in wetlands, ditches, flooded rice fields and pond edges.





Common arrowhead

Sagittaria latifolia

Aquatic perennial

Keys to Identification: Erect aquatic perennial; leaves variable on long, spongy petioles sagittate, three-lobed with basal lobes apicies varying from broadly obtuse to narrowly acute; flowers unisexual, with three white petals.

Distribution: All Louisiana parishes in wetland, ditches, flooded rice fields and pond edges.

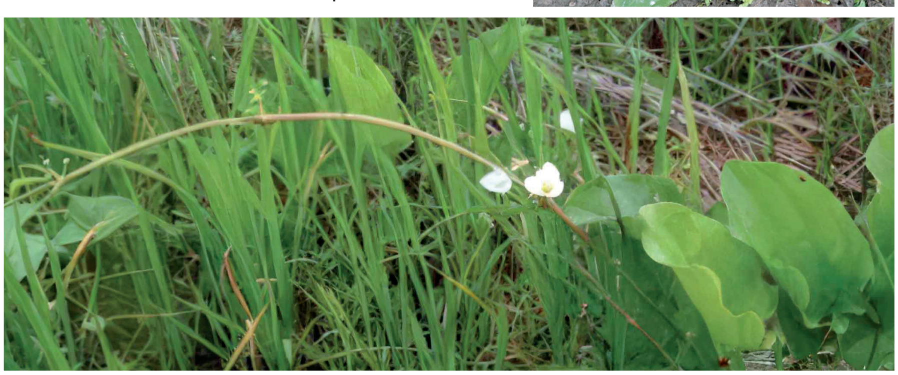
Creeping burhead

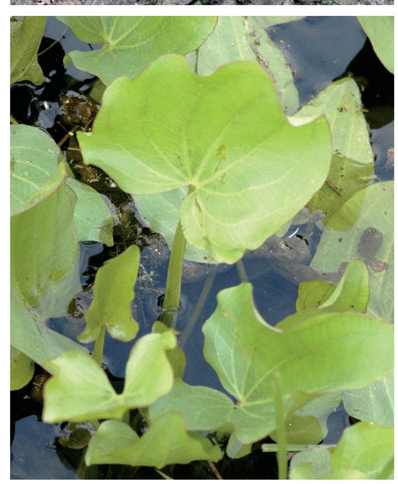
Echinodorus cordifolius

Aquatic annual/perennial

Keys to Identification: Leaf blades broadly ovate; petioles submerged with spongy cells at base; white flowers on arching scape.

Distribution: All Louisiana parishes.





Ducksalad

Heteranthera limosa

Aquatic annual/perennial

Keys to Identification: Tufted but spreading from rhizomes; leaves linear to oblanceolate; stems fleshy, rooting at the nodes; plants having a white or blue solitary flower.

Distribution: All Louisiana parishes.

Pickerelweed

Pontederia cordata

Aquatic perennial

Keys to Identification: Erect; leaves ovate to elliptical early, becoming cordate-sagittate; stems short, stout, somewhat succulent; flowers blue or lavender on a spike.

Distribution: All Louisiana parishes - wetlands, ditches, flooded rice fields and pond edges.

Red ludwigia/marsh seedbox

Ludwigia palustris

Perennial

Keys to Identification: Mat-forming, prostrate and creeping; leaves opposite, elliptic to ovate.

Distribution: All Louisiana parishes.

Roundleaf mudplantain

Heteranthera reniformis

Aquatic annual/perennial

Keys to Identification: Tufted but spreading from rhizomes; leaves linear early, becoming cordate or reniform; stems fleshy, rooting at the nodes; flowers multiple white or pale blue on a raceme.

Distribution: All Louisiana parishes.

Bog bulrush

Schoenoplectus mucronatus

Perennial

Keys to Identification: Herbaceous plant; erect, rhizomatous.

Distribution: All Louisiana parishes; wetlands, ditches and flooded rice fields.

Fimbristylis

Fimbristylis littoralis

Annual

Keys to Identification: Erect, two-ranked leaf arrangement. Young plants are extremely flat, and it begins to arrange itself in a whirl of flat fans. Entire plant is glabrous.

Distribution: All Louisiana parishes.

Rice flatsedge

Cyperus iria

Annual

Keys to Identification: Erect tufted annual; leaves three-ranked, linear-lanceolate; stems triangular, glabrous, multiple fruiting stems from plant base.

Distribution: All Louisiana parishes.

Spikerush

Eleocharis spp.

Annual/perennial

Keys to Identification: Rhizomatous, sometimes mat-forming plant; stems often round, sometimes square and smooth terminating in a single erect spike.

Distribution: All Louisiana parishes; wetlands, ditches and flooded rice fields.

Sedges and Rushes

White-margin sedge

Cyperus flavicomus

Annual

Keys to Identification: Similar to rice flatsedge in appearance but does not have a pine smell when the base of the plant is crushed. Young plants often times have a reddish tint to its roots. The underside of the leaves of a mature plant become very white leaving a green midvein. The tops of the leaves may also turn a silver-white color.

Distribution: Isolated parishes.

Photos by Tommy Butts, Arkansas Division of Agriculture

Yellow nutsedge

Cyperus esculentus

Perennial

Keys to Identification: Erect, colonial, perennial; leaves three-ranked, prominent midvein, gradually tapering to a sharp point; stems triangular, rarely branching, borne from a tuber or basal bulb.

Distribution: All Louisiana parishes.

Disease Management

Felipe Dalla Lana

Disease is a major factor limiting both yield and grain quality in rice production, accounting for nearly 20% of annual yield loss globally. In the United States, diseases typically result in a 3% to 10% annual yield reduction, with significant variation between seasons. This is partly attributable to advances in crop management technology and breeding efforts focused on disease resistance. Additionally, some major pathogens like certain viruses and bacteria, which cause severe yield losses in other rice-producing countries, are either absent or present in very weak, nonimpactful strains in the U.S.

Disease can damage rice production both directly and indirectly. Direct damage stems from the disease's impact on the plant itself, including reductions in yield components (number of panicles per area, number of kernels per panicle and kernel weight), as well as grain quality issues such as reduced milling yields, degraded grain appearance (discoloration and impurities) and mycotoxin contamination. Indirect damage arises from the costs associated with practices and choices made to mitigate direct disease damage. These include not only fungicide applications but also cultural practices, disease scouting services, and choices with opportunity costs, such as using more resistant but less productive varieties, reducing nitrogen fertilization or limiting crop rotation options.

Rice disease management using an integrated pest management (IPM) approach provides the best results, especially in the long term. Rice IPM employs multiple strategies to avoid or limit damage caused by diseases. These strategies can be classified into five principles: avoidance, exclusion, eradication, protection and host resistance.

- **Avoidance** involves managing the crop to avoid or minimize contact between the plant and the pathogen under conditions favorable for disease development. Examples include early planting to reduce blast risk or avoiding planting in areas with a history of disease problems.
- **Exclusion** aims to prevent the introduction of pathogens into an area or crop. This is often associated with regulations preventing the introduction of new pathogens into the country or region, but it also includes using pathogen-free seeds.
- **Eradication** is the elimination or reduction of pathogen levels already present in a region or field. This is often associated with strategies that manage crop debris or remove alternative hosts, such as crop rotation or tillage to destroy infected plants.
- **Protection** involves approaches that protect plants from infection or reduce the rate of disease development during the season. This typically refers to the use of fungicides, biocontrol agents or resistance inducers.
- **Host resistance** refers to the genetic resistance present in the plant. It does not require any action from producers and is considered the most efficient control method, as it generally does not incur additional costs and is more stable than other methods, which are more susceptible to execution errors.

Host resistance can be further divided into two categories: qualitative and quantitative.

- **Qualitative resistance**, also known as complete resistance, confers complete immunity to the plant. Many rice varieties exhibit this type of resistance to blast (caused by the fungus *Pyricularia oryzae*). Qualitative resistance is usually easier to breed, as it is typically associated with a single gene or a few genes. However, it is more susceptible to changes in the pathogen population, such as the emergence of pathogen strains with mutations that can overcome the resistance.
- **Quantitative resistance**, or partial resistance, refers to varieties that can still be infected and colonized by the pathogen, but at a lower rate than susceptible varieties. Alternatively, these varieties may experience less yield loss when infected (yield tolerance). This type of resistance is more stable against changes in the pathogen population, but it is harder to breed because it is associated with multiple genes, and the disease may still cause some damage to the crop.

The following section of this chapter will describe the most important diseases present in Louisiana, their symptoms and provide a brief overview of management methods. For the most up-to-date information, consult your LSU

AgCenter Extension agent and refer to Rice Varieties and Management Tips, an annual publication from the LSU AgCenter containing current research results and information on varietal resistance, fungicide application and cultural practices for managing rice diseases. This section was developed by modifying and expanding previous work done by Don Groth, Clayton Hollier and Milton Chuck Rush.

Rice Disease in Louisiana

In Louisiana and the U.S., although over 20 diseases have been reported on rice, only a few consistently cause significant yield and grain quality loss. The distribution and severity of these diseases are heavily influenced by the genetic resistance of the varieties, the initial inoculum and aggressiveness of the pathogen population, and environmental conditions, including weather and crop management practices. In plant pathology, this interaction is known as the "disease triangle" (host x pathogen x environment). Because this complex interaction can vary from season to season, or even field to field, the importance of each disease in terms of management also fluctuates. For clarity in this chapter, we categorize rice diseases into three groups based on their management requirements and economic impact.

Major diseases are those that frequently occur in Louisiana rice fields and have the potential to cause substantial yield and/or grain quality losses. This group includes sheath blight (*Rhizoctonia solani* AG1), blast (*Pyricularia oryzae*), Cercospora (*Cercospora janseana*), bacterial panicle blight (*Burkholderia glumae* and *B. gladioli*) and kernel smut (*Tilletia barclayana*).

Secondary diseases, while less prevalent than major diseases and typically observed at lower levels, can still cause significant economic losses under specific conditions. This group includes brown spot (*Bipolaris oryzae*), leaf scald (*Microdochium oryzae*), sheath rot (*Sarocladium oryzae*), sheath spot (*Rhizoctonia oryzae* [syn. *Waitea circinate*]), stem rot (*Nakataea oryzae*), crown sheath rot (*Gaeumannomyces graminis*), root rots (*Globisporangium spinosum, Pythium dissotocum,* and *Pythium* spp.), false smut (*Ustilaginoidea virens*), scab (*Fusarium graminearum*), grain discoloration (complex of species, including *Bipolaris oryzae, Cercospora janseana, Fusarium* spp., *Curvularia* spp., and many others), water mold (complex of species, including *Achlya* spp., *Pythium* spp., and *Fusarium* spp.) and seedling blight (complex of species, including *Bipolaris oryzae, Pyricularia oryzae, Cercospora janseana, Fusarium* spp., *Curvularia* spp., and others).

Minor diseases are those frequently observed in the fields but are usually not associated with significant yield losses. This group includes black kernel (*Curvularia* spp.), stackburn (*Trichoconiella padwickii*), leaf smut (*Eballistra oryzae*), sheath blotch (*Pyrenochaeta acicula*), white leaf streak (*Romularia oryzae)*, white tip (*Aphelenchoides besseyi*) and bacterial leaf blight-like (*Xanthomonas oryzae* pv. *oryzae*). Also included in this group are downy mildew (*Sclerophthora macrospora*) and root-knot nematodes (*Meloidogyne* spp.), two diseases that have been reported in Louisiana but are rarely observed in the fields.

The final group consists of diseases that pose a **potential risk** to Louisiana rice industry. This group includes bacterial blight (*Xanthomonas oryzae* pv *oryzae*), a major disease in Asia and Africa, although only weak strains of the pathogen were reported in Louisiana nearly 35 years ago. Hoja blanca (*Rice hoja blanca tenuvirus* or RHBV) is a major viral disease in parts of South and Central America. The disease was reported in Louisiana in the late 1950s but has not been reported since. However, populations of the vector, the rice delphacid (*Tagosodes orizicolus*), have been reported to be increasing in Texas. Finally, bakanae (*Fusarium fujikuroi*) is a major disease in Asia and has also been reported in California.

In the next section of this chapter, we will expand the description of these diseases, including their symptoms, disease cycles and management strategies, when available. Additional and updated information can be found through the LSU AgCenter and on the Rice Research Station website.

Major Diseases

Sheath Blight

Sheath blight is the most economically significant disease of rice globally. It is caused by the fungus *Rhizoctonia solani* AG1, which can also infect multiple other crops, such as soybean, corn, sorghum, sugarcane, and weeds. In soybean, it causes a disease referred to as aerial blight, often observed in fields with rice-soybean rotation. Sheath blight is endemic in Louisiana, where epidemics are frequent and often severe.

The soilborne disease can infect any above-ground tissue at any growth stage, but early symptoms are usually observed on the sheath near the waterline, where infection typically begins. The lesions on the sheath are approximately oval-shaped, around ⅓ to ½ inch long, water-soaked in appearance, and have a green-gray color. Under favorable conditions, the lesions rapidly expand to 1 to 1 ½ inches long, form a purple-brown border, and become whitish to pale green to whiteish (Figure 7-1, top left). The pathogen's mycelia can be observed on the leaf blades and sheaths when conditions favor disease spread (Figure 7-1, top center). On the leaves, the lesions are irregular, often referred to as having a snakeskin

appearance (Figure 7-1, top right). After heading, the disease can spread rapidly to the upper canopy, including the panicle, and to neighboring tillers and plants. The upper canopy leaves can become entangled and form a symptom called “bird’s nest.” In severe epidemics, tillers weaken and may lodge or collapse (Figure 7-1, bottom left). On susceptible varieties and under conducive conditions, large areas of the field may be compromised. As the plant matures or dies, the fungus starts to produce sclerotia, its survival structures. The sclerotia begin as a white mass of mycelia on the plant surface, which quickly develop into black to dark brown, irregular, ball-shaped structures that are easily detached from the plant (Figure 7-1, bottom right). The sclerotia can be viable for more than two years.

Figure 7-1. Sheath blight symptoms. Top left: Lesion on the base of the plant characterizing the vertical phase of the disease. Top center: Detail of *R. solani mycelia* in a rice tiller. Top right: Snakeskin symptom. Bottom left: Lodged plants due severe sheath blight. Bottom right: *R. solani sclerotia*, the survival structure of the fungus.

The disease cycle of sheath blight is divided into two phases: vertical and horizontal (Figure 7-2). The vertical phase starts when the initial inoculum, either sclerotia or infected crop residue buoyant on the water, infects the tillers at the waterline. From this point, the fungus starts to colonize the plant vertically. The horizontal phase is when the mycelia from the infected tillers spread to adjacent plants. As *R. solani* does not produce spores under normal conditions, the spatial pattern is aggregated, where often parts of the field are more heavily impacted than others.

Figure 7-2. Sheath blight disease cycle. (1) Initial infection of the base of the plant. (2) Disease progresses vertically up the same tiller. (3) Mycelia from a diseased plant spread to adjacent plants. (4) Severe epidemics can cause plants to collapse. (5) The pathogen overwinters in the soil as sclerotia, infected crop residue or on alternative hosts such as soybeans.

Conditions favorable for disease development include temperatures between 73 F and 95 F (optimal range is 86 F to 90 F), high relative humidity (greater than 95%), and cloudy conditions (low sunlight radiation). High plant populations favor disease spread by increasing plant-to-plant contact and creating a more conducive microclimate within the rice canopy. High nitrogen fertilization and short-statured rice varieties also favor disease development. Fields under rice-soybean rotation have a higher risk of sheath blight epidemics than rice-fallow or rice-crawfish rotations, as the soil inoculum density is usually higher in the first rotation.

Effective sheath blight management requires a comprehensive approach using IPM strategies, as relying on a single control method often yields unsatisfactory long-term results. To start, avoid crop rotations that can increase soil inoculum density. In fields with a history of sheath blight problems, avoid high plant populations and excessive nitrogen fertilization. While some rice varieties exhibit better resistance to sheath blight,

most are susceptible. Fungicides from the strobilurin or succinate dehydrogenase inhibitor (SDHI) groups have demonstrated good efficacy, though some fields may have strains less sensitive to strobilurin fungicides. It's crucial to apply fungicides with sufficient gallons per acres (GPA), following fungicide label recommendation, to ensuring thorough penetration within the canopy to protect potential infection points. For the most up-to-date information on fungicides and host resistance, consult the LSU AgCenter publication 2270, Rice Varieties and Management Tips, or contact your local extension agent.

Blast

Rice blast is considered one of the major and most destructive diseases on rice in Louisiana and worldwide. The disease is caused by the fungus *Pyricularia oryzae* (syn. *Magnaporthe oryzae*) and is frequently referred to with different names (leaf blast, collar blast, node blast and rotten-neck blast), depending on the infection point. While currently many varieties contain resistant genes that provide a stable protection from blast, several others are still susceptible to the pathogen. Moreover, *P. oryzae* is known for its high capacity to mutate, which could eventually overcome the rice resistance.

The disease can cause symptoms in all above-the-ground tissues, but it is less frequently observed on the sheath and culm. The leaves are more susceptible in earlier stages, and the leaves become less susceptible as it develops to elongation and reproductive stages. Leaf blast symptoms can vary depending on the age of the lesion and the variety. Overall, spots on leaves start as small white, gray or blue tinged spots that enlarge quickly under moist conditions to either diamond-shaped spots or linear lesions with pointed ends with gray or white centers and narrow brown borders (Figure 7-3). Under favorable conditions and susceptible varieties, the disease develops fast, the lesions coalescence and kill the leaves and eventually the whole plant. The flag leaf collar can also be infected forming a brown or chocolate-brown to gray lesion, and the flag leaf becomes detached from the plant as the lesion area becomes dead and dry (Figure 7-4).

Figure 7-3. Leaf blast. Left: early symptoms of leaf blast showing white and gray-green lesions. Right: Mature lesions showing brown to dark borders and whitish to gray colors with diamond or elongated shape.

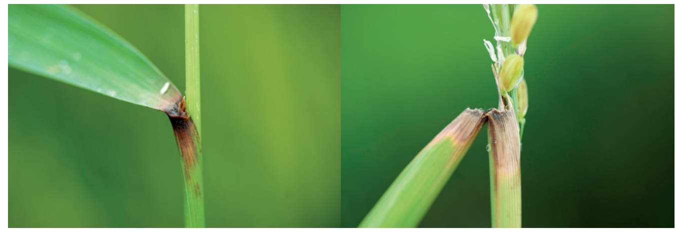


Figure 7-4. Collar blast. Left: *P. oryzae* infecting the flag leaf collar, causing a brown or chocolate-brown to gray lesion. Right: Older lesion causing the detaching of flag leaf from the sheath.

On node blast, the infected stem nodes turn black and become shriveled and gray as the plant approaches maturity (Figure 7-5). The infected area may turn dark purple to blue-gray because of the production of fungal spores. Culms and leaves become straw-colored above the infected node, as all tissue above the node infections dies. Plants lodge or break off at the infected point, or they are connected only by a few vascular strands.

Figure 7-5. Rice node blast. Left: *P. oryzae* infecting the flag leaf collar, causing a brown or chocolate-brown to gray lesion. Right: Older lesion causing the detaching of flag leaf from the sheath.

Rotten-neck symptoms appear at the base of the panicle starting at the node (Figure 7-6). The tissue turns brown to chocolate brown and shrivels, causing the stem to snap and lodge. If the panicle does not fall off, it may turn white to gray or the florets that do not fill will turn gray. Panicle branches and stems of florets also have gray-brown lesions.

Figure 7-6. Rotten-neck blast. Left: Panicles with symptoms of blast on the base of the panicle with different levels of severity. Right: Base of the panicle broken due *P. oryzae* infection.

