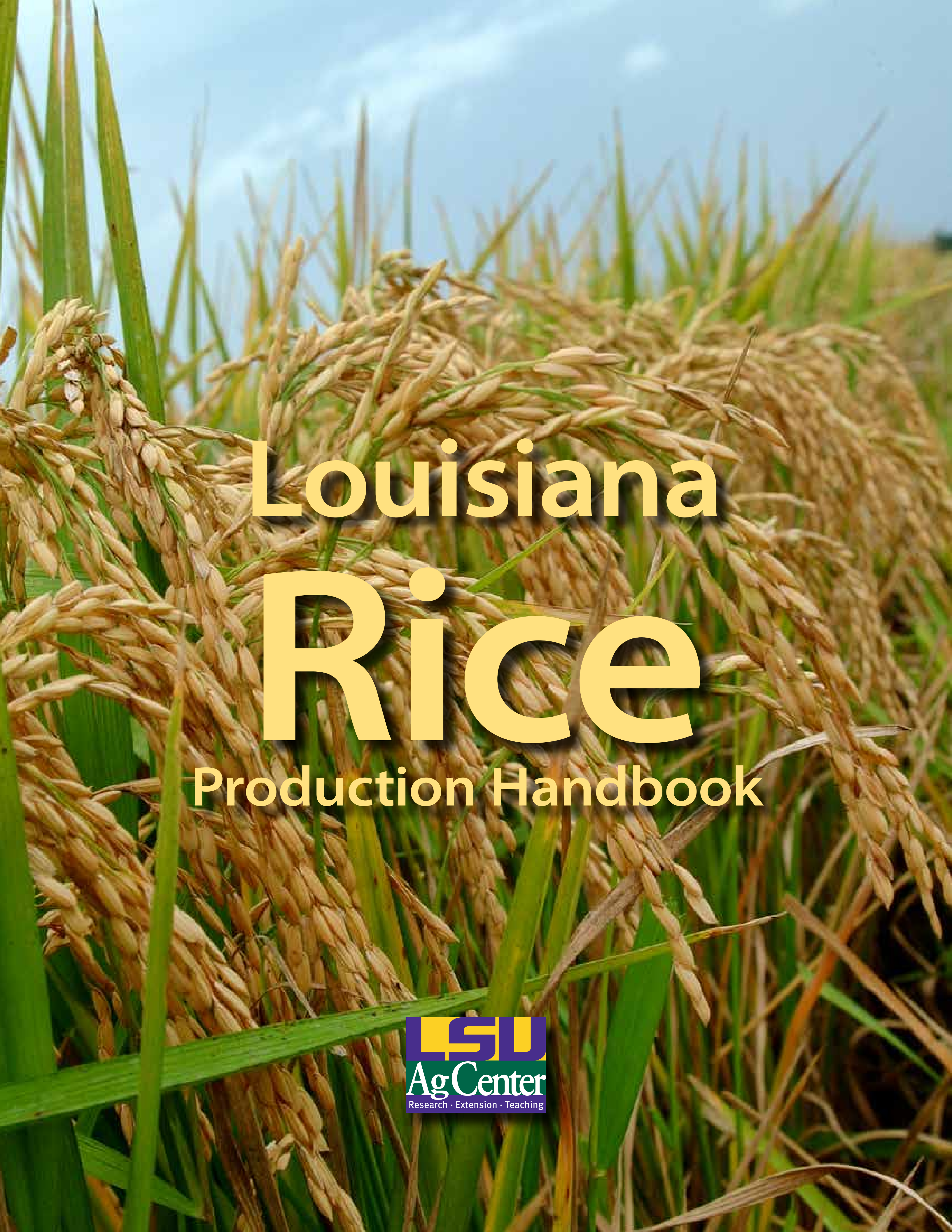

Louisiana Rice Production Handbook

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Louisiana Rice Production Handbook

Foreword

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 three 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 2009. The 2009 edition was so popular it became apparent supplies of printed copies would be exhausted well before the anticipated ten year revision anniversary would be reached. Rather than re-print that edition the authors decided to update it with new information, better and more photographs and the latest in 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
Johnny Saichuk

Table of Contents

Foreword 1
General Agronomic Guidelines 3
Rice Varieties and Variety Improvement 17
Soils, Plant Nutrition and Fertilization 24
Rice Growth and Development 41
Weed Management 54
Disease Management 82
Invertebrate Pest Management 106
Rice Drying on the Farm 126
Rice Production Economics 130
Glossary 133
Appendix 139
Contributing Authors 144

Chapter 1

General Agronomic Guidelines

Dustin Harrell and Johnny Saichuk

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 (Fig. 1-1). Some slope is required, however, to facilitate adequate drainage even though the practice of growing rice on "zero grade" or level fields has gained in popularity (Fig. 1-2). Generally, a slope of less than 1 percent 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.

Fig. 1-1. More slope requires more levees.

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

Fig. 1-2. Zero grade field.

Fig. 1-3. Laser leveling.

of land forming (Fig. 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 and is termed water leveling (Fig. 1-4).

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.

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

Fig. 1-4. Water leveling.

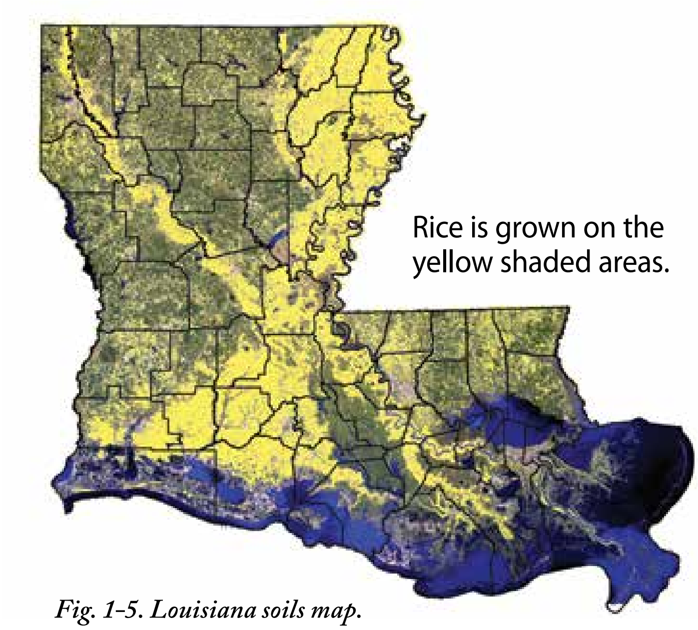


Fig. 1-5. Louisiana soils map.

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 (Fig. 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 essence, small ponds.

Experimentation with rice production under upland or nonflooded conditions in Louisiana has not been successful.

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 2 to 4 days, flooded in 4 to 5 days and drained, dried and re-flooded in 2 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.

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 (Fig. 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.

Fig. 1-6. Using polypipe for irrigation.

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 1 month that is acceptable for planting.

LSU AgCenter recommendations for planting rice are from March 10 to April 15 in Southwest Louisiana and April 1 to May 5 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 degrees 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 Clearfield technology, 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 percent 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.
- Where seed depredation by blackbirds is potentially high.

Fig. 1-7. Drilling seed into stale seedbed.

- 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 (Fig. 1-7).

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 4 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 3 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 percent 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 (Fig. 4-10), or beginning internode elongation (IE)] and panicle differentiation (PD) (1/2 inch IE) (Fig. 4-11).

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 4- to 5-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.

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-size), 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 3 to 4 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

Fig. 1-8. Aircraft sowing seed.

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.

Fig. 1-9. Loading aircraft with seed.

Fig. 1-10. Presprouted seeds.

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 (Fig. 1-9). Presprouted seed offers the advantages of higher seed weight and initiation of germination because the seed has already imbibed water (Fig. 1-10). Presprouting is accomplished by soaking seed for 24 to 36 hours followed by draining for 24 to 36 hours prior to seeding (Fig. 1-11) 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.

Fig. 1-11. Soaking seeds.

Delayed-flood System

In a delayed-flood system, fields are drained after water seeding for an extended period (usually 3 to 4 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 (Fig. 1-12). A 3- to 5-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 4-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.

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 (P), potassium (K), sulfur (S) and zinc (Zn) fertilizers are

Fig. 1-12. Emerged seedlings ready for pinpoint flood.

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.

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 used in DD-50-based predictions 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 August 15. The main crop should be harvested by August 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 main-crop harvest 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. Recent 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 August 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 grow a ratoon crop are nitrogen (N) 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-go" 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 August 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 August 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 this 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 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 post-harvest flail mowing or bush hogging to around 8 inches, and rolling the stubble have all shown a yield benefit in studies conducted at the 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 approximately 2 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 recent study at the Rice Station, application of a fungicide 4 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 make a decision to attempt a ratoon crop when the main crop was harvested after August 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 September 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, 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 3 to 6 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 (Fig. 1-13). Rice establishment practices used in conservation tillage systems are described below.

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 7- 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 Control 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

Fig. 1-13. Drilling seed into standing vegetation.

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 2 to 3 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 (P) and potassium (K) 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 spring-applied 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 5-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.

Chapter 2

Rice Varieties and Variety Improvement

Steve Linscombe, James Oard and Larry White

Development of superior rice varieties has been an important tool for improving rice production in Louisiana and in the United States. Release of improved varieties by public breeding programs in Louisiana, Texas, Arkansas, Mississippi and California, in conjunction with advancements in rice production technology, has provided a continuous increase in rice production and quality. Considerable genetic potential exists to improve on current rice varieties, and rice breeding efforts should continue to help increase rice yield and profitability in Louisiana.

Rice Varietal Improvement Program

In the early days, Louisiana rice production depended on varietal introductions by individuals. In 1909, the first rice breeding program in the United States was initiated when the Rice Research (Experiment) Station was established at Crowley. The rice breeding activities there were under the direction of USDA scientists from the inception of the program until the Louisiana Agricultural Experiment Station (LAES) assumed responsibility for the program in 1981. The Rice Research Station has a long history of developing new varieties that benefit the Louisiana rice industry. Additional research projects were added over time, but variety development has always been a major focus of the station's research activities. Since its inception, the program has formally released 49 improved rice varieties (Appendix Table 1).

Variety development efforts require a great deal of time, money, hard work and travel by those involved, specialized field and laboratory equipment, and a high level of cooperation with producers and other research personnel. The first step in the development of a new variety is to cross two different rice lines (parents). Depending on the choice of parents, subsequent generations will exhibit a variety of genetic combinations that will provide the basis for future yield and quality advancements. Since the rice flower is perfect (contains both the male and female flower parts), a female flower must be created artificially by removing the male flower parts (anthers) from a rice floret. First the tips of the lemma and palea (hull) are snipped off to expose the floral parts (Fig. 2-1). The pollen bearing structures, the anthers, must be removed to prevent self fertilization. Normally, this is accomplished by using a small pipette connected to a vacuum pump that vacuums the anther out of the flower (Figs. 2-1, 2-2 and 2-3). This is a very tedious process that must be done in a meticulous manner to prevent abortion of the rice seed. The next step is to introduce pollen (male) from a different line and pollinate the female flower.