The pathogen overwinters as mycelium and spores on infected straw and seed. Spores are produced from specialized mycelium called conidiophores and become wind-borne at night on dew or rain. The spores are carried by air currents and land on healthy rice plants. Warm day (around 80 F) and cool night (around 68 F) temperatures combined with leaf wetness and high humidity favor the infection. If the conditions remain favorable after the

infection, symptoms could appear as early as four days after, and new spores are produced two to three days after that, depending on the cultivar resistance level. Therefore, under highly favorable conditions, each disease cycle, from spore infection to a lesion producing new spores, can be as short as one week. Temperatures above 95 F or below 60 F, and low relative humidity (less than 70%) reduce the risk of blast development.

Blast is considered a bimodal disease, with two distinguishing phases where the disease is more prevalent: the foliar phase and the panicle phase. The plants are more susceptible to infection and disease development from germination to panicle differentiation; after this, leaves become less susceptible to infection. For the panicle phase, *P. oryzae* can infect the panicle from heading until the panicle tissue is mature, but earlier infection is more detrimental to yield than later. These phases are also epidemiologically distinct. The foliar phase is more associated with a polycyclic pattern; the epidemic feeds itself by producing spores that could reinfect other tissues of the same or nearby plants. The panicle phase is approximate to a monocyclic or bicyclic pattern, where the infected panicle will not be able to complete multiple cycles and produce spores to develop new infection sites. Some host resistance genes may have different levels of protection for each phase.

Some cultivation practices can also influence blast development. Nutritional imbalance, especially excessive N levels, can increase rice susceptibility. Late planting is also associated with a higher risk for disease development, as spores from infected fields are expected to be more abundant in the air in the late season. Rice susceptibility increases significantly under water stress caused by flood loss and flood delay, especially in the earlier stages of plant development.

Multiple genes that confer host resistance to blast have been identified and incorporated into commercial varieties available to producers in Louisiana. These genes can provide complete or partial resistance to blast. Several of these genes are specific to physiological races of the fungus; therefore, changes in the fungus population may result in a break of resistance. Producers are encouraged to inform LSU AgCenter Extension or research agents if symptoms similar to blast are observed on varieties that are expected to be resistant, as it may indicate a shift in the pathogen population.

Field scouting for blast should begin in the early stages of rice development. Special attention is advised for scouting susceptible varieties and parts of the field where conditions may favor disease development, such as high areas where the flood has been removed, lost or is shallow, or parts with heavy or excess N fertilization.

The use of resistant varieties is the most effective and affordable control method. However, even when blast-resistant varieties are used, producers are encouraged to scout the field for blast and maintain additional management practices that reduce the risk of the unexpected development of new physiological races that can overcome the resistance. For varieties susceptible to blast, it is advised that producers take extra precautions in advance. The field should be prepared in a way that a permanent flood of 4 to 6 inches can be maintained in all parts of the field, including edges and corners. Late planting and excessive N fertilization should be avoided. A limited number of fungicides from the strobilurin group are labeled to control blast. Consult the Louisiana Cooperative Extension Service for the latest information about rate and timing for fungicide applications.

Cercospora

Cercospora affects leaves, sheaths, panicles and grains. It is caused by the fungus *Cercospora janseana* and was previously referred to as narrow brown leaf spot. However, the recent discovery of a resistance gene that prevents leaf symptoms, but not those on the sheaths and panicles, has led to an expansion of the disease's nomenclature to include names for symptoms on sheath and panicle, similar to how blast diseases are named. Therefore, we now refer to the disease on the sheath as Cercospora net blotch and on the panicle as Cercospora panicle blight. The term narrow brown leaf spot is still used for leaf symptoms, and Cercospora is used as the overall disease name when the affected tissue is not specified.

Narrow brown leaf spot is characterized by short, linear, brown lesions that develop along the veins of leaf blades. In mature lesions, the center may turn gray (Figure 7-7). The severity of these symptoms can vary depending on the plant variety's resistance level. Cercospora net blotch, as the name suggests, presents with a distinct net blotch pattern on the sheath where cell walls appear dark brown, and the areas within the cells (intracellular areas) are tan to yellow (Figure 7-8). Cercospora panicle blight affects the base and branches of the panicle, causing dark brown lesions (Figure 7-9). This disease is associated with a range of detrimental effects, including premature ripening, chalkiness of grains, reduced milling yield, decreased kernel weight and overall lower grain yield. Additionally, *C. janseana* is one of the pathogens that cause grain discoloration.

Figure 7-7. Narrow brown leaf spot symptoms. Left: Elongated brown lesion on the leaf. Right: Mature lesions of Cercospora on the leaves.

Figure 7-8. Cercospora net blotch. Left: Elongated brown lesion on the leaf. Right: Mature lesions of Cercospora on the leaves.

Figure 7-9. Cercospora panicle blight. Left two photos: Base of the panicle infected by *C. janseana* with brown lesion symptoms. Right two photos: Panicle branches with symptoms of Cercospora panicle blight.

Cercospora was once a minor disease with sporadic occurrences and damage primarily limited to the second crop. However, its prevalence and intensity have increased significantly in recent years, causing substantial yield losses, even in the main crop. The disease cycle remains partially understood, but the initial inoculum is suspected to originate from crop residue or volunteer plants. Rice in crawfish ponds may contribute to the initial inoculum and facilitate the pathogen overwintering. *C. janseana* can infect plants at any growth stage, but symptoms typically appear in later stages, after heading. These symptoms are first observed on the lower leaves. The disease has a relatively long incubation period, often taking up to 30 days between infection and symptom appearance. Prolonged warm and wet conditions are associated with severe Cercospora epidemics.

Several factors can elevate the risk of Cercospora development, including late planting, imbalanced nitrogen fertilization (either excessive or deficient), and the presence of crop residue in the field. Fungicide applications have proven effective in reducing disease intensity, but population studies indicate that a portion of the pathogen population already carries mutations associated with fungicide resistance, particularly to strobilurin fungicides. Some rice varieties exhibit greater resistance than others, and good resistance is available for narrow brown leaf spot. However, the pathogen has demonstrated the ability to overcome genetic resistance in the past. For the most up-to-date information on variety classifications, fungicide timing, and application rates, consult the LSU AgCenter publication 2270, Rice Varieties and Management Tips, or reach out to your local extension agent.

Bacterial Panicle Blight

Bacterial panicle blight is one of the major diseases in southern U.S. rice production, and its prevalence has become significantly more prevalent in the last decade, emerging as a major threat to the industry. Outbreaks of bacterial panicle blight were registered in the 1995, 1998, 2000, 2011 and 2023 seasons, when environmental conditions favored disease development. For a long time, the etiology, the causal organism, was unknown, and the panicle blighting was associated with abiotic factors. But in the late 1990s, the gram-negative bacterium *Burkholderia glumae* was identified as the primary etiologic agent causing the disease. Later, *B. gladioli* was also identified as a causal agent of bacterial panicle blight, but less aggressive. Yield reductions are caused by the restriction of grain development. Yield loss will depend on the disease severity, variety, environment and management, and could range from trace amounts to up to 75% of yield loss. Globally, the disease is associated with close to 1% of annual yield reduction. The disease is also present in South and Central America, Africa and Asia. It is expected to increase in prevalence and severity in the future due to rising temperatures associated with climate change.

The disease symptoms can express as panicle blight, seedling blight and sheath rot. In the spikelet, a light grey to dark discoloration can be observed in the base of the glumes, with a reddish-brown margin between line separation from the rest of the spikelet that becomes straw-colored (Figure 7-10). It is common that an infected spikelet is colonized by opportunist saprophyte organisms once the lesion is mature. Other important diagnostic keys include the panicle rachis coloration remains green after the infection (Figure 7-11) and the presence of rotting rice embryos in some spikelets. The infection may be uneven in the panicle, and, on severely infected plants, the panicle will remain upright, instead of bent, as panicles with filled grains do, because of the weight of the grains (Figure 7-12). The pathogen forms a linear lesion on the flag-leaf sheath extending down from the leaf-blade collar. The lesion is distinct and has a reddish-brown border with the lesion center becoming necrotic and gray. The lesion may reach several inches in length. The panicle may have one to all of the florets blighted with grains not filling or aborted.

Figure 7-10. Early symptoms of bacterial panicle blight showing a darker line.

Figure 7-11. Rachis remains green in a panicle with symptoms of bacterial panicle blight.

Figure 7-12. Upright panicle with uneven infection.

The disease cycle is not completely understood. While infected seeds are considered the primary source of infection for new outbreaks and spread over long distances, some evidence suggests that soil and water can also harbor the bacteria. In the primary cycle, the bacteria move from the seed and roots to the upper canopy on the surface of the plant (epiphytically). However, recent research suggests this movement can also occur inside the plant (endophytically). Bacterial populations remain low during vegetative growth but rise sharply after heading, especially on the flag leaf and sheath. Under favorable conditions, the pathogen quickly infects and multiplies in the spikelets. The infection can completely block nutrients reaching the grain, causing reduced grain weight or abortion. Infected spikelets are often unevenly distributed within the panicle, but in severe cases, all grains can be compromised. Grains infected but showing no symptoms are not uncommon and are a concern for seed production. Rain splash, wind, and physical contact of the panicle with infected tissues can disperse the pathogen to nearby tillers, causing the circular patterns in the field (Figure 7-13) of plants frequently observed under favorable conditions for disease development.

Figure 7-13. Panicles with bacterial panicle blight symptoms showing a circle pattern in the field.

The disease management is limited options are limited. As it is primarily seed-borne, the use of pathogen-free seeds is the most important practice to reduce or manage the incidence of bacterial panicle blight. No pesticides are currently recommended for control of this disease in the United States. Several varieties have partial resistance (LSU AgCenter publication 2270, Rice Varieties and Management Tips).

Kernel Smut

The disease was for a long time considered a secondary or minor disease in Louisiana, but the disease has increased its prevalence and intensity, and it's now an important concern for the rice industry, especially related to grain quality. The disease is often not associated with significative impact grain yield, but on severe cases, yield reduction has been reported.

The disease is caused by the fungus *Tilletia barclayana*. Symptoms are observed at or shortly before maturity. A black mass of smut spores replaces all or part of the endosperm of the grain. The disease is easily observed in the morning when dew is absorbed by the smut spores. The spore mass expands and pushes out of the hull, where it is visible as a black mass (Figure 7-14). When this spore mass dries, it is powdery and comes off easily on fingers. At harvest, the spores from the smutted grains can cover the combine in fields with mild or severe epidemics (Figure 7-15, left). Rain washes the black spores over adjacent parts of the panicle. Affected grains are a lighter, slightly grayish color compared with normal grain (Figure 7-15, right). Smutted grains produce kernels with black streaks or dark areas. Milled rice has a dull or grayish appearance when smutted grains are present. Producers are often docked in price for grain with a high incidence of smut.

Figure 7-14. Symptoms of kernel smut. Left: A mass of spores (teliospores) replacing the kernel. Center: A mass of spores oozing from the hull. Right: Rice panicles with severe infection.

Figure 7-15. Left: Combine covered with spores of kernel smut. Right: Comparison between healthy and smutted grains.

Local spores of *T. barclayana* from the previous season act as the initial source of infection. Seeds can also transmit the spores between fields, but unlike other smut diseases, such as in wheat, the fungus does not infect the plant systemically. The spores remain dormant for four to five months on the field, and under favorable conditions, they germinate and produce another type of spore that can infect the rice flower. Note that the black spores observed on mature plants cannot directly infect rice. Frequent light rain around the flowering stage is often linked to a high incidence of the pathogen. Excessive nitrogen fertilization can also make the plant more susceptible.

Kernel smut is a challenging disease to manage, particularly if the crop experiences prolonged rain during flowering. Scouting for kernel smut is ineffective because symptoms only become apparent near harvest time. Rice varieties exhibit varying levels of susceptibility. Fungicide applications with triazoles are currently used for disease management, but results have been mixed. Recently, strains of *T. barclayana* with reduced sensitivity to propiconazole have been reported in Louisiana and Texas. For guidance on fungicide timing and application rates, please consult the LSU AgCenter publication 2270, Rice Varieties and Management Tips.

Secondary diseases

Brown Spot

In the past, brown spot was one of the most prevalent rice diseases in Louisiana and is still a major problem for many rice producer regions in the world. However, due to the advance of production technology and management improvement, brown spot is considered a minor disease in

Louisiana, more associated with nutritional status or other physiological disorders than the disease itself.

Brown spot is caused by the fungus *Bipolaris oryzae*, previously referred to as *Cochiobolus miyabeanus*. The primary inoculum is infected and infested seed and crop residue. The fungus infect rice from the seedling stage until maturity, affecting several tissues, the most common being leaves and glume, but symptoms can also be observed on sheath, panicle branches, coleoptile, and more rarely on the stem and roots from seedlings. The symptoms may vary depending on the resistance level. The symptoms of brown spot on leaves of susceptible varieties are characterized by oval or circular lesions with light brown to grey-whitish centers with reddish-brown borders (Figure 7-16, left). On moderate resistant varieties, or young lesions, the symptoms are smaller dark brown lesions (Figure 7-16, right). The symptoms on the leaves are more prevalent on senescence leaves. The spots on the leaf sheath and hulls are similar to those on the leaves.

Direct yield reduction associated with brown spot is not significant or very limited under normal production conditions in Louisiana. Infected grains may reduce the milling quality. A severe occurrence of brown spot is more likely to be associated with other physiology stress, often nutritional. Soils with deficiency of some nutrients, especially potassium, manganese, magnesium, silica, iron and calcium, have more prevalence of brown spot. Nitrogen can favor the disease development either on high or low levels. Other stress that limits the nutrient intake can also increase the susceptibility to brown spot.

Good rice management practices and proper fertilization are often enough to limit damage from the brown spot. A standard fungicide seed treatment is often effective to reduce the severity of seedling disease caused by *B. oryzae*.

Figure 7-16. Brown spot. Left: Disease symptom from mature lesions in a susceptible variety. Right: Small dark brown spots characteristic of young lesions or moderate resistant varieties.

Leaf Scald

This disease, caused by the fungus *Microdochium albescens oryzae*, is present in the southern rice-growing areas of the United States, including Louisiana. It affects leaves, panicles and seedlings. The pathogen is seed-borne, meaning it survives between crops on infected seeds. The disease typically appears on maturing leaves.

Lesions often start on leaf tips or from the edges of leaf blades (Figure 7-17). These lesions have a distinct zonate pattern, with alternating light (tan) and darker reddish-brown areas. The leading edge of the lesion is usually yellow to gold, giving fields a yellow or gold appearance. Lesions originating from the leaf blade edges have a less distinct, mottled pattern. Affected leaves dry out and turn straw-colored. When the panicles are infected, it causes a uniform light to dark, reddish-brown discoloration of entire florets or the hulls of developing grains. This can lead to sterility or the abortion of developing kernels. Currently, specific control measures for this disease are not encouraged. However, foliar fungicides used to manage other rice diseases may also have some effectiveness against this disease.

Figure 7-17. Leaf scald symptoms on leaves, starting from the tip (left) or from the side of the leaf (right).

Sheath Rot

This disease is caused by the fungus *Sarocladium oryzae*. Symptoms are most severe on the uppermost leaf sheaths that enclose the young panicle during the boot stage. Lesions are oblong or irregular oval spots with gray or light brown centers and a dark reddish-brown, diffuse margin (Figure 7-18), or the lesions may form an irregular target pattern. Early or severe infections can prevent the panicle from fully emerging from the sheath. These trapped panicles often rot, turning the florets dark brown. Grains from damaged panicles may be discolored reddish-brown to dark brown and may not fill properly. A powdery white growth, consisting of the pathogen's spores and hyphae, might be visible on the inside of affected sheaths. Insect or mite damage to the boot or leaf sheaths can worsen the impact of this disease.

While this disease affects most rice varieties and can cause significant yield losses, it usually affects only scattered tillers within a field. Therefore, specific control measures are not typically justified, as the disease rarely causes economic damage. However, fungicides used as part of a general disease management program can help reduce damage.

Figure 7-18. Sheath rot symptoms. Left and center: Panicle only partially emerged with dark reddish-brown lesion on the leaf and dark brown kernels. Right: Detail of rot panicle retained in the sheath.

Sheath Spot

This disease, caused by the fungus *Rhizoctonia oryzae*, resembles sheath blight but is typically less severe. The lesions produced by *R. oryzae* are found on sheaths midway up the tiller or on leaf blades (Figure 7-19). These lesions are oval, measuring 0.5 to 2 cm long and 0.5 to 1 cm wide. They have a pale green, cream or white center with a broad, dark reddish-brown margin. Unlike sheath blight, the lesions remain separate on the sheath or blade and do not coalesce into large, continuous areas of infection. In highly susceptible varieties, the pathogen can attack and weaken the culm (stem) beneath the sheath lesion. This weakening may cause the culm to lodge (bend over) or break at the infection point. Lodging caused by sheath spot are atypical and usually occurs midway up the culm.

The disease cycle is very similar to that of sheath blight, with the exception that the perfect stage of the fungus (*Waitea circinate*) is commonly observed in the field. In Louisiana, this disease is not usually associated with significant yield loss. However, some fungicides used to manage sheath blight may also help reduce sheath spot.

Figure 7-19. Sheath spot lesions.

Stem Rot

Stem rot, caused by the fungus *Nakataea oryzae*, is an important disease in Louisiana. Often, losses are not detected until late in the season when it is too late to initiate control practices. Stem rot can cause severe lodging, increase seed sterility and reduce grain filling.

The first symptoms are irregular black angular lesions on leaf sheaths at or near the water line on plants at tillering or later stages of growth (Figure 7-20, left). At later stages of disease development, the outer sheath may die, and the fungus penetrates to the inner sheaths and culm. These become discolored and have black or dark brown lesions. The dark brown or black streaks have raised areas of dark fungal mycelium on the surface and gray mycelium inside the culm and rotted tissues. At maturity, the softened culm breaks, infected plants lodge and many small, round, black sclerotia develop in the dead tissues (Figure 7-20, center). The sclerotia is small and produce at large numbers in the inner sheath and culm (Figure 7-20, right).

Figure 7-20. Stem rot. Left: Comparison between plants with stem rot symptom and healthy ones. Center: Lesions on the culm. Right: Sclerotia (survival structure).

The stem rot pathogen overwinters as sclerotia in the top few inches of soil and on plant debris. Once a permanent flood is established, the sclerotia rise to the water surface, contact plants, germinate and infect tissues near the waterline. The fungus then invades the inner sheaths and culm, often causing tissue death. After harvest, the fungus continues to develop, producing numerous sclerotia in the rice stubble.

Most commercial rice varieties are not resistant to stem rot. High nitrogen levels favor the disease, while early-maturing varieties tend to be less affected by stem rot. Potassium fertilization can reduce disease severity in potassium-deficient soils. Stem rot is particularly problematic in fields with a history of continuous rice cultivation, as inoculum levels are likely to be high.

Suggested management measures include using early-maturing varieties, avoiding highly susceptible varieties, managing crop residue after harvest to stop the sclerotia production, implementing crop rotation when possible, applying potassium fertilizer when needed and avoiding excessive nitrogen application. Foliar fungicides may offer

some control, but research on their effectiveness against stem rot is limited.

Crown Sheath Rot

Crown sheath rot is caused by the fungus *Gaeumannomyces graminis*. Other names for this disease include brown sheath rot, Arkansas foot rot and black sheath rot. It has been considered a minor disease of rice, but reports from Texas suggest that severe damage can occur. The pathogen kills lower leaves, thus reducing photosynthetic activity, causing incomplete grain filling and leading to plant lodging.

Symptoms appear late in the season, usually after heading. Sheaths on the lower part of the rice plant become discolored brown to black (Figure 7-21, left). Reddish-brown mycelial mats are found on the inside of infected sheaths (Figure 7-21, right). Dark perithecia are produced within the outer surface of the sheath. Perithecia are embedded in the sheath tissues with beaks protruding through the epidermis. This disease can easily be confused with stem rot.