Over 1,000 such crosses are typically made at the Rice Research Station each year. The resulting seed from these crosses will contain genetic information from both parents. This seed is called the F_1 generation and germinated to produce F_1 plants. At maturity, seed is harvested from the F_1 plants. This seed is bulk-planted the following growing season to produce a population of segregating F_2 plants. Segregation means there is a great deal of variation in the appearance of these plants since they are expressing traits from both parents in many different combinations. The F_2 generation will exhibit more variation than any other population in the breeding process. Selection in the F_2 populations is a very important step in the variety development process. Breeders attempt to select those plants with the best combination of traits. Selection criteria generally include (but are not limited to) seedling vigor, maturity, height, tillering (number and uniformity), panicle size, completeness of panicle exsertion, grain shape and appearance, lack of grain chalk, disease resistance and overall plant appearance. Individual panicles are selected from those plants expressing the best combinations of the traits listed above for advancement to the next generation and beyond.

From this point on (F_3-F_n), most of the breeding material is grown as panicle (head) rows. A panicle row is a row of plants all derived from seed harvested from a single panicle. The best rows will be selected (not individual plants) to advance to the next generation. With each succeeding generation, the amount of segregation is decreased (or the level of uniformity is increased) both naturally and through the selection process. Thus, the F_4 generation is more uniform than the F_3 from which it was derived and the F_5 generation is more uniform than the F_4 generation and so on. Each year, approximately 95,000 to 120,000 panicle rows are grown at the Rice Research Station in the various breeding projects. Each of these rows is a unique genotype and any of them could theoretically become a new variety.

A tremendous amount of meticulous work must be done before these rows are planted. The seed from

Fig. 2-1. Preparing to remove the anthers with vacuum.

Fig. 2-2. Anthers being aspirated.

Fig. 2-3. Anthers removed. Floret emasculated.

each row must be individually threshed. A specialized panicle thresher is used to accomplish this, but it was not too many years ago that this was all done by hand. Specialized planters are also used to plant the individual rows. It requires a great many hours of careful work to prepare and arrange this seed for planting in such a way as to avoid mistakes.

Lines from most of the crosses have reached sufficient uniformity by the F_4 to F_5 generation to enter a line into a preliminary yield evaluation. Lines that are selected for potential yield evaluation are bulk harvested (after several panicles have been selected and harvested). Bulk harvesting of individual rows is done the "old-fashioned" way. Each selected row is harvested by cutting the stalks with a sickle and tying the harvested stalks with a length of twine. Each individual row is threshed, cleaned and dried on a small sample drier. Several thousand rows are handled this way each summer.

During the following winter, a number of laboratory analyses are conducted on each harvested sample (grain appearance and milling, cereal chemistry and seedling vigor), and the superior lines are entered into the initial yield testing program, which is called the Preliminary Yield Tests. Some of these are two-replication tests while a number of lines are evaluated each year in single plot tests. These trials are planted in March on the Rice Research Station. This planting time will allow a sufficient growing season to evaluate first and ratoon (second) crop performance. A "plot" in the Rice Breeding Project is seven drill rows spaced 8 inches apart 16 feet long (or approximately 75 square feet). This represents approximately 0.17 percent of an acre.

These small plots are used to keep the overall test as small as possible in an effort to minimize environmental variations that might influence the performance of genotypes (breeding lines) in the tests. It is critical that any differences expressed in these trials (yield, milling quality, height, etc.) are a result of true genetic differences and not caused by differences such as soil type, fertility or water depth.

Approximately 3 weeks after the preliminary yield trials are planted, a seed increase/purification block is planted that will include 9 to 14 headrows from each of the lines included in the yield trial. This increase block is planted later than the yield evaluations to provide time to analyze data and determine which lines may be advanced, and thus, which headrow populations should be harvested. Prior to harvest, these lines are evaluated and any segregating rows (rows with too much variation within the row) are removed from the population, 25 panicles are picked from a representative row, then the remaining seed is bulk harvested. The 25 panicles will serve as a pure seed source, and the bulked seed will provide enough seed for advanced testing in multilocation yield trials.

A typical preliminary yield test has 750 entries replicated twice for a total of 1,500 plots. These tests also include commercially grown varieties so that the performance of the experimental lines can be compared with these as well as to each other. Preliminary yield trials at the Rice Research Station utilize approximately 5 acres. If everything goes without a hitch, this test can be planted in less than a day with specialized planting equipment. However, preparing the seed for this planting (cleaning, cataloging, weighing, labeling and filling seed envelopes, laying out packets in planting order, etc.) is the result of many months of meticulous work during the winter. In addition, a great deal of data entry and recordkeeping is involved as lines move from one generation to the next.

After planting, this yield trial is managed similar to any other rice field to optimize production and uniformity throughout the test area. The process includes timely water management, fertilization and weed and insect control. Fungicides are not used in the breeding program because relative disease-resistance among the experimental lines is evaluated at every step of the variety development process.

These trials are evaluated at least twice weekly during the growing season, and data are collected for the following traits: (1) emergence date, (2) seedling vigor, (3) tillering characteristics, (4) heading date, (5) plant height at maturity, (6) disease susceptibility (any diseases present), (7) lodging characteristics and (8) harvest maturity date. When a plot reaches harvest maturity, a hand-harvested sample is taken for use in milling quality evaluation. This sample is cut with a sickle, threshed using a stationary thresher, aspirated (removing chaff and stems) and dried on a specialized sample dryer. This sample is taken this way because the entire test will be harvested with a small plot combine when all plots have reached harvest maturity. Since there may be up to 10 days difference in maturity among lines in these trials, taking a sample from each plot at harvest maturity puts all lines on an equal footing for milling quality evaluation.

Prior to harvest, all experimental lines are evaluated for relative susceptibility to major and minor rice diseases. Because we often do not have consistent disease pressure in these tests, these lines are also planted in disease nurseries where disease pressure is maximized by inoculation (sheath blight and bacterial panicle blight) and the use of highly susceptible spreader varieties (blast).

When all lines in a trial have reached harvest maturity, the trial is harvested using a specialized small plot combine. This combine has a 5-foot header width so it fits these plots perfectly. The combine has the capability to harvest a plot and automatically obtain the grain weight and grain moisture for the rice from that plot. The seed then can be bagged and tagged for identification. Under ideal conditions, the 1,500-plot test can be harvested in 2 days.

The hand-harvested sample is milled using specialized milling equipment that will provide data on whole and total milled rice. In addition, these samples are evaluated for uniformity, chalkiness, grain shape and any other characteristic that might be a factor in the acceptability of the line as a commercial variety. The multitude of data collected will be analyzed to decide which lines will be entered into advanced trials the following growing season.

Getting to the preliminary yield testing stage normally takes a minimum of 5 to 6 years from the time the cross is made. The lines that display superior characteristics in preliminary testing are considered for advancement to the Commercial-Advanced (CA) trials, as well as the Uniform Regional Rice Nursery (URRN). Only about 5 percent of lines entered into the preliminary trials will be advanced. The CA trials are conducted throughout the rice-growing regions of Louisiana. The off-station location trials are conducted in cooperation with rice producers who are willing to provide land, land preparation, irrigation and assistance with these trials in countless other ways. The farmer will provide an area that has independent flooding and draining capabilities. The trials are planted using the same small plot equipment that is used on the Rice Research Station. After emergence, the trial is handled just as it would be on the Rice Research Station to optimize production and minimize any environmental variation that would impact the ability to evaluate true genetic differences among the lines in the trials. These trials are evaluated at least weekly, and data are collected for all characteristics just as is done on the Rice Station. These trials are harvested using the small plot combine. Trials that are harvested prior to August 15 will be ratoon cropped to provide data on this important characteristic.

The URRN is a cooperative endeavor conducted by the public rice breeding programs in Arkansas, Louisiana, Mississippi, Missouri and Texas. The nursery is a yield-testing program that is conducted at the primary research location in each of those states. The "Uniform" refers to the fact that the same rice lines are tested at each of the five locations. The test normally contains 200 rice lines (or genotypes), each representing an elite line from each breeding program. Breeders submit lines that might have the attributes that would warrant their consideration as a new release. Among the 200 entries are several currently grown commercial varieties included to provide a standard of comparison. The yield test is conducted at the research station in each state using the best cultural practices for that region. All data from the testing program are provided to each cooperator. Most of the experimental lines in the CA trials are also entered into the URRN.

Therefore, between the CA and URRN trials, the most advanced experimental lines in the Louisiana program are evaluated in numerous yield trials each year. The CA and URRN trials are extremely important in making decisions on potential variety releases. It is critical that a line be evaluated under different environmental conditions to determine its area of adaptation. In a potential new variety, one is looking for superior and stable performance. Often, a line will have excellent performance in two or three of these trials but average or inferior performance in several others. This line will be eliminated because of the lack of stability. As with the preliminary trials, all of the entries in each of these trials are evaluated for relative susceptibility or resistance to major rice diseases.

Lines that show excellent yield potential and milling quality, a high level of adaptation and good agronomic characteristics across all these diverse environments will be reentered into these trials the following year. A line that shows good potential as a future release will also be included in the statewide Variety by Nitrogen rate testing program. These lines may also be evaluated for differential response to selected rice herbicides. This research is conducted so that if a line is released as a variety, a package of agronomic recommendations for its production is also available.

If a line displays significantly better performance than the current commercial varieties, it also may be grown as a larger headrow population as a step toward potential increase. In each generation of testing, these experimental lines are concurrently being grown as panicle rows for purification and increase. A typical headrow population for a potential release is approximately 1,000 rows, which is often grown at the winter nursery facility in Puerto Rico. A 1,000-headrow increase will provide enough seed for up to a 20-acre foundation seed field on the Rice Research Station.

Generally, at least three years of CA and URRN data are required before an experimental line is considered as a new variety release. Seed will be increased on superior lines during this same time period so foundation seed is often produced during the third year of testing. If the line consistently has shown superior and stable performance after the third year of advanced testing and adequate foundation seed is available, a comprehensive data package on the line is provided to the director of the Louisiana Agricultural Experiment Station. If, after reviewing the data, the director agrees this is a candidate line for release, a committee is appointed to evaluate the data and make a recommendation on the release. The final decision rests with the director. If the decision is made to release the line as a variety, the director will ask for suggestions and approve the name for the new rice variety. Appendix Table 2 outlines the sequence of events in the development of the rice variety Catahoula as an example of the procedure described above.

Rice variety development is a long-term process that demands a great deal of time, hard work and dedication by a large number of people within the LSU AgCenter. The rice breeding project depends heavily on many cooperating projects for assistance in the development and evaluation of experimental lines. Cooperators include agronomists, entomologists, pathologists, biotechnologists, geneticists, weed scientists, food scientists and physiologists. This cooperation is essential for the success of varietal improvement efforts aimed at numerous characteristics, including but not limited to yield, milling quality, cooking quality, insect resistance, disease resistance, herbicide tolerance, seedling vigor, lodging resistance, fertilizer responsiveness, stress tolerance, earliness and ratooning.

The Rice Breeding and cooperating projects also evaluate potential varietal releases from other breeding projects (both private and public) to determine their adaptability under Louisiana growing conditions. Many rice varieties from out-of-state breeding programs are well adapted to Louisiana and are widely grown.

Rice Variety Characteristics

The two primary grain types grown in Louisiana are long grains and medium grains. Long grains are characterized by a grain length:width ratio of more than 3:1 and typically cook dry and fluffy because of a high- to intermediate-gelatinization temperature characteristic and a relatively high amylose content. Medium grains typically have a length:width ratio of between 2:1 and 3:1 (usually closer to 3:1) and cook soft and sticky because of a low gelatinization temperature characteristic and a relatively low amylose content. Southwest Louisiana producers have historically planted from 20 to 50 percent of rice acreage in medium grains, and those in northeastern Louisiana grow almost exclusively long-grain varieties. Due to market demands, the percentage of the state rice acreage planted to medium grains has continually decreased. In recent years, less than 10 percent of Louisiana rice acreage has been seeded to medium-grain varieties.