The fungus survives as perithecia and mycelia in plant residues. The fungus produces spores (ascospores) that are wind-borne in moist conditions. Several weeds can serve as alternative hosts and may provide the initial inoculum for epidemic development. Heavy nitrogen fertilization may increase rice susceptibility. Fungicides from the strobilurin group may reduce the infection, but studies on chemical control for crown sheath rot are limited.

Figure 7-21. Crown sheath rot. Left: Lesions on a lower sheath. Right: Mycelia of *G. graminis* infecting rice.

Root Rots

Root rots in rice are caused by several species of oomycetes (fungi-like organisms), including *Globisporangium spinosum*, *Pythium dissotocum* and other *Pythium* species. The rice plant becomes susceptible to this disorder due to a combination of factors, such as physiological stress, insect feeding (especially rice water weevil larvae), extreme environmental conditions and other pathogens.

Symptoms may be noticeable as early as seedling emergence. Roots exhibit brown to black discoloration and necrosis (Figure 7-22). As the roots decay, nutrient absorption is impaired, leading to yellowing leaves and stunted plant growth. Severe root infections can cause plants to lodge due to lack of support, creating challenges during harvest. Often, plants with root rot also show severe brown leaf spot infections. The disease is referred to as feeder root necrosis when the small, fine roots and root hairs are destroyed on seedlings and young plants. In such cases, lodging does not occur, and symptoms may not be as apparent on the above-ground parts of the plant.

Applying fertilizer can often mask the above-ground symptoms, but the plant's ability to utilize nutrients is compromised. Controlling rice water weevil populations significantly reduces the incidence of root rots. Draining fields can stimulate new root growth but may increase the risk of blast disease, weed problems or inefficient nutrient uptake.

Figure 7-22. Root rot.

False Smut

False smut, caused by the fungus *Ustilaginoidea virens*, is not currently associated with significant yield losses in the United States. However, like kernel smut, it poses a concern for grain quality. Additionally, the disease can be severe on certain susceptible rice varieties and under favorable environmental conditions. Reports from other rice-producing regions suggest that this disease is becoming more prevalent globally.

The disease is characterized by the presence of large, orange to brown-green fruiting structures (sclerotia) on one or more grains (Figure 7-23). When the silvery covering of these structures ruptures, a mass of greenish-

black spores is exposed. The affected grain is replaced by these sclerotia.

Conditions that favor disease infection include rain and high humidity around flowering with warm temperatures. Late planting and excessive nitrogen fertilization can also increase the severity of the disease.

While there is variation in resistance among rice varieties, limited research has been conducted on this aspect due to the challenges in developing consistent and reliable inoculation methods, as well as the irregular natural occurrence of the disease. Fungicides from the triazole group are sometimes used to manage false smut, but their efficacy is not consistently high. Crop rotation, balanced nitrogen fertilization and early planting are also recommended practices to help manage the disease.

Figure 7-23. False smut.

Scab

Scab, caused by the fungus *Fusarium graminearum*, is a disease that is not usually associated with significant yield reduction in rice. The pathogen is present in all agricultural regions of the world and causes important diseases on other crops, such as Fusarium head blight in wheat and Gibberella ear rot in corn, which are associated with the production of mycotoxins. Although the disease is endemic in most rice-producing regions, its severity and intensity are usually low. However, the disease can cause bleached discoloration on the glumes or reddish-brown discoloration. The infected areas can produce a salmon-colored mass, consisting of the fungus's sporodochia and conidia. The disease can also infect branches of the panicle, limiting the translocation of nutrients. Spikelets infected by *F. graminearum* can become sterile or produce light, shrunken and brittle grains. Plants are most susceptible at flowering and less susceptible from the milk stage to maturity. The disease is favored by wet and warm conditions around flowering. No specific management is advised, and information on varietal susceptibility is usually not available.

Figure 7-24. Rice spikelet infected by *Fusarium graminearum*.

Grain Discoloration

Grain discoloration, also referred to as pecky rice or dirty rice, is caused by a complex of microorganisms. These include fungi like *Bipolaris oryzae*, *Cercospora janseana*, *Fusarium* spp., *Curvularia* spp., the bacterium *Burkholderia glumae* and many other microbes. Damage from the rice stink bug (*Oebalus pugnax*) can also cause kernel discoloration. Additionally, grains can become infected during storage, particularly by fungi such as *Aspergillus* and *Penicillium* species.

Many microbes can infect developing kernels, leading to spots and discoloration on the hulls or kernels. Kernels discolored by fungal infections or insect damage are commonly called pecky rice (Figure 7-25). High winds during the early heading stage can cause similar symptoms. Rainfall and high humidity during grain development favor disease severity. Lodging is also associated with an increased incidence of grain discoloration. In storage, maintaining moisture content below 14.5% is crucial to reduce the risk of infection.

Effective management of foliar, sheath and panicle diseases can help control grain discoloration. Controlling rice stink bug populations, implementing practices to prevent lodging, and harvesting and storing the crop at the proper moisture content are key to preventing grain discoloration.

Figure 7-25. Grain discoloration (pecky rice).

Water Mold

When using the water-seeding method for planting rice, it is challenging to achieve uniform stands of sufficient density for maximum yields. The most critical biological factor contributing to this difficulty is the water mold or seed rot disease complex, primarily caused by oomycetes (fungi-like microorganisms) of the genera *Achlya* and *Pythium,* as well as fungi of the genus *Fusarium*.

The severity of this disease is more pronounced when water temperatures are low (below 55 F) or unusually high (above 80 F). Low water temperatures slow the germination and growth of rice seedlings but do not affect the growth of these pathogens. Surveys conducted in Louisiana during the 1970s and 1980s revealed that an average of 45% of water-planted seeds were lost to water mold.

In addition to the direct cost of lost seeds and replanting, water mold also causes indirect losses through reduced competitiveness of rice with weeds in sparse or irregular stands. Furthermore, replanting or overseeding the field delays rice maturity, leading to less favorable conditions for high yields due to unfavorable weather and increased disease pressure.

Water mold can be observed through clear water as a ball of fungal strands surrounding seeds on the soil surface (Figure 7-26). After the seeding flood is removed, seeds on the soil surface are typically surrounded by a mass of fungal strands radiating outward from the affected seeds. This results in a circular copper-brown or dark green spot about the size of a dime with a rotted seed in the center. The color is caused by bacteria and green algae mixed with the fungal hyphae.

Figure 7-26. Water mold.

Achlya species (Figure 7-27, left) typically attack the endosperm of germinating seeds, destroying the food source for the growing embryo and eventually attacking the embryo itself. *Pythium* species (Figure 7-27, right) usually attack the developing embryo directly. When a seed is affected by the disease, the endosperm becomes liquefied and oozes out as a white, thick liquid when the seed is mashed. The embryo initially turns yellow-brown and finally dark brown. If affected seeds germinate, the seedlings' shoots and roots are attacked. If infection by *Pythium* species occurs after the seedling is established, the plant is stunted, turns yellow and grows poorly. If the weather is favorable for plant growth, seedlings can often outgrow the disease and avoid severe damage. The pathogens survive in the soil between seasons.

Figure 7-27. Water mold caused by *Achlya* spp. (left) and *Pythium* spp. (right).

The disease is less severe in water-seeded rice when weather conditions favor seedling growth. Temperatures averaging above 65 F are conducive to seedling growth, and water mold is less severe under these conditions. Seeds should be vigorous and have a high germination percentage. Seed with poor vigor will be more susceptible to damage by water mold fungi when water seeded.

Proper seed treatment reduces the damage caused by water mold. Water management is also crucial to minimize the impact of water mold. Avoid deep and continuous floodwater, as it slows seedling development. Employ practices that accelerate seedling development, such as using varieties with good vigor and avoiding planting during periods when cold temperatures may occur.

Seedling Blight

Seedling blight, or damping-off, is a disease complex caused by several seed-borne and soil-borne fungi, including species of *Bipolaris, Curvularia, Sarocladium, Fusarium, Rhizoctonia* and *Athelia*. Typically, the rice seedlings are weakened or killed by these fungi. Environmental conditions play a significant role in disease development, with cold, wet weather being most favorable to disease development.

Seedling blight causes stands of rice to be spotty, irregular and thin. Fungi invade the young seedlings, either killing or injuring them. Blighted seedlings that emerge from the soil die soon afterward. Those that survive are generally weak, yellow or pale green, and unable to compete well with healthy seedlings.

The severity and incidence of seedling blight depend on three factors: (1) the percentage of seed infested with seed-borne fungi, (2) soil temperature and (3) soil moisture content. Seedling blight is more severe on rice that has been seeded early when the soil is usually cold and damp. The disadvantages of early seeding can be partially mitigated by seeding at a shallow depth. Conditions that tend to delay seedling emergence favor seedling blight. Some blight fungi that affect rice seedlings at the time of germination can be controlled by treating the seed with fungicides.

Seeds carrying blight fungi frequently have spotted or discolored hulls, but seed can be infected and still appear clean. *Bipolaris oryzae*, one of the primary causes of seedling blight, is seed-borne. A seedling attacked by this fungus has dark areas on the basal parts of the first leaf (Figure 7-28).

If rice seed is sown early in the season, treating the seed is likely to be crucial in achieving a satisfactory stand or avoiding the need to replant. Little benefit is gained from treating rice seed sown late in the season unless unfavorable weather prevails.

The soilborne seedling blight fungus, *Athelia rolfsii,* kills or severely injures large numbers of rice seedlings after they emerge when the weather is humid and warm. A cottony white mold develops on the lower parts of affected plants. This type of blight can be controlled by flooding the land immediately.

Seed treatment with a fungicide is advice to improve or ensure stands. Proper cultural practices for rice production, such as optimal planting dates or shallow seeding of early-planted rice, will reduce damage from seedling blight fungi.

Water- and soilborne fungi in the genus *Pythium* attack and kill seedlings from germination to about the three-leaf stage of growth. Infected roots are discolored brown or black, and the shoot suddenly dies and turns straw-colored. This disease is most common in water-seeded rice, and the damage is often more visible after the field is drained. It may also occur in drill-seeded rice during prolonged wet, rainy periods.

Seed treatment, using seeds with good vigor, planting when temperatures favor rapid seedling growth and draining the field are the best management practices for seedling disease control.

Figure 7-28. Seedling blight caused by *Bipolares oryzae*.

Minor diseases

Black Kernel

Black kernel is considered a secondary and relatively minor disease in Louisiana. Ten species from the fungal genus *Curvularia* have been reported to cause black kernel, with *Curvularia lunata* being the most prevalent. The fungus develops its spores on the surface of the hulls (Figure 7-29), a key distinction from kernel smut, where the spores are produced between the hulls and ooze out. The fungus can cause grain discoloration, and after milling, the kernels may appear black. In severe infections, the fungus can cause seedling blights or weaken seedlings. The infection is believed to occur at flowering, but the disease cycle is not fully understood. This disease is rarely severe enough to justify specific management practices. Seed treatments used to manage other diseases should provide sufficient protection against seedling damage. No other specific management measures are necessary.

Figure 7-29. Spikelet with symptoms characteristic of black kernel.

Stackburn

Stackburn or Alternaria leaf spot, caused by the fungal pathogen *Trichoconiella padwickii,* is a common disease affecting rice worldwide. It is prevalent in most rice fields in Louisiana. While typically only occasional spots are observed, the disease can be more severe in localized areas of a field. The spots are characteristically large (0.3 to 1 cm in diameter), oval or circular, with a dark brown margin or ring surrounding them (Figure 7-30). The center of the spot is initially tan and eventually becomes white or nearly white. Mature spots have small, dark or black dots in the center, which are sclerotia of the fungus. Grain or seeds affected by the disease exhibit tan to white spots with a wide, dark brown border. The disease can cause discoloration of kernels or disrupt kernel development, resulting in shriveled grains.

This fungus is the most common seed-borne fungus in Louisiana and can also cause seedling blight. In Louisiana, it is more frequently found on panicles and grain than on leaves. No specific management practices are currently available for stackburn, but seed-protectant fungicides can help reduce seedling blight caused by this pathogen and limit the number of spores available to initiate leaf infections.

Figure 7-30. Stackburn symptom on the rice leaves.

Leaf Smut

Leaf smut, caused by the fungus *Eballistra oryzae*, is a widely distributed but minor disease of rice. The fungus produces slightly raised black spots (sori) on both sides of the leaves (Figure 7-31), as well as on sheaths and stalks. The blackened spots are typically 0.5 to 5.0 mm long and 0.5 to 1.5 mm wide. Numerous spots may be present on a single leaf, but they remain distinct from one another. Heavily infected leaves turn yellow, and their tips may die and turn gray.

The fungus spreads through airborne spores and overwinters on diseased leaf debris in the soil. Leaf smut tends to occur late in the growing season and generally causes little to no yield loss. Therefore, control measures are not typically recommended.

Figure 7-31. Leaf smut symptom on the rice leaves.

Sheath Blotch

This fungal disease primarily affects the leaf sheaths, particularly the flag-leaf sheath near the collar. The lesion typically begins at an edge of the sheath and expands to form an oblong blotch. While it can grow to cover the entire sheath, it is usually restricted and develops a zonate pattern (Figure 7-32). This characteristic distinguishes it from sheath rot caused by the fungus *Pyrenochaeta acicula*. Numerous black fruiting structures (pycnidia) are visible within the lesion. Generally, this disease is not severe or widespread enough to necessitate control measures.

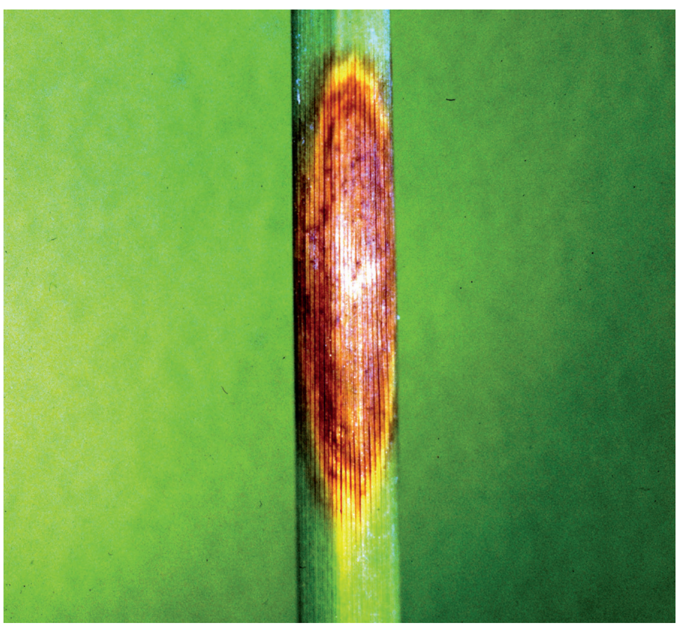


Figure 7-32. Sheath blotch symptom.

White Leaf Streak

White leaf streak, caused by the fungal pathogen *Romularia oryzae*, exhibits symptoms very similar to narrow brown leaf spot caused by *Cercospora janseana*. The key difference is that white leaf streak lesions are slightly wider and have distinctive white centers (Figure 7-33). Although this disease is common on leaf blades in some years, it is generally not severe enough to require control measures.

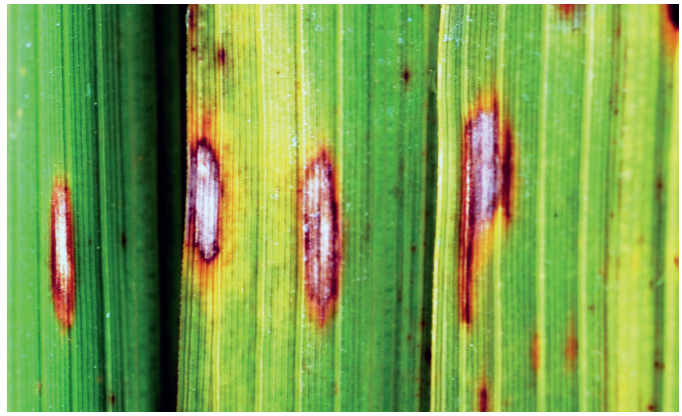


Figure 7-33. White leaf streak symptom.

White Tip

This disease is caused by the nematode *Aphelenchoides besseyi*. Characteristic symptoms, typically appearing after tillering, include yellowing of leaf tips, white areas on portions of the leaf blade (Figure 7-34), stunting of affected plants, twisting or distortion of the flag leaf, and distortion and discoloration of panicles and florets. Leaf tips progress from green to yellow and eventually white. The tip then withers above the white area, turning brown or tan and becoming tattered or twisted. Even resistant varieties may exhibit some symptoms and experience yield loss. The nematode infects the developing grain and is seed-borne.

While this disease is endemic in Louisiana, it is generally considered a minor rice disease. Fumigating stored seeds can help reduce the nematode population. Currently, no other specific control measures are recommended.

Figure 7-34. White tip, nematode *Aphelenchoides besseyi*.

Downy Mildew

Downy mildew, caused by the fungus *Sclerophthora macrospora*, affects rice plants in their early growth stages. Infected seedlings become dwarfed and twisted,

exhibiting chlorotic (yellow to whitish) spots. Symptoms are most severe on the panicle, which, due to failure to emerge properly, becomes distorted, resulting in irregular, twisted and spiral-shaped heads that retain their green color longer than usual (Figure 7-35). This disease is extremely rare, and no control measures are currently recommended.

Figure 7-35. Downy mildew in rice.

Root-Knot Nematodes

Species of the nematode *Meloidogyne* cause root knot. Symptoms include enlargement of the roots and the formation of galls or knots (Figure 7-36). The swollen female nematode is in the center of this tissue. Plants are dwarfed, yellow and lack vigor. The disease is rare and yield losses low. The nematode becomes inactive after prolonged flooding. No control measures are recommended.

Figure 7-36. Root-knot nematodes.

Bacterial Leaf Blight-Like

Bacterial leaf blight is caused by the bacterium *Xanthomonas oryzae* pv. *oryzae*. It was first identified in the United States in Texas and Louisiana in 1987. At the time, additional testing proved the bacterium was not the severe strains found elsewhere, such as in Asia and Africa. No major losses have been associated with this disease in the United States, but bacterial leaf blight in other parts of the world causes severe yield loss, as much as 70%, and is associated with a global rice yield reduction of 2.7%.

The primary source of inoculum is rice stubble or weeds that serve as alternative hosts between seasons. The pathogen can also survive on infected seeds and soil for a short time, and the epidemiology relevance of these sources of inoculum is questionable. The pathogen is spread by wind-blown rain, irrigation water, plant contact and plant debris on machinery. Once on the plant, the bacteria infect the hydathodes (pores on the leaf that secrete water – guttation), alternatively wounded tissue on the leaves or roots can also serve as a point of infection. *X. oryzae* pv. *oryzae* colonize and multiply on intercellular rice tissue. The bacterial ooze produced by infected plants serves as a secondary inoculum, spreading the disease to other plants. High humidity and temperatures between 77 F to 86 F favor the disease development. Rain and strong winds increase the dispersion of the pathogen in the field and can cause wounds in the plant, which will serve as an entry point for the bacteria. Heat stress, higher N fertilization, deep water and high plant population are also associated with more severe epidemics.

Characteristics symptoms started as water-soaked areas appear on the leaf margins near the tips, enlarge, and turn white to yellow. As the lesions mature, they expand and turn white (Figure 7-37). Eventually, opportunist saprophytic organisms can colonize the dead tissue and frequently can turn the lesion to a gray coloration. Accurate identification is important since the symptoms can be confused with other diseases, especially leaf scald, herbicide damage and other plant stress.