Interest in special-purpose varieties has increased in recent years. These varieties have distinctly different cooking attributes, such as aroma, elongation or unique cooking characteristics that may be favored by many ethnic populations living in the United States, as well as other consumers interested in gourmet or premium rice. The major specialty types include soft cooking aromatic Jasmine, flaky cooking elongating and aromatic Basmati, Kokuhoe, waxy, standard long-grain aromatic Della, soft cooking non-aromatic Toro and other less known gourmet types. Most specialty rice marketed in the United States is imported from Thailand, India and Pakistan. The Rice Research Station has been successful in developing and releasing a number of specialty varieties in recent years, including Della, Jasmine, Basmati and Toro types.

Development of Hybrid Varieties

Hybrid rice, produced from the first generation (F_1) of seeds between a cross of two genetically dissimilar pure line (inbred) parents, represents a relatively new option for Louisiana farmers. Commercial hybrids typically yield 10-20% more than the best inbred varieties grown under similar conditions believed to be the result of "hybrid vigor" or "heterosis" from crossing the two parents. The heterosis advantage of hybrids may be expressed by superiority over inbred varieties in grain yield, vigor, panicle size, number of spikelets per panicle, and number of productive tillers. To exploit the benefits of hybrids, farmers normally purchase seed from commercial companies for each cropping season.

Hybrid varieties are generally developed by the "three-line" or the "two-line" breeding method. For the three-line method, the Hybrid Breeding Project generates 200-300 crosses each year for development of cytoplasmic male sterile (A), maintainer (B), and restorer (R) lines used in the production of hybrids. The cytoplasmic male sterile lines do not produce viable pollen; therefore serve as the female parent in hybrid crosses. Because the A line cannot produce viable pollen it must be crossed with another source, the maintainer or B lines to provide A line seed for the future. A and B lines are crossed in an isolation plot to maintain a supply of seed of the A line. Hybrid seeds are produced by crossing an A line with a suitable R line in separate isolated plots. The R line both restores fertility to the seed harvested from the A line and provides desirable traits in the resulting hybrid.

In the two-line method, certain lines, referred to as S lines, can be either male sterile (functionally female) or male (produces viable pollen) depending upon temperature and day length. Under one set of temperature/day length combination, the S lines are crossed as females to fertile inbred lines to produce hybrid seed, while under separate temperature/day length combination, the same lines are allowed to self-pollinate and produce viable seed to maintain a source of the line. Use of S lines in this manner eliminates the need to develop maintainer B lines that are required in the three-line method but requires two different temperature/day length combinations be possible either in the field or in an artificial environment.

To develop and evaluate new A, B, R, and S lines used in producing new hybrids, agronomic and management data are collected from various nurseries and field trials located at university field plots and farmers' fields across Louisiana. The Observational/Testcross nursery evaluates 600-1000 new F_1 hybrid combinations each year at the Rice Research Station in one or more short rows along with three to five inbred and hybrid check varieties. The hybrids and checks are evaluated for grain production, height, maturity, lodging, disease and insect resistance, and milling and appearance traits to identify elite A, B, R, and S lines.

Hybrids that yield 15–20% higher than the check varieties in the Observational/Testcross nursery are advanced to the small-plot Preliminary Yield Trial at the Rice Research Station. Data on agronomic traits, yield, disease and insect resistance, and grain quality are recorded. Outstanding hybrid entries in the Preliminary Yield Trial are also screened for milling and grain appearance and cereal chemistry. Superior lines are then evaluated in Multi-location Yield Trials in five or more parishes across Louisiana. Grain yield and other agronomic data are recorded. To assess adaptation and productivity in Louisiana and other states, superior hybrids identified from the Multi-location Yield Trials may be entered into the Uniform Regional Rice Nursery (URRN) trials.

For commercial production of hybrid seeds, an A or S line is used as a female and planted in ~ 10 rows bordered by 3 rows of fertile male plants on each side that pollinate the female. These fields must be isolated to avoid pollination from other sources. The female rows are harvested to produce bulk quantities of hybrid seed.

The potential for hybrid rice in Louisiana is good, but there are several challenges, including but not limited to, lodging, maturity, whole-grain milling yields, grain appearance, and shattering (grain retention). The Rice Research Station is currently engaged in breeding research to address these challenges.

For additional updated varietal information, check the Extension Service's publication 2270, "Rice Varieties and Management Tips," which is revised each year.

Foundation Seed Production

Once a variety has been released by the LSU AgCenter, a mechanism is needed to purify, maintain and distribute high quality, genetically pure seed of this variety to the rice industry. Seed certification accomplishes this and provides an operating procedure to guarantee a source of high quality seed to the user. The field and laboratory purity standards for seed rice certification are very strict with regard to varietal mixtures and noxious weeds. In all phases of production, therefore, great care must be exercised to prevent these impurities from contaminating the seed stocks. The foundation seed rice program at the Rice Research Station is the first step in the seed certification process.

A small amount of seed of a new variety is supplied by the breeder to the foundation seed program. Seed harvested from individual rice panicles are grown in separate identifiable rows (one panicle per row) called headrows. This allows the breeder and foundation seed personnel to purify lines and discard mixtures, off-types or outcrosses and maintain identity of potential variety releases. Acceptable headrows are combined in bulk to produce breeder seed, which is maintained by the foundation seed program and used to plant the next stage in the seed certification process. The foundation seed program plants this small amount of breeder seed from which foundation seed is harvested.