There is no specific management for bacterial leaf blight in Louisiana, as the disease is not commonly observed in the region, and it is not associated with yield losses under current southern U.S. conditions. However, more aggressive strains can be introduced to the state, therefore, the monitoring of the status of this disease is very important. Growers are encouraged to contact the local LSU AgCenter Extension agent if they suspect this disease is present in the field. In regions where an aggressive population of *X. oryzae* pv. *oryzae* is present, the use of resistant varieties is the most effective method to mitigate the detrimental effect of the disease, although even resistant varieties can be infected by the pathogen. Cultural methods, such as management of the rice straw, rotation with no host crop, avoiding fields with historical problems, use of adequate levels of N fertilization and

shallow water, are also associated with improved disease control. Chemical and biological control were not tested under field conditions in the U.S.

Figure 7-37. Bacterial leaf blight. Photos by knowledgebank.irri.org

Considerations for Disease Management

While each rice disease may have an optimal management strategy, producers must often manage multiple diseases simultaneously using limited resources and facing economic, practical and legal constraints. The decision-making process needs to account for these limitations, consider the uncertainty of available information and anticipate future events. To facilitate this process, we propose a framework with six components that growers, agricultural consultants and stakeholders can utilize when making decisions about disease management:

1. **Field disease history**: Several diseases produce inoculum that overwinters and accumulates in the field. Also, a site may also have unique conditions that either favor or not disease development. By considering the prevalence and intensity of diseases in previous seasons, it's possible to anticipate which diseases might be of greater concern for a specific field. For example, a field under soybean-rice rotation is likely to have a higher risk of sheath blight than a crawfish-rice rotation. This is because sheath blight is a soilborne disease, and soybean is a host for the pathogen (*R. solani*). Therefore, more viable inoculum is expected to be present, increasing the risk of infection in rice. However, this doesn't guarantee that soybean-rice rotations will always experience severe sheath blight epidemics or that crawfish-rice rotations will be problem-free. It simply suggests a higher likelihood of issues in the former due to the pathogen's biology.
2. **Varieties' resistance and seed quality**: Host resistance is the most effective and economical way to manage diseases. Consider the disease resistance package of the variety you intend to plant and its implications for your disease management strategy. Also, high-quality seed with good vigor and free of disease is crucial for successful disease management.
3. **Crop management**: Planting date, fertilization practices, plant density and tillage practices (till vs. no-till) all significantly impact disease development in the field. Consider how your crop management decisions might affect the overall health of your crop.
4. **Weather**: While we can't control the weather, we can monitor and adapt disease management strategies based on past and predicted weather patterns. For example, you may consider delaying or anticipating a fungicide application based on the weather forecast.
5. **Disease intensity**: As mentioned earlier, while various diseases may be present, they often don't cause significant yield or grain quality losses. Even for diseases known to have a substantial impact, their severity might be below the economic threshold for intervention.
6. **Yield expectation and market:** Crop prices can fluctuate considerably in a short period. A management practice, such as fungicide application, might be economically profitable at one price point but not at another. Also, consider the target market for your crop (e.g., seed production, specialty grains) and the current condition of your crop. Assess whether additional inputs (financial or labor) are likely to provide a sufficient return on investment.

Disease management can be complex, especially for a crop like rice in Louisiana, where the weather is highly conducive to disease development and management tools are limited. If you have any questions about disease management, please contact your nearest LSU AgCenter Extension office or the Rice Research Station.

Invertebrate Pest Management

Blake Wilson

The major invertebrate pests of rice in Louisiana are the rice water weevil, a complex of stem borers and the rice stink bug. In addition, armyworms, chinch bugs, bill bugs, colaspis, the rice leaf miner and the South American rice miner can be important rice pests. Sporadic pests rarely reaching damaging levels include stem feeding stink bugs, skippers and grasshoppers. Thrips, aphids and other invertebrates can occasionally be found on rice but are not considered pests. This section contains information about the identification, life cycle, injury to rice and current scouting and management practices for these pests. The scouting and management recommendations are based on the best available information and will be modified as additional research is conducted. If you suspect insect injury in your field(s), contact your county agent for verification and help with insect management and damage assessment.

The preferred approach to controlling insect pests is by developing and following an integrated pest management plan (IPM). IPM is the integration of a variety of pest control strategies to effectively maintain a pest insect population at densities below the economically damaging levels. An effective IPM plan relies on knowledge of the important pest species attacking the crop and utilization of a variety of control tactics. These tactics can include cultural practices, application of insecticides, biological control and breeding for resistance. The use of a variety of control strategies can result in a more effective and less expensive control program. Cultural control strategies include such practices as water and weed management. Resistant rice varieties may have the ability to tolerate insect infestations or may be more difficult for insects to feed and develop on. The use of insecticides with varying modes of action remains a vital component of the management program for most rice pests, but use of insecticides and miticides ideally should be limited because insecticides disrupt natural controls, can affect nontargets and are expensive. In addition, if an insecticide is used repeatedly within a season, insects can develop resistance to this product, making it ineffective for controlling insects. To avoid the development of resistance, it is important to use a variety of means to control insects. The products, which are discussed in this section, have varying levels of toxicity to crawfish and extreme caution should be used when controlling insects in rice fields which are near crawfish ponds.

The first step in effective IPM is to properly identify the insect attacking the crop. Once the pest has been identified, it is important to develop an understanding of the life cycle of the pest and how it damages the crop. Finally, a well-thought-out plan must be developed to effectively manage the pest while continuing to utilize best management practices. For this reason, it is very important to be familiar with your field and what complex of diseases, insects and weeds exists in the particular agroecosystem.

Rice Water Weevil

Lissorhoptrus oryzophilus **Kuschel**

Description and Life Cycle

The rice water weevil is the most important insect pest of rice in Louisiana and throughout the Midsouth U.S. The pest is ubiquitous throughout Louisiana's rice growing regions and damaging infestations are common. Yield losses in excess of 25% can occur from severe infestations. A management program should be implemented in every rice field, every year to avoid losses.

Figure 8-1. Adult rice water weevil.

Rice water weevil adults are grayish-brown weevils (beetles) about 1/8 inch long with a dark brown V-shaped area on their backs (Figure 8-1). Adults of this insect emerge from overwintering sites beginning in early April in southern Louisiana and later in northern Louisiana. Adults then fly to rice fields, where they feed on young rice leaves. This form of injury is not economically important except under unusually heavy infestations or prolonged cold springs when rice grows slowly. Oviposition (egg-laying) commences when standing water is present in a field that is infested with adults. This condition is usually met immediately after a permanent flood is applied to a field. Young rice is preferred for oviposition. White, legless, C-shaped larvae with small brown head capsules emerge from eggs in about seven days. After eclosing (hatching) from eggs, larvae (Figure 8-2) burrow into the mud and begin feeding on the roots of rice plants. The larvae continue to feed in or on the roots of rice plants and weeds in and around the field developing through four instars in about 27 days. Larvae increase in size with each succeeding molt. Fourth instar larvae are about 3/16 inch long. Peak larval density occurs three to five weeks after flooding. Mature larvae pupate, and oval pupae remain attached to the roots until adult emergence. Pupae are covered with a compacted layer of mud and resemble small mud balls when roots are cleaned (Figure 8-3). Adults then either migrate to surrounding rice fields or overwintering sites.

Figure 8-2. Rice water weevil larva (root maggot).

Figure 8-3. Rice water weevil pupae.

Rice water weevils overwinter as adults in grass clumps and ground debris near rice fields and in wooded areas. A degree day model based on historical records of weevil emergence from overwintering was recently developed to predict adult emergence. According to this model, emergence from overwintering sites usually begins in the first two weeks of April in southwestern Louisiana. Adults emerging from overwintering will invade either unflooded or flooded rice fields and begin feeding on the leaves of rice plants. One key aspect of the biology of female rice water weevils is that females do not lay many eggs until fields are flooded. In unflooded fields, females may lay eggs in areas of fields that contain standing water, such as low spots, potholes or tractor tire tracks. Application of the permanent flood is a trigger for females to lay numerous eggs in leaf sheaths of rice plants. Females deposit white, elongate eggs in the leaf sheath at or below the waterline. In addition to rice, adult rice water weevils will oviposit in most aquatic grasses and sedges, including barnyard grass, fall panicum, red rice, yellow nutsedge and broadleaf signalgrass. Thus, the presence of these weeds on levees surrounding rice fields may make the fields more susceptible to attack by rice water weevil adults.

The life cycle from egg to adult takes about 30 days. The length of the life cycle is temperature-dependent, however, and can vary from 25 to 45 days in warm and cool weather, respectively. The number of generations per year varies with latitude. As many as three to four generations can occur in the southern rice-growing areas of Louisiana. Fewer generations occur in the northern rice-growing areas.

Injury

Adult rice water weevils feed on the upper surface of rice leaves, leaving narrow longitudinal scars that parallel the midrib (Figure 8-4). Adult feeding can kill plants when large numbers of weevils attack very young rice, but this is rare and is usually localized along the field borders. Most economic damage is caused by larvae feeding in or on rice roots. Under heavy infestation, the root systems of affected plants can be severely damaged (Figure 8-5). This feeding or root pruning results in a reduction in the number of tillers and in the amount of aboveground plant material produced by the damaged plant. Root pruning may interfere with nutrient uptake by plants. Damage to roots ultimately can result in yield losses by decreasing panicle densities, numbers of grains per panicle and grain weights. Plants with severely pruned root systems will appear stunted and may turn yellow and appear to be N deficient.

Figure 8-4. Rice water weevil feeding scars.

Figure 8-5. Heavily pruned roots, left, versus healthy roots.

Infested stands are often thin in appearance and are more susceptible to lodging. At harvest, plants from heavily infested fields will be shorter than normal and have lower yields. Each larva found in a 4-inch (diameter) by 3-inch (deep) core sample is associated with an approximately 0.5% to 1.5% loss in yield. Yield losses tend to be higher in water-seeded rice fields. Losses are higher because these fields are usually flooded at an earlier stage of plant growth and thus are susceptible to oviposition and infestation by larvae earlier. Young rice plants are more susceptible to yield losses than are older plants with more established root systems.

All currently grown rice varieties are susceptible to the rice water weevil. Recent research, however, indicates some differences in varietal susceptibility. Medium-grain varieties appear to be more susceptible to infestation than long-grain varieties. Hybrid varieties suffer less yield loss than inbred varieties under comparable infestation levels.

Scouting and Management

A variety of cultural and chemical controls can control rice water weevils in rice fields. Cultural strategies include planting rice early in the season rather than late, delaying the application of permanent flood and perhaps managing weeds in and around rice fields. However, insecticides are often needed in addition to cultural control tactics to prevent yield losses. Insecticide management practices for

the rice water weevil are evolving as pesticides are added to and removed from the integrated pest management plan. These insecticides fall into three general categories: (1) prophylactic seed treatments, (2) early post-flood adulticides and (3) larvicides. For the most current list of registered pesticides, please consult LSU AgCenter publication 1838, Pest Management Guide, and publication 2270, Rice Varieties and Management Tips.

Prophylactic Seed Treatments

Insecticidal seed treatments are the most widely used chemical control tactic for rice water weevil. With this method of control, the insecticide is applied directly to the seed. Depending on the type of insecticide, either larval or adult control may occur. Scouting is not required with this method since it is used as a preventative treatment. Research has demonstrated that the yield protection obtained from insecticidal seed treatments provides a return on investment in most fields every year because of the high weevil populations throughout the state. Effectiveness of prophylactic seed treatment, however, should be assessed by monitoring larval populations using the bucket sampling method described above. Widespread use of insecticidal seed treatments across the Midsouth rice-producing regions has created potential for development of insecticide resistance. Consult annually updated AgCenter publications or your local extension agents for current insecticide recommendations. Many insecticidal seed treatments control other pests in addition to the rice water weevil including stem borers, armyworms and chinch bugs. The spectrum of pests controlled differs among products. Product selection should consider efficacy against rice water weevil as well as the pest complex most frequently encountered at your farm. Seed treatments differ in their ability to be used in drill versus water seeding as well as in allowed crop rotations. Be sure to check current insecticide labels to ensure the legality of intended product use.

Adult Monitoring and Management

Adulticides include liquid and granular formulations of insecticides. The timing of application of foliar and granular applications of insecticides to control adults is crucial, and more than one application may be required. Applications of adulticides should be made immediately prior to or after establishment of the permanent flood to kill adults before oviposition occurs. To apply an adulticide at the optimum time for adult weevil control, scout for adults immediately after application of the permanent flood. To scout for weevil adults, check at least five to 10 locations per field for the presence of adults or their feeding scars. Treat when adult weevils or their scars are observed and conditions for egg laying are favorable as described above. Applications made 24 hours before initiation of permanent flood also can be effective when adults are present in unflooded fields and feeding scars are visible. More than one application of insecticide may be required because residual activities of most insecticides appear to be less than one week, and weevils will continue to invade the field. Be sure to follow label instructions for limitations on the number of insecticide applications allowed in one season and the preharvest interval. Once fields have been treated, begin sampling again after seven days.

The goal of the use of adulticidal insecticides is to reduce larval infestations by killing adults before they lay eggs. Once eggs are laid in rice leaf sheaths or larvae are in the roots, these insecticides will not be effective. Applications of adulticides for the control of eggs or larvae are ineffective. Work on managing rice water weevil using foliar insecticides is ongoing. As insecticides are added to and removed from the market, recommendations for the management of the rice water weevil with foliar insecticides may change.

Larval Monitoring and Management

Larvicidal compounds are insecticides that target larval rice water weevils after they have established on the roots of rice plants. Carbofuran (Furadan) was a widely used example of this type of insecticide. Carbofuran is no longer registered for use in rice fields, but larvicidal insecticides may become available in the future. Larvicidal insecticides should be applied when densities of larvae exceed three larvae per core. The numbers of larvae on rice roots peak three to five weeks after application of permanent flood. At this time, many of the larvae will be large, and a significant amount of root pruning will have occurred. Larvicidal compounds should be applied before larval populations reach their peak. Early scouting of fields (10 to 20 days after flooding) can indicate if and when larvicidal treatment is required to prevent damaging infestations.

To scout for rice water weevil larvae, take the first larval count 14 to 21 days after establishment of the permanent flood in a drill-seeded system. At least six sites should be randomly selected in each field.

At each site, remove a single core of plants and soil 4 inches in diameter and 3 inches deep and place it in a 10-quart bucket with a 40-mesh screen bottom (Figure 8-6). Wash the soil from the plant roots through the screen bottom in the bucket by thoroughly stirring the soil in the water. Place the mesh bucket in a tub of salt water and gently dip it up and down. This forces water up through the screen bottom and helps to separate larvae from any plant debris remaining in the bucket. After a few seconds, larvae will float to the surface where they can be counted and removed. Repeat the washing procedure several times to make sure all larvae in a sample have been counted. If

larvae are not found in any sample, sample the field again in five to seven days. If the average number of larvae per sample is fewer than three, sample the field again three to five days later. If the average number of larvae per sample is three or more, the field should be treated with available larvicides or drained. Sampling should cease when the field has been treated or when plants have reached the 2-mm panicle stage of development.

Figure 8-6. Rice water weevil sampling bucket.

Management Using Cultural Control

Three primary cultural control strategies can be used to augment use of insecticides to control rice water weevils. The first cultural control strategy is early planting of rice. Early planting can help avoid the highest populations emerging from overwintering later in the spring. However, damaging infestations can occur at any planting date. More weevils are present in late-planted rice fields because they are infested by weevils both from overwintering sites and surrounding rice fields. A second advantage of early planting is the plants are infested at a later stage of development, when they are more tolerant to injury and less susceptible to oviposition. Adults prefer to oviposit on young rice plants.

Another cultural control strategy is draining fields to reduce rice water weevil larvae numbers. Soil must dry to the point of cracking. Draining fields for rice water weevil control requires careful planning so conflicts with weed, disease and fertilizer management programs can be avoided or minimized. Moreover, draining may not effectively kill larvae if rainfall prevents soil from drying until "cracking."

Finally, delaying the application of permanent flood can substantially reduce the amount of damage caused to your crop by rice water weevils. On average, 10% greater yield losses were observed in early flooded rice plots compared with yield losses in field in which flooding was delayed by two weeks. Delaying flood may also interfere with weed control and other production practices.

Stem Borers

The rice crop in Louisiana can be attacked by the Mexican rice borer, sugarcane borer, rice stalk borer and rarely the European corn borer. Since approximately 2016, the Mexican rice borer has become the predominate species in southwest Louisiana and has increased the economic importance of stem borers in that region. Stem borers are less prevalent in Louisiana's northeastern rice production regions. All four species have similar feeding habits and effects on rice yields. Rice is susceptible to attack from stem borers from late tillering stages through the dough stage. Larvae feed first in the leaf sheath before tunneling into the stem and feeding internally. Internal feeding in tillering stages causes a dead heart (dead tiller) (Figure 8-7) while injury during panicle initiation and flowering results in a whitehead (blank panicle) (Figure 8-8). Impacts of dead hearts on rice yields are not well understood, but high densities of whiteheads can cause considerable economic losses.

Figure 8-7. Dead heart caused by Mexican rice borer.

Figure 8-8. Whitehead.

All four stem borer species will also attack other crop and noncrop grasses. Potential crop hosts include sugarcane, corn and grain sorghum. Noncrop hosts include a variety of weedy grasses common to rice production regions including johnsongrass, barnyardgrass, *Paspalum* spp. and others. Stem borers overwinter as larvae in grass hosts and rice stubble. Removal of these hosts during the winter can reduce spring borer populations.

Mexican Rice Borer

Eoreuma loftini **(Dyar)**

Description and Life Cycle

The Mexican rice borer is a devastating pest of sugarcane and a serious rice pest. Basic life cycle biology of the Mexican rice borer moth is light tan with delta-shaped wings (Figure 8-9). Adult moths lay spherical, cream-colored eggs in groups of five to 100. Most eggs are laid in crevices of dry, folded leaves, but eggs may also be laid on green leaves and stems. Young larvae feed on the tissue inside the leaf sheath and quickly migrate from the oviposition site to bore into the rice stem after about one week of feeding.

Larvae are honey-colored with four parallel purple-brown stripes running the length of the body (Figure 8-10). Larvae are most easily distinguished from other species by the light-colored head capsule. Larvae pass through four to six instars depending on sex and temperature, with five being most common. Larval developmental duration varies with temperature and host plant but lasts approximately 30 days on rice during the growing season. Pupation takes place inside the rice stem after mature larvae have constructed an emergence window covered by one or two layers of plant tissue. Pupae are golden-brown (Figure 8-11) and slightly smaller than other stem borer species. The pupal stage lasts seven to 10 days under summer temperature regimes. Adults live six to 14 days, typically mating within one to two days of emergence from rice stems. After mating, females will search for suitable host plants for oviposition. Four to six overlapping generations occur per year, with a higher occurrence at more southern latitudes.

The Mexican rice borer is considered invasive and has been expanding its range northward and eastward along the Gulf Coast, first entering Louisiana in 2008. The species has been a widespread pest of rice in Texas for more than 30 years. It was first reported infesting rice in Louisiana in 2008 and is now present throughout the southwestern and central Louisiana rice production regions. As of 2024, the species was not known to occur north of Rapides Parish in Louisiana, but range expansion is anticipated to continue. Transportation of plant materials potentially harboring Mexican rice borers such as hay or rice straw can aide in the spread of this damaging insect pest to new regions.

Figure 8-9. Adult Mexican rice borer.

Figure 8-10. Mexican rice borer larvae.

Figure 8-11. Mexican rice borer pupae.