Allocation of foundation seed rice in Louisiana is directed by the Louisiana Seed Rice Growers Association. It is allocated to Louisiana producers by a formula based on the previous year's rice acreage in each parish. For example, if the acreage of a parish represents 20 percent of the total rice acreage in the state in that year, 20 percent of the foundation seed of each variety available the following year will be allocated to that parish. After these initial allocations are met in each parish, any remaining seed is offered to producers whose requests were not met initially. If any seed remains after the requests of all Louisiana producers have been met, seed then is sold to out-of-state seed growers.

Grain harvested from foundation seed is certified and sold as registered seed. Registered seed is used to produce the last generation, certified seed. In some instances, certified seed may be produced directly from foundation seed. Certified seed is used by farmers to plant rice crops for milling and cannot be used to produce seed in the seed certification process.

The official seed certifying agency in Louisiana is the Louisiana Department of Agriculture and Forestry. This agency establishes the guides 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 Louisiana Department of Agriculture and Forestry.

Chapter 3

Soils, Plant Nutrition and Fertilization

Dustin Harrell and Johnny Saichuk

Rice requires an adequate supply of plant nutrients throughout the growing season. Four major nutrients and one micronutrient 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 phosphorus (P) and potassium (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 (S) is adequately supplied by most rice soils unless native fertility is inherently low (typical in coarse texture low, organic matter topsoil) or topsoil has been removed. Zinc (Zn) is the only micronutrient known to be deficient on some Louisiana rice soils. As with S, Zn 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 understood to manage these nutrients properly.

Nitrogen

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 (with oxygen) to an anaerobic (no oxygen) 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 and re-oxygenated ammonium-N can be transformed to nitrate-N through a process called nitrification.

When the soil is reflooded, nitrate-N will be lost rapidly. 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 has 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 (Fig. 3-1). 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 percent of the applied N at rice maturity.

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,

Fig. 3-1. Nitrogen deficiency.

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 a rice soil (1) eliminates moisture deficiency, (2) increases the availability of most essential plant nutrients, (3) minimizes weed competition and (4) 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 4- to 5-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: (1) soils conducive and/or varieties susceptible to straighthead, (2) severe Zn deficiency is observed or expected, (3) is required for application of certain herbicides or (4) field is infested with rice water weevil larvae.

The development of Clearfield 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 percent) 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 3 to 5 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 3 days before permanent flood establishment. Results may vary with year and/or environment.

Ammonium sulfate contains 21 percent 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 percent 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 percent blend of urea and ammonium sulfate, which has a N analysis of approximately 33 percent. 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 percent 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. Recently, a new soil test for N has been developed which can aid in determining the N needs for rice grown in the mid-southern United States. The nitrogen soil test for rice, coined N-STaR, has separate calibration curve for silt loam and clay soils. Fertilizer N recommendations, generated from the N-STaR extraction, are being validated on commercial rice fields and are currently not a recommended practice in Louisiana. However, the use of N-STaR has become a recommended practice in Arkansas.

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.”

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, efficiency and use. 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 (Fig. 4-10) or beginning internode elongation (IE)] and panicle differentiation (1/2 inch IE) (Fig. 4-11) as needed unless the total requirement was applied preplant incorporated.

In the delayed flood systems (dry broadcast, drill- or water-seeded), the permanent flood may not be established until 3 to 4 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 4- to 5-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 (NH_3) 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 over the past several years

Fig. 3-2. Straighthead symptoms.

have shown that when urea is left on the soil surface for 10 days, volatilization losses can range from 17 percent to 25 percent. 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 breakeven point generally occurs between 3 and 5 days. The use of a urease inhibitor product will be economically beneficial in most years when it takes longer than 5 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 (Fig. 3-2) 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 midtillering, no more than 60 to 70 percent of the required N fertilizer should be applied preplant or preflood, with the remainder applied before reflooding.

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

Fig. 3-3. Phosphorus deficiency.

Fig. 3-4. Left, normal plant. Right, phosphorus-deficient plant.

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 August 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 August 15, the ratoon N fertilizer application rate should be reduced by approximately 5 pounds a day past August 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 (Fig. 3-3 & 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.

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 (4 to 5 weeks after planting).

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 (Fig. 3-5). 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 and K sulfate 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.

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, where as 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) 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 90percent 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 (Fig. 3-6). Dark brown spots develop on the leaves, and when deficiency is severe, stand loss occurs. Zinc deficiency is usually referred to as bronz-

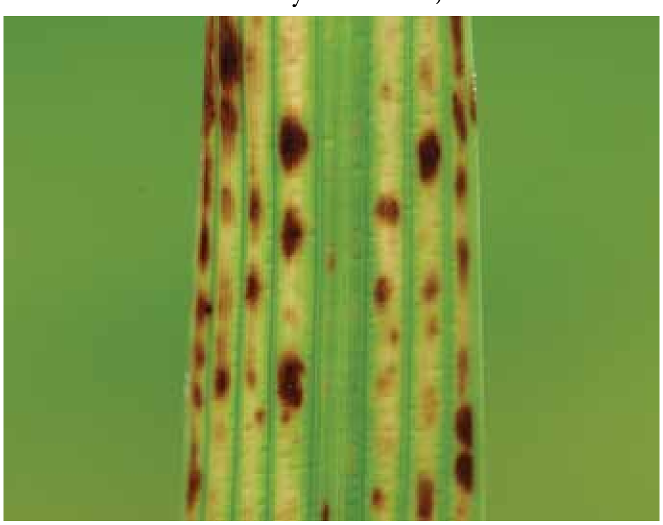


Fig. 3-5. Potassium deficiency symptoms on leaf.

Fig. 3-6. Typical zinc deficiency symptoms.

ing because of the rusty appearance that develops. Calcareous soils with an alkaline pH, inadequate Zn levels in the soil, removal of topsoil during landforming, 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.