Sugarcane Borer

Diatraea saccharalis **(F.)**

Description and Life Cycle

The sugarcane borer has been present in Louisiana for more than 100 years and has historically been the primary species infesting rice until the recent establishment of the Mexican rice borer. Sugarcane borers overwinter as last instar larvae in the stalks of rice and other weedy plants. These larvae pupate in the spring, and adult moths emerge as early as May, mate and live on various hosts until the rice stem diameter is large enough to support larval feeding. Adult sugarcane borers are straw-colored moths about 3/4 inch long with a series of black dots, arranged in an inverted V-shape pattern, on the front wings (Figure 8-12). Egg-laying on rice can begin as early as May, but economically damaging infestations generally do not occur until July through September. The flat, oval, cream-colored eggs are laid at night in clusters of two to 100 on the upper and lower leaf surfaces over one to six days after adult emergence (Figure 8-13). Larvae emerge in five to seven days, crawl down the leaf and bore into the plant stem. They move up and down the stem, feeding for 15 to 20 days before chewing an exit hole in the stem and pupating. Larvae are pale yellow-white in the summer, with a series of brown spots visible on the back and dark red-brown head capsule (Figure 8-14). The lack of stripes distinguishes sugarcane borer larvae from other rice stem borer species. Overwintering and freshly molted larvae lighter in color, have less prevalent spots, and a lighter head capsule giving them a greater resemblance to Mexican rice borer larvae. Mature larvae are about 1 inch long and do not enclose themselves in a silken web before pupation. The pupae are brown, about 1 inch long and roughly cylindrical in shape (Figure 8-15). The pupal stage lasts seven to 10 days. There are three to five generations per year.

Figure 8-12. Adult sugarcane borer.

Figure 8-13. Sugarcane borer egg mass.

Figure 8-14. Sugarcane borer larvae.

Figure 8-15. Sugarcane borer pupa.

Rice Stalk Borer

Chilo plejedellus **(Zink)**

Description and Life Cycle

The rice stalk borer is a sporadic pest of rice in Louisiana. Rice stalk borers overwinter as last instar larvae in the stalks of rice and other host plants. Larvae pupate in the spring, and adult moths emerge in early to late June, mate and live on various hosts until rice stem diameter is large enough to support tunneling larvae. Adults are about 1 inch long with pale white fore and hind wings tinged on the edges with metallic gold scales. Front wings are peppered with small black dots (Figure 8-16). Although egg laying may begin in late May, injurious infestations usually occur from August through September. Flat, oval, cream-colored eggs are laid in clusters of 20 to 30 on the upper and lower leaf surfaces. Eggs are laid at night over one to six days after adult emergence. Larvae emerge in four to nine days and crawl down the leaf toward the plant stem. Larvae may feed for a short time on the inside of the leaf sheath before boring into the stem. Larvae of the rice stalk borer are pale yellow-white with four stripes running the entire length of the body and have a black head capsule (Figure 8-17). The dark head capsule can distinguish rice stalk borer larvae from Mexican rice borer. The sugarcane borer has a similarly colored head capsule but does not have stripes. Mature larvae are about 1 inch long. Larvae move up and down the stem feeding for 24 to 30 days before moving to the first joint above the waterline, chewing an exit hole in the stem. Pupae are about 1 inch long, brown and smoothly tapered. The pupal stage lasts seven to 10 days. There are two to three generations per year in rice.

Figure 8-16. Rice stalk borer adult.

Figure 8-17. Rice stalk borer larva.

European Corn Borer

Ostrinia nubilalis **(Hübner)**

Description and Life Cycle

The European corn borer is the least common stem borer attacking rice in Louisiana. Infestations in southwest Louisiana have rarely been observed. Infestations in northeastern Louisiana rice have historically been more common, particularly in corn and sorghum producing regions. However, widespread adoption of transgenic *Bt* corn is thought to have reduced European corn borer populations in these regions in recent years. Adult European corn borers have delta-shaped wings with wavy dark lines running across them (Figure 8-18). Biology of European corn borer in rice has not been well studied, but the life cycle is similar to that of other stem borer species. Larvae of the European corn borer have a flesh-colored body that may have a grayish, greenish or pinkish tinge (Figure 8-19). Spots run the length of the body and may

be the same color as the body. It has two distinct light brown spots on the top of each abdominal segment and a distinctive mid-dorsal dark band. The head capsule is reddish to black.

Figure 8-18. European corn borer adult.

Figure 8-19. European corn borer larva.

Injury

Injury to rice results from stem borer larvae feeding on plant tissue as they tunnel inside the stem. Injury is often first noticed when the youngest partially unfurled leaf of the plant begins to wither and die, resulting in a condition called dead heart. Later in the growing season, these rice stems are weakened and may lodge before harvest. Stem feeding that occurs during panicle development causes partial or complete sterility and results in the whitehead condition (Figure 8-8.) The white, empty panicles are light in weight and stand upright. Whitehead densities in rice planted in March and early April tend to be less than 2/m^2 and cause negligible yield losses. Whitehead densities in later planted rice are often more than 8/m^2 and can cause yield losses in excess of 10%. Under severe infestation, 40% to 50% of tillers may produce whiteheads resulting in near complete crop loss. Heavy infestations are most often observed in late-planted rice and in the ratoon rice crop.

Whiteheads can result from any major stem damage that occurs during reproductive stages. Whiteheads caused by stem borers can be confirmed by dissecting tillers and observing larvae or pupae within. In the absence of larvae, stem borer infestations can also be diagnosed by observation of powdery frass (excrement) in the tillers or leaf sheaths. Mixed infestations of two or more stem borer species in the same field are common. Multiple larvae may be present in the same tiller, but typically all of the same species.

Scouting and Management

Scouting for stem borers should start at green ring and must be intensified as plants get closer or reach early boot stages. Scouts should look for feeding lesions located on the inside surface of the leaf sheath (Figure 8-20). These lesions are caused by larva that feed underneath the leaf sheath during the two or three days before it bores into stems. These feeding lesions are easily observed from the outside. Care must be taken, however, to avoid confusing these lesions with those caused by sheath blight. Peel off the leaf sheath to expose the feeding larva or to detect the presence of frass to ensure it is the stem borer and not sheath blight damage (Figure 8-21). Pheromone traps are available to aid in scouting for the Mexican rice borer, and trap captures have been shown to be well correlated to larval infestation during the growing season.

Figure 8-20. Borer damage at collar of leaf.

Figure 8-21. Borer feeding on stem behind leaf sheath.

Unfortunately, by the time signs of field infestations (dead hearts, whiteheads) are noted, it is usually too late to apply effective insecticides. For insecticides to be effective, application must coincide with larval emergence so small larvae are killed before they enter rice stalks. Once larvae enter the stalks, insecticides are not effective. Extensive scouting of rice fields is required to time insecticide applications properly. Eggs are laid over an extended period, however, and although some injury may be prevented, satisfactory control using foliar-applied insecticides is difficult and is not always successful. Some foliar insecticides can be applied as tank mixtures with fungicides applied for blast if treatable stem borer infestations are observed. No economic thresholds have been developed for these insects in rice. Some insecticidal seed treatments have good efficacy against all species of stem borers and have been successfully used to prevent damaging infestations. The spectrum of pests controlled differs among seed treatments and not all products provide control of stem borers. Please consult LSU AgCenter publication 1838, Pest Management Guide, and publication 2270, Rice Varieties and Management Tips, for the most current list of insecticides labeled to control borers in rice.

Borer resistant varieties may be utilized to minimize the need for insecticidal protection. Stem borer infestations differ among rice varieties by as much as five- to tenfold in small plot experiments. Consult rice extension personnel or the most recent Rice Varieties and Management Tips for information on stem borer susceptibility among current rice varieties.

Biological control can sometimes be effective to control stem borers. Stem borer eggs and larvae are parasitized by a variety of small wasps. It is believed these parasites play an important role in maintaining stem borer numbers below economic levels. Early season application of insecticides may disrupt naturally occurring biological controls.

Cultural controls for stem borers include early planting and destruction of overwintering habitats. The most effective means for reducing overwintering borer populations is areawide destruction of crop residues after harvest. For this to be effective, plant stubble must be destroyed close to or below the soil surface. Mowing or herbicidal control of weedy grasses on field margins can also aid in reducing area wide borer populations. Please consult your parish LSU AgCenter Extension agent for the latest recommendations to control stem borers in rice.

Rice Stink Bug

Oebalus pugnax **(F.)**

Description and Life Cycle

Adult rice stink bugs are shield-shaped, metallic-brown insects about 1/2 inch long (Figure 8-22). Rice stink bugs overwinter as adults in grass clumps and ground cover. They emerge from overwintering sites in early spring and feed on grasses near rice fields before invading fields of maturing rice. They are particularly attracted to rice during the flowering stage. Adults live 30 to 40 days. Females lay masses of light green cylindrical eggs on the leaves, stems and panicles of rice plants. Eggs are laid in parallel rows with about 20 to 30 eggs per mass (Figure 8-23). As they mature, eggs become black with a red tint. Immature stink bugs (nymphs) emerge from eggs in four to five days in warm weather or as long as 11 days in cool weather. Nymphs develop through five nymphal stadia in 15 to 28 days. Newly emerged nymphs are about 1/16 inch long, with a black head and antennae and a red abdomen with two black bars (Figure 8-23). Nymphs increase in size with successive molts, and the color of later instars becomes tan-green (Figure 8-24).

Figure 8-22. Rice stink bug adults.

Figure 8-23. Rice stink bug hatchling (first instar nymphs).

Figure 8-24. Rice stink bug nymph.

Injury

Nymphs and adults feed on the rice florets and suck the sap from developing rice grains. Feeding on florets and on grains in the early milk stage can reduce rough rice yields; however, most economic loss results from reductions in grain quality that results from stink bugs feeding on developing kernels. Pathogens enter the grain at the feeding spot and the pathogen infection and bug feeding together cause discolored and pecky rice kernels. Discolored or pecky rice kernels have lower grade and poor milling quality (Figure 8-25). Both adult and nymph rice stink bugs feed on developing rice grains, but adults account for most economic losses in rice. Relationships between stink bugs and stink bug injury show a strong increase in percentage of pecky rice and a strong decrease in percentage of head yield with increasing numbers of adult stink bugs during the heading period.

Figure 8-25. Pecky rice, stink bug damage.

Scouting and Management

Several natural enemies are important in reducing rice stink bug numbers in rice. Adults and nymphs are parasitized by the flies, *Beskia aelops* (Walker) and *Euthera tentatrix* Lav. Rice stink bug eggs are parasitized by the tiny wasps *Oencyrtus anasae* (Ashm.) and *Telonomus podisi* (Ashm.). Management relies significantly on the activity of these naturally occurring biological control agents. Insecticidal control based on the results of field scouting is recommended when rice stink bugs escape from the control provided by natural enemies.

Rice fields should be sampled for stink bugs using a 15-inch diameter insect sweep net once each week beginning immediately after pollination and continuing until kernels harden. Do not sample fields at midday when stink bugs may be seeking shelter from the heat in the shade at or near the ground. Avoid sampling field borders, where stink bug numbers are often higher than in the field interiors.

A sample consists of 10 consecutive 180-degree sweeps made while walking through the field. Hold the net so that the lower half of the opening is drawn through the foliage. After 10 successive sweeps, count the number of rice stink bug nymphs and adults. Normally, 10 samples of 10 sweeps each are made per field.

During the first two weeks of heading, fields averaging three or more rice stink bugs per ten sweeps (30 or more per 100 sweeps) should be treated with an insecticide. After the first two weeks of heading, treat fields when an average one or more stink bugs per sweep (100 or more per 100 sweeps) is found. Do not treat fields within two weeks of harvest.

Rice stink bug populations have developed insecticide resistance to some insecticides in some regions, and control failures have been reported. Avoid use of foliar insecticides in close proximity to crawfish production. Contact your parish LSU AgCenter Extension agent for specific treatment recommendations. Please consult LSU AgCenter publication 1838, Pest Management Guide, and publication 2270, Rice Varieties and Management Tips, for the most current list of pesticides registered to control rice stink bugs.

Fall Armyworm

Spodoptera frugiperda **(J.E. Smith)**

Description and Life Cycle

The fall armyworm feeds on most grasses found in and around rice fields. It is also a serious pest of corn and pasture grasses. Since rice is not its preferred host, the fall armyworm is only an occasional pest on rice. Adult moths are about 1 inch long with gray-brown sculptured front wings and whitish hind wings (Figure 8-26). The front wings of male moths have a white bar near the wing tip. This bar is absent in female moths. Females lay masses of 50 to several hundred whitish eggs on the leaves of rice and other grasses in and around rice fields. Egg masses are covered with moth scales and appear fuzzy. The larvae emerge in two to 10 days, depending on temperature, and begin feeding on rice plants. They vary from light green to brown to black but have distinctive white stripes along the side and back of the body (Figure 8-27). Larvae feed for two to three weeks, developing through four instars. Mature larvae are about 1 inch long and have a distinctive inverted “Y” on the head (Figure 8-28). Mature larvae prepare a cocoon and pupate in the soil or decomposing plant material. Moths emerge in 10 to 15 days, mate and disperse widely before laying eggs on new plants. At least four generations per year occur in Louisiana.

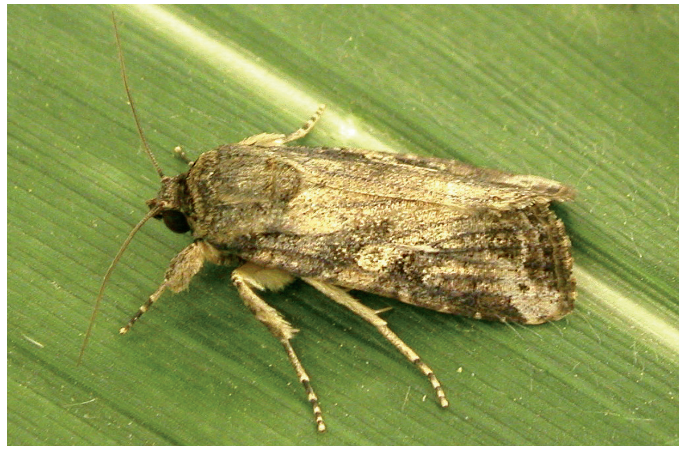


Figure 8-26. Fall armyworm adult.

Figure 8-27. Fall armyworm larvae.

Figure 8-28. Mature larvae have a distinctive inverted “Y” on the head capsule.

Injury

Fall armyworm larvae feed on the leaves of young rice plants, destroying large amounts of tissue. When large numbers of armyworms are present, seedlings can be pruned to the ground, resulting in severe stand loss. Fall armyworm infestations generally occur along field borders, levees and in high areas of fields where larvae

escape drowning. The most injurious infestations occur in fields of seedling rice that are too young to flood. Larvae from the first overwintering generation, occurring in early spring, are the most injurious. Young rice is able to recover from low to moderate levels of defoliation, and yield loss does not result from most infestations. Infestations later in the season may cause feeding injury to rice panicles, although this is rare.

Scouting and Management

After germination of seedlings, scout fields weekly for larvae on plants. Sample plants every 10 feet along a line across the field and repeat this process in a second and third area of the field. Treat when there is an average of one armyworm per two plants. Detecting infestations when larvae are small will reduce the risk of severe defoliation and improve control. Fall armyworm management consists of cultural, chemical and biological control. Naturally occurring populations of parasitic wasps and pathogenic microorganisms frequently reduce armyworm numbers below damaging levels. Since adults lay eggs on grasses in and around rice fields, larval infestations can be reduced by effective management of grasses. Cultural control consists of flooding infested fields for a few hours to kill fall armyworm larvae. This requires that levees be in place and that rice plants be large enough to withstand a flood. Cultural control may be more expensive than chemical control but will reduce risk of harming beneficial insect populations. Armyworm populations have become resistant to some registered insecticides. Some insecticidal seed treatments can aid in controlling armyworms. Contact your parish LSU AgCenter Extension agent for specific recommendations if chemical control is needed.

Rice Leaf Miner

Hydrellia griseola

Description and Life Cycle

Adult flies have clear wings on a metallic blue-green-to-gray thorax (Figure 8-29). Less than 1/4 inch long, they can be seen flying close to the water and landing on rice leaves. They lay eggs singly on rice leaves. Eggs are laid on seedlings before application of permanent floodwater. After application of permanent flood, white eggs are laid singly on leaves that float on the floodwater. Transparent or cream-colored legless larvae emerge in three to six days and begin feeding between the layers of the rice leaf. Larvae become yellow to light green as they feed. Mature larvae are about 1/4 inch long (Figure 8-30). The larvae feed for five to 12 days before pupating. Adults emerge after five to nine days and live two to four months. Under ideal conditions, the life cycle can be completed in as few as 15 days. In cool weather, the life cycle can extend for more than one month.

Figure 8-29. Adult leaf miner.

Figure 8-30. Rice leaf miner larva.

Injury

The rice leaf miner is a sporadic problem in Louisiana. Rice is attacked in the early spring, and infestations usually occur on the upper side of levees where water is deepest. Rice leaf miner is not usually a problem in water 4 to 6 inches deep. Problems are more severe in continuously flooded rice than in periodically flooded rice and when water is more than 6 inches deep. Larvae tunnel between the layers of the leaf, attacking and killing leaves closest to the water. Larvae move up the plant, killing additional leaves, and under heavy infestations the entire plant may

die, reducing stands severely (Figure 8-31). Yield loss from rice leaf miner is not well understood but is thought to be minimal under most infestation.

Figure 8-31. Rice leaf miner damage in fields where water is more than 6 inches deep.

Scouting and Management

Scout fields for rice leaf miners by walking through flooded rice fields and gently drawing the leaves of rice plants between the thumb and forefinger. Bumps in the leaves indicate the presence of leaf miner larvae or pupae (Figure 8-32). The larvae or pupae can be found by separating the layers of the leaf (Figure 8-33). If leaf miners are present and plant numbers are reduced to less than 15 per square foot, consider control options. Rice leaf miner management involves cultural control or insecticide application. Maintaining water depth at 4 to 6 inches will usually prevent problems with rice leaf miner. If leaf miners are present, lowering the water level in rice fields so that rice leaves can stand up out of the water also will help to prevent injury. Efficacy of many registered insecticides against rice leaf miner is unknown. Contact your parish LSU AgCenter Extension agent for specific control recommendations.

Figure 8-32. Bumps in leaves indicate leaf miners.

Figure 8-33. Rice leaf miner pupa.

South American Rice Miner

Hydrellia wirthi **Korytkowski**

Description and Life Cycle

The South American rice miner (SARM) is an invasive insect pest of rice in the United States. It is a close relative of the rice leaf miner, which is widely distributed across U.S. rice fields. Current SARM distribution places this insect across the most important rice areas of Louisiana and Texas. SARM adults are small, gray to dark gray flies of about 1/10 inch in length. SARM eggs are elongated, ribbed, white or creamy-white and approximately 0.5 mm long and 0.2 mm wide (Figure 8-34). Eggs are laid singly on the upper surface of rice leaves, near the leaf margins. Larvae are small, white or yellowish legless maggots of approximately 1/4 inch in length (Figure 8-35). The puparium is brown, elongated, and tapered at both ends (Figure 8-36).

Figure 8-34. South American rice miner egg.

Figure 8-35. SARM maggot.

Figure 8-36. SARM pupa.

Injury

Injury to rice plants tends to occur in young rice from emergence until the tillering stages, particularly in late-planted fields (planted in May and June in central and southwest Louisiana). Injury is caused by the larva or maggot, which causes large, elongated lesions along the margins of emerging leaves. The maggot mines the leaf or rasps the leaf surface before the leaf unfurls. As the leaf expands, yellow damaged areas with a characteristic withered appearance are visible (Figure 8-37). The maggot continues to feed on the whorl tissue and enters the stem of developing plants. Because of the damage to the whorl of rice plants, the SARM also is termed "whorl maggot" by several rice producers. It is common to find more than one maggot in a single stem. Affected seedling plants are killed, or their growth is severely retarded. Pupation occurs inside the affected stem, near the collar of the leaf. Field damage is distributed in large patches either in the center or along the margins of the field (Figure 8-38). Impacts of SARM infestation on rice yields are unknown, but it is thought that rice recovers most infestations with minimal impacts.

Figure 8-37. SARM or "whorl maggot" damage.

Figure 8-38. SARM field damage.

Scouting and Management

Scout young rice for large, elongated lesions along the margins of emerging leaves. Early planting prevents the risk of severe infestations. No chemical controls are currently recommended. Some insecticidal seed treatments provide benefits against SARM, but injury may still occur. If you suspect a SARM infestation, contact your parish LSU AgCenter Extension agent for damage assessment and to obtain the latest developments on this insect pest.

Chinch Bug

Blissus leucopterus leucopterus **(Say)**

Description and Life Cycle

Chinch bugs overwinter as adults in grass clumps, leaf litter and other protected areas, emerging in early to mid-spring to feed and mate on grass hosts, including many grassy weeds, turf grass, rice, corn, small grains and other grasses. Adults are small, black insects about 1/6 inch long, with white front wings (Figure 8-39).

Figure 8-39. Chinch bugs on rice.

Each wing has a triangular black spot near the outer wing margin. Adults lay white, elongated eggs 1/24 inch long behind the lower leaf sheaths or in the soil near the root. Eggs turn red as they mature, and larvae emerge in seven to 10 days. There are five nymphal instars. Early instar nymphs are red with a yellow band on the front part of the abdomen (Figure 8-40). Last instar nymphs are black and gray with a conspicuous white spot on the back (Figure 8-41). The life cycle from egg to adult takes 30 to 40 days, and adults may live two to three weeks.

Figure 8-40. Early instar nymph of chinch bug on rice.

Figure 8-41. Late instar nymphs and adult chinch bugs.

Injury

Chinch bugs are a sporadic pest of rice in Louisiana. They tend to be more of a problem in drill-seeded rice because of the delayed application of permanent flood. Economic injury to rice generally occurs when favorable weather conditions and production practices allow chinch bugs to build in grass host habitats. Serious economic losses have resulted from chinch bug infestations in north and south Louisiana, though this is rare. Chinch bug injury results when adults and nymphs feed on the leaves and stems of rice plants. Feeding on young seedlings causes leaves and stems to turn light brown (Figure 8-42). High numbers of chinch bugs can kill young plants, severely reducing plant stands. Infestations tend to be clumped and are most severe on field edges.

Figure 8-42. Firing of lower leaves from chinch bugs.

Scouting and Management

Check unflooded rice near small grain fields or recently cut grassy areas every three to five days from seedling emergence until application of permanent flood. Check foliage in rice fields for chinch bugs. During warm weather, chinch bugs will hide in cracks at the soil line. Young nymphs can be found feeding on roots. Thresholds for chinch bugs in rice are not available. If high numbers of chinch bugs are present and plant stands are being reduced, consider control options. Cultural and chemical control methods are available. Cultural control consists of flooding infested fields to kill chinch bugs or to force them to move onto rice foliage where they can be treated with an insecticide. This tactic requires that levees be in place and that rice plants be sufficiently large to withstand a flood. Cultural control may be more expensive than chemical control. Contact your parish LSU AgCenter Extension agent for specific recommendations if chemical control is needed.

Billbugs

Sphenophorus **spp.**

Description and Life Cycle

Billbugs (also known as rice levee billbug) are weevils in the same family as the rice water weevil (Curculionidae). A complex of multiple species in the genus *Sphenophorus* can attack rice, but the most prevalent in southern U.S. rice fields is *Sphenophorus pertinax*. Adults are 3/4 inch to 1 inch long, large brown to black beetles with a pronounced snout (Figure 8-43). Larvae are about 1/2-inch-long white, legless grubs with a red-orange head capsule (Figure 8-44).

Figure 8-43. Billbug adult.

Figure 8-44. Billbug larvae.

Injury

Billbugs were previously considered only minor pests but have recently emerged as a consistent threat to furrow-irrigated rice (row rice). Both billbug adults and larvae can attack rice, but larvae cause most economic damage. Adult feeding occurs at the bases of young rice plants and can occur in both row rice and paddy rice before the application of the permanent flood. Adult billbugs feed on the stems of young rice tillers (Figure 8-45), causing new leaf death or a dead heart. Severe stand reductions from adult billbug infestations are rare, and this injury is generally not considered economically damaging. Larvae feed low in rice stems near roots and can only survive in row rice or unflooded portions of paddy rice fields such as levees. Larval feeding occurs inside the root crown and lower stem, often resulting in plant death. Feeding cavities are filled with powdery frass. The primary symptom of billbug larval infestations is the presence of whiteheads. Whiteheads are completely blank panicles and are also a symptom of stem borer infestations. Symptomology in row rice can occur anywhere in a field where irrigation water does not accumulate for extended periods of time. Field edges closest to furrow irrigation pipe and high sides of the field often exhibit symptomology first.

Figure 8-45. Billbug tunneling damage and frass.

Scouting and Management

No formal thresholds or scouting procedures have been established for billbug infestations in row rice. Billbug adults typically reside near the base of the plant, making scouting difficult. Larvae can be found by digging up injured tillers and dissecting the stems near the root crowns. Once symptomology appears, injury to the rice has already occurred and management options may not produce an economic benefit. Limited information is available on the efficacy of foliar treatments or insecticidal seed treatments alone or in combinations. Temporarily flooding fields may produce some benefit; however, adequate water coverage over affected areas is often not possible due to the nature of row rice production.

Colaspis

Colaspis brunnea **and** *Colaspis louisianae*

Description and Life Cycle

There are two species of colaspis that can be found in Louisiana rice: *Colaspis brunnae* and *Colaspis louisianae*. Adults are small (1/4 inch) tan beetles with striped backs (Figure 8-46). Larvae are white grubs resembling billbug larvae, but smaller with lighter-colored head capsules (Figure 8-47). Rice is not a preferred host plant for colaspis. Colaspis will complete a single generation in soybeans and

lespedeza. This is why they are often called Lespedeza worms. Colaspis eggs are laid in soybeans during the summer where larvae feed on roots. The larvae of colaspis will overwinter in the soil. When rice, or another crop, is planted into a field that is infested with colaspis larvae, the larvae will begin to feed on the roots of those plants. Feeding on fine root hair may result in plant death. The larvae will then pupate (Figure 8-48) and emerge as adults. in length. Adults will not lay eggs on rice but will most likely travel to a nearby soybean field.

Figure 8-46. Colaspis adult.

Figure 8-47. Colaspis larva.

Figure 8-48. Colaspis pupa.

Injury

This pest can be found damaging fields of dry-seeded rice in a soybean-rice rotation. Damage appears as thin or weak stand prior to the establishment of the permanent flood. It is common to find a clumped distribution of larvae in the soil and patches of stand loss (Figure 8-49)._In Arkansas, damage from this pest is typically more severe in light textured soils. The damage is often concentrated in high spots in the field where larvae escape water. Colaspis are not pests of water-seeded rice or rice produced in a crawfish rotation.

Figure 8-49. Rice field damage caused by colaspis larvae feeding on roots.

Scouting and Management

To scout for this pest, locate plants that are stunted, dying and surrounded by declining plants. Dig around the base of the plants, carefully peeling back the soil and looking for larvae. You may also find pupae or adults in the soil. Establishment of the permanent flood is the best management strategy to control this pest. These insects are not aquatic and cannot survive in a permanent flood. If colaspis injury and larvae are observed, apply the permanent flood as soon as possible. Foliar application of insecticides is not effective as larvae are beneath the soil. Some insecticidal seed treatments have activity against colaspis. Consider applying seed treatments if rice is rotated with soybeans, and fields have a history of colaspis infestation. Contact LSU AgCenter Extension personnel for the latest chemical control options.

Rice Seed Midge

Chironomus **spp.**

Description and Life Cycle

Adult midges can be seen in swarms over rice fields, levees, roadside ditches, and other bodies of water (Figure 8-50). Adult midges resemble small mosquitoes but lack needlelike mouthparts and hold their forelegs up when resting. Elongate eggs are laid in strings, usually on

the surface of open water. The strings are held together by a sticky material that forms a gelatinous coat around the eggs. After emerging, the larvae move to the soil surface, where they live in tubes constructed from secreted silk, plant debris and algae. The larvae mature through four instars before pupating (Figure 8-51). The life cycle from egg to adult requires 10 to 15 days.

Figure 8-50. Seed midge swarms.

Figure 8-51. Midge tubes on soil under water.

Injury
Larvae injure rice by feeding on the embryo of germinating seeds (Figure 8-52) or on the developing roots and seeds of very young seedlings. Midge injury occurs in water-seeded rice and is usually not important once seedlings are several inches tall. The potential for midge injury increases when fields are flooded far in advance of water-seeding rice. Injury from the midge can be insignificant (not economically important) to very severe. Injury can also be localized, making damage assessment difficult. In some instances, whole fields may need to be replanted. In other instances, only parts of fields may require reseeding.

Figure 8-52. Seed midge damage.

Scouting and Management
Water-seeded fields should be scouted for midge injury, checking for hollowed out seed within five to seven days after seeding. Repeat scouting at five-day to seven-day intervals until rice seedlings are about 3 inches tall. Midge presence is indicated by larval tubes on the soil surface. There are many midge species, most of which do not attack rice, and the presence of midge tubes alone does not indicate the need to treat a given field. Midge injury is indicated by the presence of chewing marks on the seed, roots, and shoots and by the presence of hollow seeds (Figure 8-52).

Rice seed midge management includes chemical and cultural control options. One cultural management option is to drain fields to reduce numbers of midge larvae. Reseeding of heavily infested fields may be necessary. The potential for damaging levels of seed midge can be reduced or prevented by using recommended water and crop management practices. Holding water in rice fields for more than two to three days before seeding encourages the buildup of large midge numbers before seeding and should be avoided.

Practices that encourage rapid seed germination and seedling growth, such as using presprouted seed and avoiding planting in cool weather, will help to speed rice through the vulnerable stage and reduce the chance for serious damage.

Apple snails
Pomacea maculata

Description and Life Cycle
Invasive apple snails are large freshwater mollusks originating from South America which have become invasive in aquatic habitats across the U.S. Gulf Coast and elsewhere in the world. The snails are present throughout natural waterways across much of southern Louisiana. They became established in some rice and crawfish ponds in southwest Louisiana in 2018 and infest new acres each

year. Adults are large (apple-sized), considerably larger than any of Louisiana's native snails. Shells are spherical in shape with color that varies from bright golden to dark brown or black (Figure 8-53). Snail flesh is grey (Figure 8-54). The opening of the shells is sealed with a leathery cover called an operculum when snails are dormant or threatened. Hatchling snails are approximately the size of a bb, have semi-translucent shells, and are often spotted (Figure 8-55). Immature snails resemble adults and frequently co-occur in a variety of sizes. The presence of apple snails is most easily detected by their bright pink egg masses laid on plant material or structures above the water surface (Figure 8-56). Apple snail eggs contain a toxin that can irritate skin and eyes and should not be touched with bare hands.

Figure 8-53. Apple snail coloration.

Figure 8-54. Apple snail flesh.

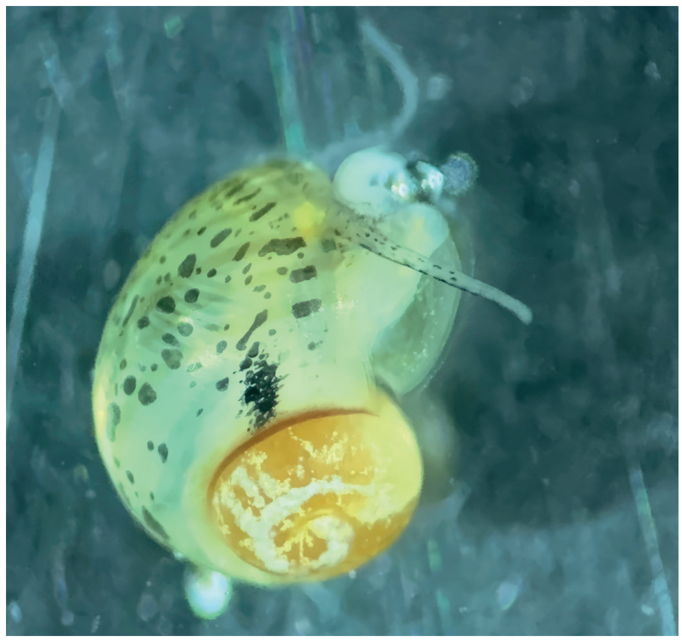


Figure 8-55. Hatchling apple snail.

Figure 8-56. Apple snail egg mass.

Apple snails can be observed in all life stages year around. The snails become inactive during cold periods but will resume feeding and reproduction when temperatures warm. During extreme cold or if their pond dries out, snails will burrow into the mud where they can remain dormant for more than six months. Apple snail growth rates are temperature dependent. During warm months, snails can reach sexual maturity in approximately 60 days from hatching. Eggs hatch in eight to 10 days after being laid, turning whitish as they mature. Apple snail reproductive rates are extremely high. During warm months apple snail females can lay one egg mass, containing 1,000 to 2,000 approximately every seven to 10 days. When food is readily available, apple snail populations can reach densities of more than two per square foot.

Injury

Apple snails are voracious eaters consuming large volumes of vegetative plant material in addition to decaying plant matter, amphibian eggs and many other potential food sources. Apple snails will forage and feed as long as water depth is sufficient to cover the base of their shells. Apple snails are major pests of rice across the globe including South and Central America, Asia and parts of Europe. Apple snails consume seedling rice up to the early tillering stage, but do not appear to consume more mature rice plants. In Louisiana, apple snails have had minimal impact to drill-seeded, delayed-flood rice because rice is no longer susceptible to snail attack after establishment of the permanent flood. Water-seeding into fields infested with apple snails can result in complete stand loss and the need to reseed. Apple snails are highly disruptive to crawfish production done in rotation with rice.

Scouting and Management

Every precaution should be taken to avoid introduction of apple snails into uninfested rice and crawfish farms. Well-water irrigation should minimize the risk of introductions during flooding. Surface water-irrigated fields will be difficult to protect once source water ways are infested. Equipment including boats, tractors, irrigation materials, crawfish traps or other supplies should never be moved from apple snail-infested ponds to other locations because of the risk they may harbor live snails or viable eggs. Once established, apple snails have never been successfully eradicated.

No scouting protocols for apple snails in rice have been developed. Detection of apple snails or their egg masses in rice fields previously uninfested should be reported to LSU AgCenter Extension personnel. No formal management recommendations have been developed, but research has identified cultural and chemical controls that may be effective. The influence of management tactics on apple snail populations has not been determined. Population recovery from any controls should be expected. Long term (more than one year) drying of infested ponds or rotation with dry-land crops such as soybeans could cause substantial snail mortality. Deep tillage (more than 4 inches) can be used to crush snails beneath the soil surface. Submerging eggs in water for more than 24 hours prevents hatching. Periodically increasing flood depth to “drown” the eggs may slow reproduction. No molluscicides are currently registered for apple snail control in rice or crawfish production, but chemical control options may become available in the future. Contact LSU AgCenter Extension personnel for the most current control recommendations.

Other Insect Pests of Rice

Several other insects may occasionally attack rice in Louisiana. They include the southern green stink bug, (*Nezara viridula*) (Figure 8-57), the black rice bug (*Amaurophrous dubius*) (Figures 8-58 and 8-59), several grasshopper species and the larvae of several species of skippers (Figures 8-60 and 8-61). The numbers of these insects in rice fields are usually below levels justifying treatment, but they may increase rapidly under favorable conditions and yield losses can occur. Contact your parish LSU AgCenter Extension agent for specific treatment recommendations.

Figure 8-57. Southern green stinkbug.

Figure 8-58. Amaurochrous dubius nymph.

Figure 8-59. Amaurochrous dubius adult.

Figure 8-60. Skipper adult.

Figure 8-61. Skipper larvae.

Potential pests which are not currently known to attack rice in Louisiana include the rice delphacid (*Tagosodes oryzolcolus*) (Figure 8-62) and the panicle rice mite. The rice delphacid has emerged as a consistent late-season pest of rice in Texas but has not been reported in Louisiana in more than 50 years. Rice delphacid feeding causes yellowing of rice leaves and can lead to plant death. Infestations are often observed as patches of dead rice called hopperburn (Figure 8-63). The panicle rice mite (*Steneotarsonemus spinki*) (Figure 8-64) is a pest of rice in Asia, Central America and the Caribbean. It was reported from a single rice field in Louisiana in 2007 but had not been observed until the 2025 rice crop.

Figure 8-62. Rice delphacid.

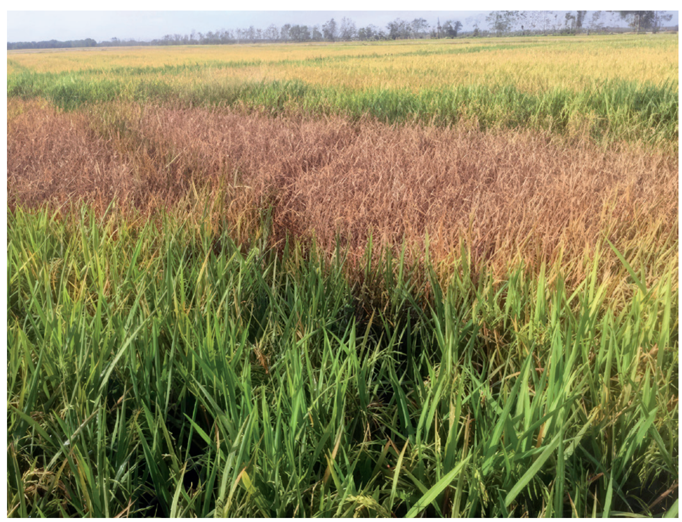


Figure 8-63. Hopperburn caused by rice delphacid.

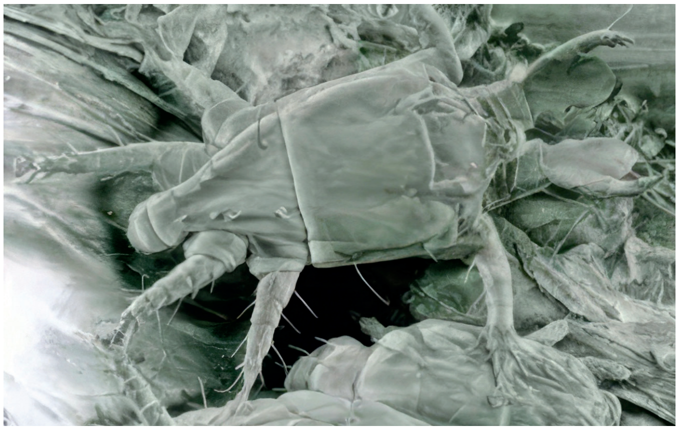


Figure 8-64. Adult panicle rice mite. Photo by USDA

Panicle Rice Mite

Amaurochrous dubius

(formerly called Black Rice Bugs)

Both nymphs (Figure 8-57) and adults (Figure 8-58) cause damage by feeding with their piercing mouthparts. Feeding on the leaf sheath can cause dead or dying leaves, usually lower leaves, in otherwise healthy rice. The damaged leaves will often have a yellow, orange or red coloration (Figure 8-63). Adults are related to the more traditional stink bugs as evidence by their odor when disturbed. These bugs are sometimes called turtle bugs. Neither the term black rice bug nor turtle bug is the correct common name for this insect.

Stored Grain Pests of Rice

Rice that is stored as seed or grain for consumption may be susceptible to attack by grain pests. These include beetles and moths. The most important pests of stored rice in Louisiana are the lesser grain borer (Figure 8-65), the rice weevil (Figure 8-66), the angoumois grain moth (Figure 8-67) and the Indian meal moth (Figure 8-68). The lesser grain borer and the angoumois grain moth larva bore into the kernels and destroy them whereas the rice weevil attacks those kernels with broken hulls. Other insects of lesser importance that may be found in rice bins include the saw-toothed grain beetle, the red flour beetle, flat grain beetle, cigarette beetle and the Mediterranean flour moth. These insects infest secondarily, feeding mostly on broken kernels, flour and on the frass of the lesser grain borer and the other insects that bore directly into whole kernels.