A soil test can identify soils prone to Zn deficiency. Inorganic Zn salts, such as Zn sulfate, 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 50percent 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 (>50percent 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 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 100percent 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 top soil 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 county 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 local 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 Web site (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 3-1 to 3-4). Second, you must make sure that the soil test results are in parts per million (ppm). To change pounds per acre to parts per million, simply divide the number by 2.

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

	Soil Test Category			
	Very Low	Low	Medium	High
	ppm			
Mehlich-3 Extractable P	<10	1 - 20	21 - 35	≥36
	lb P_2O_5 / Acre			
Fertilizer Recommendation	60	40	20	0

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

Soil Type	Texture	Very Low	Low	Medium	High	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				lb K_2O / Acre		
		60	40	20	0	0

Table 3-3. 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 50percent water soluble or higher rates of zinc may be needed.

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

Table 3-4. 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 lb N and 24 lb 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 – 1000	Medium
1001 – 1500	High
>1500	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 (EC1:2 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 – 1000	Or	<4	Little to no effect on yield
Moderate	1000 – 2000	Or	<6	Some yield reduction possible
Severe	2000 – 6000	Or	<13	Substantial yield reduction w/0 remediation
Very Severe	>6000	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 p.p.m.) of salt would leave 800 pounds of salt per acre in the surface soil. Three such floodings would leave 2400 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 p.p.m.) 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 1000 p.p.m. 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	p.p.m.	Stage of Growth
35	600	Tolerable at all stages, not harmful
75	1300	Rarely harmful and only to seedlings after soil is dry enough to crack. Tolerable from tillering on to heading
100	1700	Harmful before tillering, tolerable from jointing to heading
200	3400	Harmful before booting, tolerable from booting to heading
300	5100	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 Dr. M. B. Sturgis, head, L.S.U. Department of Agronomy and Mr. 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

Fig. 3-7. Common commercial poultry litter.

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 (Fig. 3-7). 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 (N), phosphorus (P) and potassium (K), 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.

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 do 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_2O_5 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 7000 lb/A (43 barrels) rice yield will remove approximately 112, 60 and 168 lb 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 (Fig. 3-8). Physical and chemical variability of poultry litter between delivered batches are not uncommon (Fig. 3-9). 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.

Fig. 3-8. Litter delivered by 18-wheelers to field edges.

Fig. 3-9. Litter piles prior to spreading.

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.

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 onetime 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 1-2 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 lb of P_2O_5 and 60 lb of K_2O are required to grow a rice crop. Poultry litter analysis indicated that the litter contains 2.5 percent N, 3.2 percent P_2O_5, 2.7 percent K_2O and 40 percent moisture. Litter analysis is reported on an "as is" wet basis.

1. Determine how much total litter will be needed to supply 40 lb of P_2O_5. Calculate nutrients based on dry basis first then adjust to wet (as applied) basis.
   a. Divide total lb needed by percent P_2O_5 in litter.
      i. 40 lb P_2O_5 divided by 3.2 percent = 40/0.032 = 1250
   b. Convert to as applied (wet) basis.
      i. Need 1250 lb dry
      ii. Litter is 40 percent water
      iii. 100 percent - 40 percent = 60 percent dry matter
      iv. 1250 lb dry litter / 0.60 dry matter = 2083 lb 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. 2083 lb (wet) applied * 0.60 dry matter = 1250 lb dry litter
      ii. Litter contains 2.7 percent K_2O
      iii. 2.7 percent of 1250 lb = 0.027 * 1250 = 33.7 lb K_2O
   b. Determine additional K_2O needed from potash (0-0-60). A total of 60 lb K_2O is needed based on the soil test.
      i. 60 lb needed – 33.7 lb supplied by litter = 26.3 lb K_2O needed
   c. Determine potash rate
      i. K_2O fertilizer (0-0-60) is 60 percent K_2O
      ii. 26.3 lb K_2O needed / 0.60 lb K_2O per lb of 0-0-60 = 43.8 lb 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 lb/A preflood N rate.
   a. Determine N supplied by litter. Assume that the litter will provide a 25 percent urea equivalent.
      i. 2083 lb (wet) applied * 0.60 dry matter = 1250 lb dry litter
      ii. Litter contains 2.5 percent Nitrogen
      iii. 2.5 percent of 1250 lb = 0.025* 1250 = 31.2 lb of N
      iv. N in litter is only 25 percent of the value of urea
      v. 25 percent of 31.2 = 0.025 N in litter * 0.25 urea equivalent = 7.8 lb N supplied by litter
   b. Determine additional preflood N needed.
      i. 90 lb needed - 7.8 lb N supplied = 82.2 lb N needed
   c. Convert to lb of urea
      i. Urea (46-0-0) is 46 percent N
      ii. 82.2 lb N / 0.46 = 178.7 lb urea needed to supply 82.2 lb 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.

Chapter 4

Rice Growth and Development

Richard Dunand and Johnny Saichuk

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. 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 ends 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 a continuous process 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 degrees 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 imbibition of water. The seed swells, gains weight, conversion of carbohydrates to sugars begins and the embryo is activated.