Figure 8-65. Lesser grain borer. Photo by Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org

Figure 8-66. Rice weevil. Photo by Joseph Berger, Bugwood.org

Figure 8-67. Angoumois grain moth. Photo by Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org

Figure 8-68. Indian meal moth

The first step in control of stored grain pests is to thoroughly clean storage bins. Good sanitation may prevent infestation of stored grain and decrease cost by preventing the need for fumigants. Both old and new bins should be prepared in the same manner. The bins should be thoroughly cleaned at least two weeks prior to storing grain. To properly clean bins, all old grain, trash and debris should be removed from within the storage bin and fumigated or burned. Brush away all debris, including spider webs, attached to the sides of the bin, and wash the inside and outside surfaces of the bin with a high-pressure hose. Be sure to remove all grain from cracks and crevices. Any grain left in the cracks can increase your chance of infestation by stored grain pests.

After the bin is clean, it should be treated with an insecticide. Spray the bin inside and out (including overhead) with a labeled insecticide. Consult LSU AgCenter publication 1838, Insect Pest Management Guide, for currently labeled insecticides for treating bins. Treat the wall surfaces and any cracks and crevices. Be sure to follow all label instructions when applying any insecticides. The pH of the tank water should be adjusted using a buffering adjuvant as necessary. For best results, the tank water should be slightly acidic with a pH of 5.5 to 6.5. You may want to consider applying a grain protectant to rice that will be stored. This action may prevent early infestation of stored grain. Grain must be at the proper moisture content for storage prior to application. Do not apply the grain protectant before high temperature drying. If your rice becomes infested with a stored grain pest while it is being stored in a bin, fumigation is the only option of treatment. Check LSU AgCenter publication 1838, Insect Pest Management Guide, for the latest fumigation registrations. Be sure to follow label instructions for application method, rate, and insects to treat. The bin must be closed a minimum of four days during fumigation.

Rice Drying on the Farm

Dennis Gardisser and Ronnie Levy

Drying and storing rice on the farm can be an excellent marketing strategy. The way that rice is handled during the drying and storage process will determine its quality at the point of sale, thereby influencing its value.

Rice should be quickly dried down to a moisture level of about 12% for storage, especially if it is going to be stored for several months. The reduction of grain moisture is done by passing relatively large quantities of dry air over the rice after it is placed in the bin. The quality and quantity of this air determines the final moisture content of the rice kernel.

Air quality is typically referred to as the equilibrium moisture content (EMC). It is the combination of temperature and relative humidity at which rice will not gain or lose moisture from the air. If the air has an EMC of 12%, the grain moisture will eventually reach 12% if air of that quality is moved over the grain long enough.

The EMC may be determined by measuring air temperature and relative humidity. Relative humidity is determined by measuring wet bulb and dry bulb temperatures and comparing these values with a table. Relative humidity is a measure of how much moisture is in the air at a given temperature in comparison with how much it could hold at that same temperature. At 100% relative humidity, the air is holding all of the moisture it is capable of holding at that temperature. The actual amount of moisture capable of being held varies with air temperature. Hot air holds more water than cold air. Wet bulb and dry bulb temperatures are measured by using a device called a sling psychrometer. This device has two identical thermometers, but the bulb of one is covered with a cloth sack that is moistened when it is used. The thermometers are mounted on a board or similar structure that permits them to be slung through the air. The wet bulb temperature will be lower than the dry bulb as a result of evaporative cooling.

In drying rice, maintaining a steady EMC as close to the target storage moisture (12% or 13%) content is important. Usually, there are many days during and shortly after the harvest season when the EMC is at or below the desired level without adding any heat. At night or during damp weather conditions, it may be necessary to add some heat to condition the air to a desirable EMC or to maintain the same level available during the daylight hours. If heat is not available, it may be better to turn the fans off at night instead of pumping in moist air. Moist air that is pumped in at night has to be removed later. This increases drying cost and may result in significant head rice yield reduction. Fans should be turned off almost any time the EMC of the air is greater than that of the grain. The exception might be for very damp rice to avoid heat buildup.

A given volume of air has the capability of holding a given amount of moisture. That amount will depend on the quality. One way to increase drying potential or cause the grain to reach equilibrium with the air sooner is to pass larger amounts of air over the grain. Doubling air flow typically cuts the drying time in about one-half. Airflow rates for drying vary from a low of 1 cubic foot per minute (CFM) per hundred-weight (cwt) to a high of 100 or more CFM per cwt. Recommended minimum airflow rates for different moisture contents are:

- 13% to 15% moisture — 1 to 2 CFM per cwt
- 15% to 18% moisture — 4 CFM per cwt
- 18% to 20% moisture — 6 CFM per cwt
- 20% to 22% moisture — 8 CFM per cwt
- 22% moisture and above — 12 CFM per cwt

As grain bins are filled and the grain depth increases, it becomes more difficult to pass air up through the grain. As the grain depth increases, less air is available for each bushel of grain in the bin. High volumes of air are needed to carry the moisture away in a timely fashion when the grain is at high moisture levels. Most on-farm bins have a limited amount of available air capacity.

The grain drying industry offers basically two types of drying fans, the centrifugal and axial flow fans. From these two types, manufacturers provide a number of variations to meet the needs of field applications. The two critical characteristics of fans are flow rate (CFM) and static pressure expressed in inches of water.

The axial fan utilizes a propeller wheel mounted directly to the motor shaft; thus, it develops a very high tip speed and is often noisy. Some axial fans incorporate air straightening vanes to increase efficiency and increase static pressure. The normal upper limit of static pressure of an axial fan is about 5 inches of water. Axial fans are cheaper and are most often used where high airflow rates at low static pressures are needed.

Centrifugal fans provide a relatively constant air volume over a wide range of static pressures with a practical limit of 9 to 10 inches of water (Figure 9-1). Higher static pressures can be obtained with special design; however, the 9 to 10 inches of water pressure will meet most on-farm

drying system needs. Centrifugal fans are more expensive than axial fans and can be purchased as a direct-driven or a belt-driven unit. Belt-driven units are more expensive but have a greater life expectancy. Centrifugal fans are highly recommended where high static pressures are needed (Figure 9-2).

These criteria dictate that bins should not initially be filled too full if the grain is at high moisture content. Once grain moisture reaches 15% or less throughout the bin, the bin filling process may be completed.

Dry grain (moisture content less than 15%) should not be mixed with moist grain (moisture content greater than 18%). Once a rice kernel is dried to a level below 15%, any rewetting may cause excessive fissuring and reduction in head rice yield. This also may occur if damp air is pumped through already-dry grain.

Stirring devices help to mix the upper and lower portions of grain in the bin. This speeds up the drying process and loosens the grain so that additional air may be moved up through the grain. Stir-alls and similar devices should not be turned on unless the bottom end of the auger is about 1 foot deep in grain. They can run almost continuously after that point, when the drying fans are running. Many producers are concerned that these devices may grind away at the rice if left on, but there is no research evidence to support this claim. A small amount of flour-like substance will form around the auger top, but the small particles were most likely already there and are just being gathered in one place with the auger action.

Grain should not be allowed to cone as the bin is being filled. If coning occurs, the large particles will migrate to the outside and the flour-like small particles and trash will remain at the center of the cone. This results in a very uneven airflow through each portion of the grain bin. Most of the air will pass up the outside of the bin through the larger and cleaner grain. A level height should be maintained through the filling process. Once particle separation occurs, it is hard to correct even if the bin is later shoveled level.

Air temperature is important when drying rice. When air is being pushed through deep depths for prolonged periods of time, the air temperature should not exceed 105 F (Figure 9-3). If higher temperatures are used, the rice kernel can be overheated, resulting in low milling characteristics. Commercial dryers can use much higher air temperatures than on-farm dryers because the rice is subjected to heated air for shorter periods of time. Rice can be successfully dried on the farm, but different management techniques are necessary than when drying commercially.

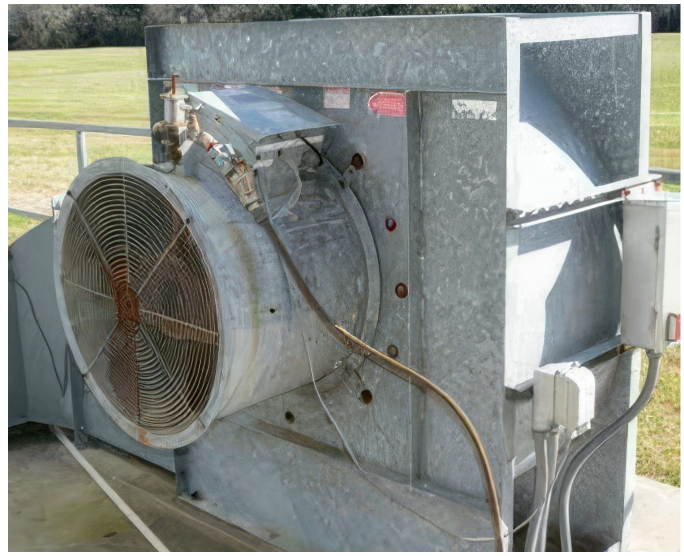


Figure 9-1. Centrifugal fan.

Figure 9-2. Blades of a centrifugal fan.

Figure 9-3. Temperature is critical in drying rice.

Some of the main causes of problems that occur with on-farm drying are:

1. Hurrying the drying process to make room for freshly harvested rice.
2. Using drying temperatures that are too high, resulting in extremely low humidity drying air causing over-dried and stress-cracked rice and low head rice yields.
3. Attempting to dry with insufficient airflow, usually caused by excessive depth of high moisture rice.
4. Lack of attention after rice has been dried to at least 13%.
5. Harvesting rice with a moisture content in excess of 20% to be dried in on-farm facilities.
6. Inadvertently rewetting dried rice by aerating with high humidity air. Usually occurs if fans are run night and day with no addition of heat at night.

Suggested Steps for On-farm Rice Drying

1. Harvest rice at 20% or less and avoid attempting to dry rice on the farm if the moisture at harvest exceeds 20%.
2. Clean the rice to be dried as much as practical by adjusting harvesting equipment to minimize the amount of foreign material.
3. Determine the rice moisture content of incoming rice and avoid mixing rice of different moisture contents once its moisture content has reached 15% or less.
4. Place the rice harvested first in the drying bin at a depth of 6 to 12 feet. When layer drying, this depth is dependent on the initial moisture content of the rice and the capabilities of the fan.
5. Level the rice equally across the entire drying bin at the depth selected. It is very important to level the rice in order to equalize the pressure throughout all horizontal cross-sections of the bin to obtain uniform airflow.
6. Open air exits so that air can exhaust readily from the drying bin.
7. Turn on the fans as soon as the ducts or the perforated floor is covered with approximately 1 foot or more of rice.
8. If possible, do not hold wet rice in a bin, truck, combine hopper or grain cart longer than 12 hours without moving air through the container to cool the rice.
9. Measure the relative humidity and temperature of the ambient air to determine the maximum temperature setting of the heater.
10. Exercise extreme caution when rice kernel temperature exceeds 100 F.
11. Dry high moisture rice in shallow batches until the rice moisture content is 15% or less. Then, deeper depths with lower airflow requirements are acceptable.
12. Drying time per batch is dictated by air flow rate, measured as cubic feet per minute (CFM) per hundred weight (cwt), temperature difference between air entering and leaving the rice, the moisture content of the ambient air, and the original moisture content of the rice.
13. The best way to reduce drying time is to increase airflow.
14. Once the rice has reached 15% moisture, move it to another bin where the depth can be increased and the airflow per cwt can be decreased. Continue drying by controlling relative humidity of the drying air.
15. Once the rice is 12.5% to 13% grain moisture through the entire depth of storage, fill the storage bin and level the grain surface.
16. Aerate to cool the grain kernels for the next few weeks when the humidity is below 60% and the air is cool (50 F to 60 F).
17. Do not operate fans when ambient temperature is below 32 F.
18. Probe the bin periodically (once a week is ideal) for temperature or moisture variation.
19. Normally, the first place that moisture migration will occur is the center of the top layer. If there is any indication that moisture or temperature is increasing in this area or other areas, turn on the fans to cool and/or dry moistened rice.
20. Do not let any spoiled rice mix with good rice.
21. Periodic aeration may be necessary to counter extreme temperature changes during storage.

Rice Production Economics

Michael Deliberto

Production Costs

In Louisiana, rice is produced under different types of agronomic production systems. Rice can be water seeded by airplane onto a flooded field, drill seeded by tractor and grain drilled on a dry field, or broadcast onto a dry seedbed by air or ground equipment. Rice can be produced in a crop rotation, following soybeans or crawfish, or it may be produced following a fallow (idle) year. Tillage operations may involve stale seedbeds or include conventional operations. The types of rice varieties produced in Louisiana may be conventional, herbicide-resistant, or hybrid. Sources of irrigation water may be from a deep well groundwater source or a surface canal source. All these production system options have a direct impact on the structure of rice production costs.

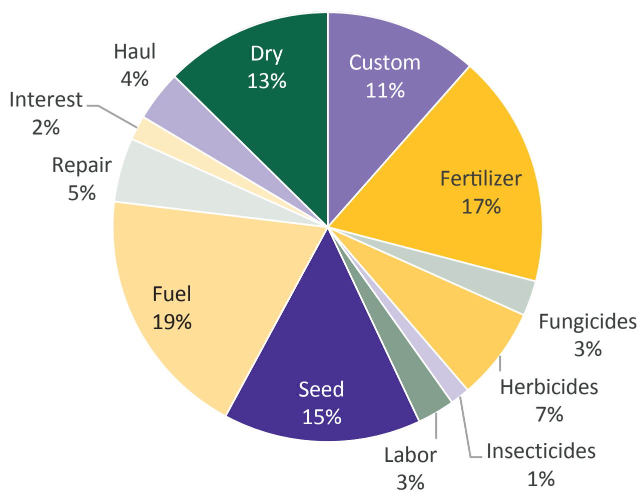


Figure 10-1. General variable production cost structure of rice produced in southwestern Louisiana, 2018-2022 average.

Figure 10-1 provides a general percentage breakdown of the major production cost items associated with rice production in Louisiana. Fuel costs for irrigation pumping and machinery (19%) and fertilizer costs (17%) account for a 36% share of the variable production costs per acre. Other major costs are seed (15%) and drying (13%). Irrigation pumping costs are generally lower for surface water sources in southwestern Louisiana and for both water sources in northeastern Louisiana. Total variable production costs for conventional and herbicide-resistant rice in Louisiana range between $600 to $700 per planted acre. Total variable costs for hybrid rice production systems can range between $750 to $800 per planted acre. Total fixed equipment production costs are in the range of $70 to $90 per acre. In southwestern Louisiana, a portion of the rice acreage is ratoon cropped each year. This second production period following the first crop harvest generally entails application of nitrogen fertilizer, reflooding the field for a period of time, then draining the field just prior to harvest.

Most of the rice acreage in production in Louisiana is produced in land that a grower leases from a landowner with share rental arrangements being the most common. Under these types of rental arrangements, the grower and landowner each pay a specified portion of the production expenses. A survey of rice growers in the state indicated that the two most common types of rice share rental arrangements were: (1) an 80/20 arrangement where the grower received 80% of the crop market and farm program income and paid all of the variable production expenses, including irrigation pumping costs, with the exception of 30% of the drying expense paid by the landowner who received 20% of the crop market and farm program income; and (2) a 60/40 arrangement where the grower received 60% of the crop market and farm program income and paid all variable production expenses, excluding irrigation pumping and 40% of fertilization, pesticides and drying expenses paid by the landowner who received 40% of the crop market and farm program income. Some rice tracts are leased under a cash rental arrangement. In these cases, the grower generally pays all production expenses and receives 100% of the crop market and farm program income. Average cash rental rates, based upon the same survey data, were in the range of $75 to $125 per planted acre.

Farm Programs

Rice is one of several commodities produced in the United States whose price/income is supported by the federal government though various farm programs, commonly referred to as farm bills. Current rice farm program provisions are specified in the Agricultural Act of 2018 (2018 Farm Bill). Although the specific mechanisms to support rice market prices have varied from one farm bill to the next, the basic farm policy tools utilized over the years has remained relatively similar. Under the 2018 Farm Bill, farmers and landowners can choose between three commodity title alternatives: ARC-CO (payment based on county revenue), ARC-IC (payment based on individual farm revenue) and PLC (payment based on market year average). Listed below are definitions for several terms unique to the rice farm program.

ARC program: The ARC-CO program provides income support tied to historical base acres, not current production, of covered commodities. ARC-CO payments are issued when the actual county crop revenue of a covered commodity is less than the ARC-CO guarantee for the covered commodity.

Base acres: The acres of established rice base on which price/income support payments are based. Regardless of whether actual planted rice acreage in a given year exceeds or is less than a farm's established rice base acres, rice program payments are always the based and paid on a percentage of base acre.

Covered commodities: This includes wheat, oats, barley, corn, grain sorghum, rice, soybeans, sunflower seed, rapeseed, canola, safflower, flaxseed, mustard seed, crambe and sesame seed, dry peas, lentils, small chickpeas, large chickpeas and peanuts.

Decoupled payment: A general class of farm program payments that are based on established program yields and price levels rather than actual market prices and production yields.

Loan deficiency payment: Program payments are made to rice growers when market prices are below the loan rate. In the case of rice, when the world rough rice price is below the loan rate, loan deficiency payments are made to growers as the difference between the loan rate and the world market price. Unlike other rice program payments, loan deficiency payments are paid on actual production rather than established program acres or yield.

Loan rate: The minimum level of income support on a price per unit basis. The loan rate represents a floor price. In general, if market prices fall below the loan rate, the government will purchase rice at the loan rate value and take ownership of the commodity. In an effort to prevent the federal government from accumulating stocks of commodities such as rice, the marketing loan program was developed, which basically pays the rice grower the difference between the loan rate and a lower market price and allows the grower to maintain ownership of the commodity.

Payment acres: The portion of established base acres on which rice price/income support payments are determined and paid. For the past several farm bills, program payments for rice, as well as for other covered commodities, were paid on 85% of established base acres, which are referred to as program payment acres.

PLC program: PLC program payments are issued when the effective price for a covered commodity falls below the respective reference price for that commodity. The effective price equals the higher of the market year average price (MYA) or the national average loan rate for the covered commodity.

Program yield: The yield per acre value that is used in determining rice program payments.

Reference price: prices for covered commodities set in Title I of the 2018 Farm Bill that apply for 2018-2023 crops and are used in the PLC and ARC programs. The reference price is the maximum level of income support on a price per yield unit basis. Income support program payments are determined as the difference between the reference price and some lower price level. If market prices are above the reference price, certain program payment values fall to zero.

Marketing

More than half of the rice produced in the United States is marketed domestically with the remainder being exported. The domestic rice market has more than doubled over the past 25 years. Approximately 75% of domestic rice use is for food use, both directly and in processed foods. Direct food use of rice accounts for 60% of total use, while use of rice in processed foods (package mixes, cereal and rice cakes) accounts for about 15% of total use. Of the remaining domestic use of rice, roughly 10% is used in pet food and 15% is used in beer production.

About 65% of rice exported is in milled form with the remaining 35% exported as rough rice. Latin America is the primary export market for U.S. rice. Leading U.S. rice export customers by volume include Mexico, Haiti, Japan, Venezuela, Canada, Costa Rica, South Korea, Jordan, Honduras, Saudi Arabia, Columbia, Guatemala, El Salvador, Libya and Turkey. Because such a large portion of U.S. rice production is exported, the global rice market has a significant impact on U.S. domestic price levels The U.S. is essentially a price-taker in the world rice market, with Thailand and India driving world market price dynamics.

Futures contracts for U.S. rough rice are traded on the Chicago Board of Trade (CBOT). The main functions of a futures market are price risk management and price discovery. Price risk can be managed by hedging rough rice contacts on the exchange. Hedging provides an opportunity to lock in a rough rice price, as gains or losses in the cash market are usually offset by the positions held in the futures market. Use of the futures market to manage price risk is available to rice producers, mills, merchandisers, food processors, exporters and importers. The futures market also provides a means of price discovery for the rice industry. Daily quotes of rough rice prices for future delivery serve as predictions of what buyers and sellers in the rice market expect prices to be at that time. Contract specifications for the rough rice futures contracts traded on the CBOT, along with grades for rough and milled rice are shown in the following tables.

Table 10-1. Rough rice futures contract specifications from the CBOT.

Contract Size	2,000 hundredweight (cwt)
Deliverable Grades	U.S. No. 2 or better long-grain rough rice with a total milling yield of not less than 65%, including head rice of not less than 48%. Premiums and discounts are provided for each percent of head rice over or below 55% and for each percent of broken rice over or below 15%. No heat-damaged kernels are permitted in a 500-gram sample and no stained kernels are permitted in a 500-gram sample. A maximum of 75 lightly discolored kernels are permitted in a 500-gram sample.
Tick Size	$0.005 per cwt ($10 per contract)
Price Quotes	Cents per cwt
Contract Months	September, November, January, March, May and July
Last Trading Day	Business day prior to the 15th calendar day of the delivery month.
Last Delivery Day	Seventh business day following the last trading day of the month.
Trading Hours	Sunday-Thursday, 7-9 p.m. CT and Monday-Friday, 8:30 a.m.-1:20 p.m. CT. Trading in expiring contracts closes at noon on the last trading day.
Ticker Symbols	Open auction: RR; Electronic: ZR
Daily Price Limit	$1.20 per cwt ($2,400 per contract). Expanded limit $1.80.

Source: Chicago Board of Trade.

Table 10-2. Grades and grade requirements for the classes of rough rice. (Table represents maximum limits.)

Grade	Total (Slightly or Combined) Seeds and Heat-Damaged Kernels	Heat-Damaged Kernels and Objectionable Seeds (Singly or Combined)	Heat-Damaged Kernels	Red Rice and Damaged Kernels (Singly or Combined %)	Chalk in Long-Grain Rice (%)	Chalk in Medium- or Short-Grain Rice (%)	Other Types (%)	Color Requirements (Minimums)
U.S. No. 1	4	3	1	0.5	1.0	2.0	1.0	Shall be white or creamy
U.S. No. 2	7	5	2	1.5	2.0	4.0	2.0	May be slightly gray
U.S. No. 3	10	8	5	2.5	4.0	6.0	3.0	May be light gray
U.S. No. 4	27	22	15	4.0	6.0	8.0	5.0	May be gray or slightly rosy
U.S. No. 5	37	32	25	6.0	10.0	10.0	10.0	May be dark gray or rosy
U.S. No. 6	75	75	75	15.0	15.0	15.0	10.0	May be dark gray or rosy

Note: U.S. Sample grade shall be rough rice that: (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 6, inclusive; (b) contains more than 14% of moisture; (c) is musty or sour, or heating; (d) has any commercially objectionable foreign odor; or (e) is otherwise of distinctly low quality.

Source: U.S. Standards for Rough Rice, USDA.

Table 10-3. Grades and grade requirements for the classes of long grain, medium grain, short grain and mixed-milled rice. (Table represents maximum limits.)

Grade	Seeds, Heat Damaged, and Paddy Kernels (Single or Combined), Total (Numberin 500 Grams)	Heat-Damaged Kernels and Objectionable Seeds (Number in 500 Grams)	Red Rice and Damaged Kernels (Singly or Combined)	Chalky Kernels in Long Grain Rice (%)	Chalky Kernels in Medium or Short Grain Rice (%)	Broken Kernels Total (%)	Broken Kernels Removed by a 5 Plate (%)	Broken Kernels Removed by a 6 Plate (%)	Broken Kernels Through a 6 Sieve (%)	Whole Kernels (%)	Whole and Broken Kernels (%)	Color Requirement (Minimum)	Milling Requirement (Minimum)
U.S. No. 1	2	1	0.5	1.0	2.0	4.0	0.04	0.1	0.1	--	1.0	Shall be white or creamy	Well-milled
U.S. No. 2	4	2	1.5	2.0	4.0	7.0	0.06	0.2	0.2	--	2.0	May be slightly gray	Well-milled
U.S. No. 3	7	5	2.5	4.0	6.0	15.0	0.1	0.8	0.5	--	3.0	May be light gray	Reasonably well-milled
U.S. No. 4	20	15	4.0	6.0	8.0	25.0	0.4	1.0	0.7	--	5.0	May be gray or slightly rosy	Reasonably well-milled
U.S. No. 5	30	25	6.0	10.0	10.0	35.0	0.7	3.0	1.0	10.0	--	May be dark gray or rosy	Lightly milled
U.S. No. 6	75	75	15.0	15.0	15.0	50.0	1.0	4.0	2.0	10.0	--	May be dark gray or rosy	Lightly milled

Note: U.S. Sample grade shall be milled rice of any of these classes that: (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 6, inclusive; (b) contains more than 15% of moisture; (c) is musty or sour, or heating; (d) has any commercially objectionable foreign odor; (e) contains more than 0.1% of foreign material; (f) contain two or more live or dead weevils or other insects, insects webbing or insect refuse; or (g) is otherwise of distinctly low quality.

Source: U.S. Standards for Milled Rice, USDA.

Glossary

Abiotic – Literally "without life," refers to problems not caused by pathogens.

Active ingredient (ai) – Component of a pesticide that has toxic activity against the pest in contrast to the inert or inactive ingredients.

Adventitious – Refers to a structure arising from an unusual part, such as roots growing from stems or leaves.

Amylographic – Spectrographic analysis of starch.

Amylopectin – A polymer of glucose associated with the outer layers of starch grains; higher content makes rice cook stickier.

Amylose – Type of starch in rice grain; higher content makes rice cook drier.

Anaerobic – Literally "without air," refers to an organism able to live and grow without air or oxygen.

Antagonistic – Decreased activity of an organism or chemical from the effect of another organism or chemical.

Apical meristem – Rapidly dividing cells at the tip of plant organs such as roots and stems; the growing point.

Ascospores – The sexual spores of one group of fungi.

Auricle – An ear-shaped structure at the junction of the leaf blade and leaf sheath of grasses such as rice.

Axillary bud –A bud located between the leaf sheath and stem where the leaf sheath attaches to the stem.

Bacterium (pl. bacteria) –A one-celled microscopic organism that lacks chlorophyll and multiplies by fission (splitting apart).

Biological control – Disease control by means of predators, parasites, competitive microorganisms and decomposing plant material that restrict or reduce the population of the pathogen.

Biotype – Genetic variant of a species.

Boot –Growth stage of rice when the panicle is more than 1 inch long but before emergence (heading).

Brewers –Smallest size kernels of broken milled rice that is less than one-quarter of the whole kernel.

Broken yield – Pounds of broken grain milled from 100 pounds of rough rice (total milling yield – head milling yield).

Brokens – Milled rice kernels that are smaller than three-fourths of the whole kernel. This includes second heads, screening and brewers.

Brown rice –Rice kernels with only the hulls removed.

Carbohydrate – A class of organic chemicals composed of carbon, hydrogen and oxygen; in plants, photosynthesis-produced sugars and starch are examples.

Chevrons – Stripe-like pattern consisting of several curved or V-shaped bands.

Chlorophyll – Green pigment associated with photosynthesis.

Chlorosis – Yellowing of normally green tissue caused by the destruction of chlorophyll or the partial failure of chlorophyll to form.

Coalesce – The coming together of two or more lesions to form a large spot or blotch.

Coleoptile – The protective covering of an emerging shoot; it is not the true leaf.

Commingled rice – Rice that has been blended with other rice of similar grain type, quality and grade.

Conidiophore –Specialized hypha-bearing asexual spores called conidia.

Conidium (pl. conidia) –A spore formed asexually, usually at the top or side of a specialized hypha (conidiophores).

Crown – Junction between stem and root.

Culm – The jointed stem of grass.

Damage – Economic loss to a crop caused by an insect, disease or injury.

Dead heart – Condition where the growing point (apical meristem) of the stem dies.

Debris – The crop residues left from the previous crop.

Denitrification – Conversion of nitrate nitrogen to gaseous nitrogen.

Dough – The stage when the endosperm of the grain has begun to solidify.

Drift – The spread of airborne spray droplets to nontarget areas.

Drying – Removal of kernel moisture to obtain a safe storage condition (12.5% moisture).

Eclosing – Emergence of an insect from its egg or a pupal case; hatching.

Economic injury level – The lowest pest density that will cause damage equal to the cost of control.

Economic threshold –The density of a pest at which control action must be taken to prevent a pest from reaching the economic injury level.

Embryo – The microscopically small plant at the base of a rice kernel. The germ.

Endemic – The normal presence of a pest in a crop year after year in less than epidemic amounts.

Endosperm – The stored food of a seed outside of the embryo composed mostly of starch in rice.

Enzyme –Protein specialized to catalyze chemical reactions related to metabolic activity necessary for growth.

EPA – Environmental Protection Agency, an agency of the U.S. government.

Epidermis – The outer layer of cells on all plant parts.

Epiphytotic or epidemic –The extensive development of a disease in a geographical area.

Etiology – The study of the causes of disease.

Fissuring – The cracking or breaking of grains prior to harvest caused by alternating periods of wetting and drying.

Flag leaf – The uppermost leaf of the rice plant, immediately below the panicle.

Floret – The rice flower including lemma, palea and reproductive floral parts.

Flush – Flooding of the field with drainage soon after for the purpose of keeping the seedbed moist.

Foliar –Of or referring to the leaves of a plant.

Fungus (pl. fungi) – An undifferentiated plant lacking chlorophyll and conductive tissues.

Gelatinization temperature – Index to classify the cooking types of long, medium and short grains.

Gibberellic acid (GA) –Plant growth hormone that stimulates elongation.

Glume – A tiny, modified leaf at the base of the rice kernel.

GMO – Genetically modified organism; usually refers to an organism into which a gene or genes not naturally found in that organism has been inserted.

GPA – Gallons per acre.

Green rice – Rough rice from which the excess moisture has not been removed (usually 18.5% to 22.5% moisture).

Green ring – Rice plant growth stage during which the tissue of the first internode appears green because of the accumulation of chlorophyll, indicates a change from vegetative to reproductive growth and the beginning of internode elongation.

Heading – The period during which panicles exert from the flag leaf sheath.

Head milling yield – Pounds of head rice milled from 100 pounds of rough rice.

Head rice – Milled rice kernels that are more than three-fourths of the whole kernel.

Head row – A short row of plants grown from the seed of a single panicle or head of rice.

Horizontal resistance – A uniform resistance against all races of a pathogen. The level of resistance is usually only moderate and often influenced by the environment.

Hulling – A process of removing husks from rough rice.

Hulls – Outer husk of the rice grain, usually a waste product but can be used in rice mill feed and as a filler for feed products. Actually the lemma and palea of the floret.

Hybrid rice – Rice produced from a single cross between two different lines. An F1 hybrid**.**

Hydrophopic – Resistant to wetting.

Hypha (pl. hyphae) – A single thread or filament of a fungus.

Imbibe – Absorption of water.

Infestation level – Percent of the population affected by a pathogen, or density of pest in a unit area.

Inflorescence – A flower cluster. In rice, it is a panicle.

Injury – Feeding by an insect on a crop but not necessarily causing economic loss.

Instant rice – Milled rice that is cooked, cooled and dried under controlled conditions and packaged in a dehydrated form. Before packaging, it is enriched with thiamine, riboflavin, niacin and iron.

Instar – The stage of an insect between molts.

Internode – The tissue of a rice stem between two nodes (joints).

Internode elongation –Jointing, the rapid lengthening of the tissue between nodes of a rice stem. Begins with accumulation of chlorophyll in the stage called green ring.

IPM – Integrated pest management; the reduction of plant pests through the combined use of various control practices.

Joint – The section of a stem defined by two nodes and the internode.

Key pest – A pest that causes economic loss in most years.

Label – Document accompanying a pesticide container giving specific information about a pesticide, also a legal document specifying how and when a product can be used.

Larva – The second developmental stage of insects with complete metamorphosis (egg, larva, pupa, adult). Larvae look different from adults, live in different places and feed on different food.

Lemma – The larger of two enclosing structures that form the hard outer covering (hull or husk) of a rice seed.

Lesion – A localized area of diseased tissue of a host plant.

Ligule – Structure found at the junction of the leaf blade and leaf sheath of a grass plant where the blade contacts the stem.

Lodging – The leaning or falling over of rice plants before harvest.

Long-grain rice – Rice that is long and slender, measuring 1/4 inch or more in length. Kernel size is 6.5 mm or more long, and the length-width ratio is from 3.27 to 3.41:1.

Main shoot – The first noticeable aboveground portion of a rice plant originating directly from the seed.

Medium-grain rice – Rice that is plump, measuring less than 1/4 inch long. Kernel size is from 5.37 to 6.06 mm or has a length-width ratio of from 2.09 to 2.49:1.

Meristem – Region of rapidly dividing cells.

Mesocotyl – Portion of the shoot between the seed and the cotyledon.

Metamorphosis – A change in form during development.

Milk – The stage when the endosperm of the grain is the consistency of milk.

Milled rice – Rice grain from which husks, bran and germ have been removed.

Milling – Processing the rough rice into milled or brown rice.

Mycelium (pl. mycelia) – A mass of fungus hyphae; the vegetative body of a fungus.

Neck – Region of the head consisting of the joint below the panicle.

Necrotic – Dead.

Nematode – Generally microscopic, unsegmented roundworm, usually threadlike, free-living or a parasite of plants or animals.

Node – The pronounced area of rice stem from which a leaf originates.

Nymph – The immature stage of insect with incomplete metamorphosis (egg, nymph, adult). Nymphs look similar to adults, live in the same place as adults and feed on the same food.

Occasional pest – A pest that sometimes causes economic loss.

Overwinter – A term used to describe a pest's ability to survive the winter. The overwintering stage and site are important.

Oviposition – The act of an insect laying an egg or eggs.

Palea – The smaller of two enclosing structures that form the hard outer covering of a rice seed.

Panicle – A type of inflorescence consisting of a main axis with branches arranged on it.

Panicle 2 mm – Same as panicle differentiation.

Panicle differentiation (PD) – Rice plant growth stage during which the panicle is recognizable as a small tuft of fuzz about 2 mm (1/8 inch) long.

Panicle initiation (PI) – Rice plant growth stage during which a specialized group of cells in the growing point begin to actively divide. It often corresponds to or closely follows green ring and can be positively identified only with magnification.

Parboiled rice – Rough rice soaked in warm water under pressure, steamed and dried before milling.

Parboiling – A process by which rough rice is steeped in water, steamed or heated to gelatinize starch, then subsequently dried.

Pathogen – A specific agent that causes infectious disease.

Pathogenic – Capable of causing disease.

Pedicel – The stem or stalk supporting the individual florets (grains) in the inflorescence.

Penultimate – The next to last syllable in a word.

Perithecium (Pl. perithecia.) – A flask or globe shaped sexual spore bearing structure with an opening at one end characteristic of certain fungi.

Pest – Any destructive organism that competes with humans.

pH – A measure of the acidity or alkalinity of soil, water or solutions. Values range from 0 to 14 with 7 being neutral, less than 7 acidic and above 7 alkaline.

Photosynthesis – The process by which plants absorb light and in the presence of chlorophyll convert carbon dioxide and water to glucose and oxygen.

Physiological – Of or relating to processes in cells, tissues and organs associated with growth and development of an organism.

Phytotoxic – Having the ability to cause injury to a plant.

Pollination – Transfer of pollen from the male to female flower structures.

Precooked rice – Milled rice that has been processed by various methods to make it cook quickly.

Processed rice – Rice used in breakfast cereals, soups, baby foods and packaged mixes.

Pupa – The third stage of insects with complete metamorphosis (egg, larva, pupa, adult). A pupa does not feed but is in a resting stage.

Pycnidium (Pl. pycnidia) – A spherical or flask shaped asexual spore-producing structure characteristic of some fungi.

Radicle – First root of a germinating seed.

Ratoon crop (second crop) – Production of harvestable rice from regrowth of rice from the stalks harvested earlier.

Resistance – The inherent ability of a host plant to suppress, retard or prevent entry or subsequent activity of a pathogen or other injurious factor.

Rice bran – Tissue directly beneath the hull containing the outer layers of the seed coat and parts of the germ. Bran is rich in protein and vitamin B. It is used as livestock feed and vitamin concentrates. It is part of the fiber of whole grains.

Rice polish – A layer removed in the final stages of milling that is composed of the inner layers of the seed coat. It is rich in protein and has high fat content; used in livestock feed and baby food.

Rough rice (paddy) – Rice grains with the hulls, but without any part of stalk; consists of 50% or more of paddy kernels (whole or broken unhulled kernels of rice).

Saprophytic – Referring to an organism that derives its nutrition from dead or decaying organic matter.

Saturated soil – Condition when all soil pore spaces are full of water.

Scenescence – The process of aging leading to death after the completion of growth in plants and individual plant parts.

Sclerotium (pl. sclerotia) – Dense, compacted mass of hyphae, resistant to unfavorable conditions and can remain dormant for long periods; able to germinate when favorable conditions return.

Screenings – Broken milled rice that is more than one-half of the whole kernel size.

Second heads – Largest size of broken milled rice that is more than one-half of the whole kernel size.

Semidwarfs – Plants changed genetically to a reduced plant height.

Shoot – New growth originating from a crown in rice.

Short-grain rice – Rice that is almost round. Kernel size ranges from 4.56 to 5.01 mm in length, and the length-width ratio varies from 1.66 to 1.77:1.

Skipper – A group of insects closely related to moths and butterflies. Adult skippers have knobs on the end of antennae (similar to butterflies), and the antennae are widely spaced on the head (similar to moths).

Sorus (Pl. sori) – A compact group of spores or spore-bearing structures associated with certain fungi.

Spikelet – In rice, a single floret, below which are two reduced bracts. Each bears a single grain.

Spore – A minute propagative unit that functions as a seed but differs from it in that a spore does not contain a preformed embryo. The fruit of certain fungi.

Spreader variety – A variety very susceptible to a given disease that is planted among test varieties or lines to serve as a source of disease inoculum.

Stale seedbed – Seedbed prepared several weeks or months prior to planting. A component of reduced tillage management.

Stooling – Tillering.

Straighthead – Physiological disorder characterized by sterile, deformed seeds and upright panicles.

Stubble – Rice stalks and their associated crowns remaining after harvesting.

Sun checking – Fissuring.

Suppression – The act of reducing or holding back rather than eliminating.

Susceptibility – The inability of a plant to resist the effect of a pathogen or other damaging factor.

Tiger moth – A group of moths with hairy caterpillars (the woolly bear).

Tiller – A young vegetative shoot arising from nodes at the base of the plant; most can produce a panicle.

Tillering – The period during which tillers are formed, usually beginning at the four- to five-leaf stage and continuing until early reproductive growth. Also the process of forming tillers.

Tolerance – Amount of pesticide that can safely remain in or on raw farm products at time of sale, or the ability of a plant to yield equally under diseased condition as healthy.

Total milling yield – Pounds of head, brewers, second heads and screenings milled from 100 pounds of rough rice.

White rice – Total milled rice after the hulls, bran layer and germ are removed. This includes head rice and broken rice.

Y-leaf – The most recently expanded leaf, at least three-fourths unfurled. The leaf is usually selected for tissue analysis.

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