Nutrition from the endosperm can supply the growing embryo for about 3 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) (Fig. 4-1). The coleoptile elongates until

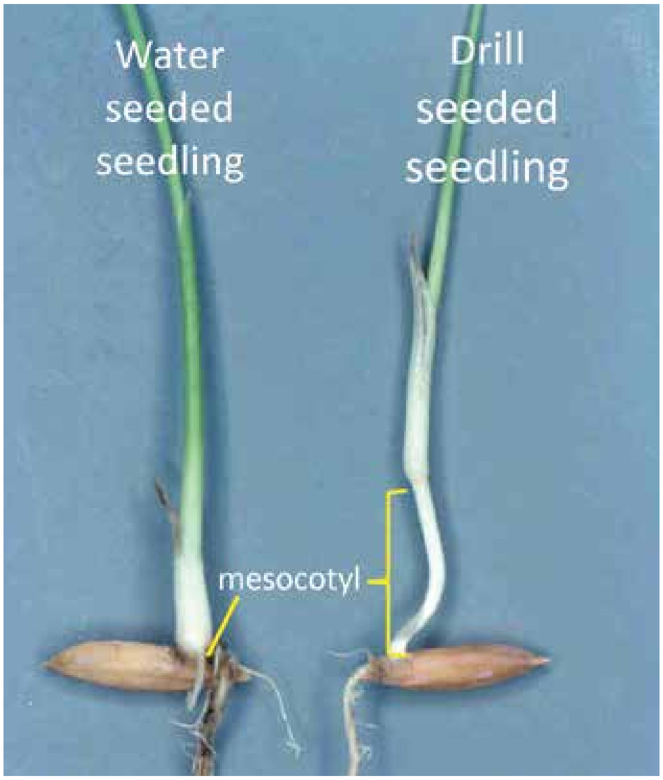


Fig. 4-1. Left, water-seeded seedling. Right, drill-seeded seedling.

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

Fig. 4-2. Emergence, water-seeded rice.

a production perspective (and in the DD50 program), emergence is called when 8 to 10 seedlings 3/4 inch tall are visible per square foot in water-seeded rice or 4 to 7 plants per foot for drill-seeded rice, depending on drill spacing (Fig. 4-2)

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 (Fig. 4-3). The

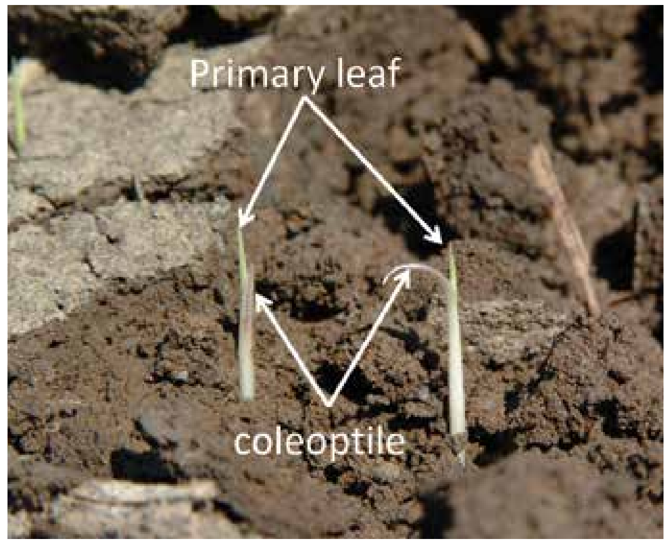


Fig. 4-3. Emergence, drill seeded rice.

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 (Fig. 4-4). A leaf that is differentiated into a sheath, collar and blade is considered complete; thus, the first leaf to develop after the primary leaf is the first complete leaf. The

Fig. 4-4. One leaf seedling.

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 (Fig. 4-5). 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.

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 (Fig. 4-6). Subsequent leaves develop in the same manner, with the number of fully developed leaves being used to describe the seedling stage of growth.

Fig. 4-5. Collar of rice leaf.

Fig. 4-6. 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 (Fig. 4-7). 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.

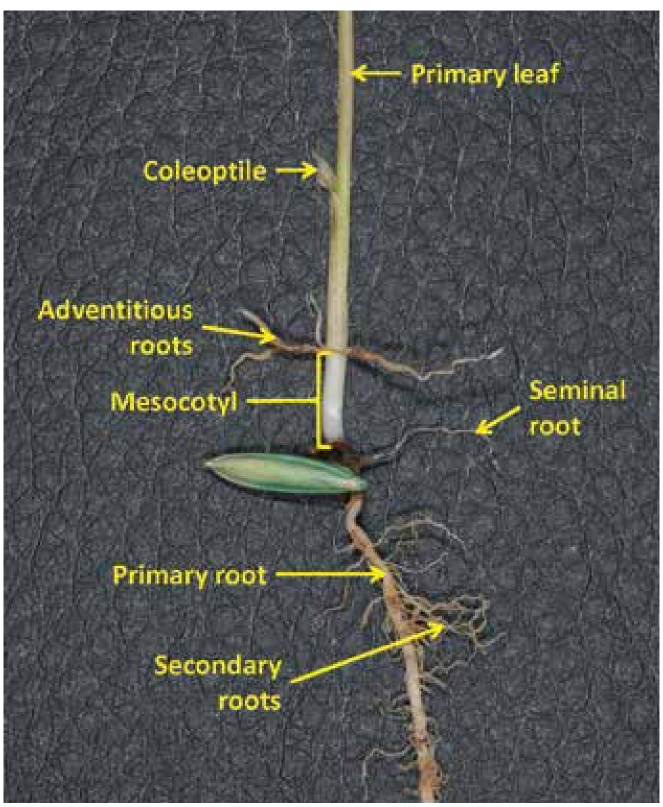


Fig. 4-7. Rice seedling root system.

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 (Fig. 4-1). 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 (Fig. 4-8). 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

Fig. 4-8. One tiller rice seedling.

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.

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 ¼ 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 ½ 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

Fig. 4-9. Plant with three distinct crown nodes and a fourth developing.

similar to that of the crown nodes (Fig. 4-9). 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 (Fig. 4-10). It also signals a change

Fig. 4-10. Green ring-internode elongation.

Fig. 4-11. Half-inch internode.

in the plant from vegetative to the reproductive stage of development (Fig. 4-11).

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 et cetera. 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 (uppermost internode) inches 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 6 weeks after planting. Varieties classified as early season maturity (head 80 to 84 days after planting) reach first internode about 7 weeks after planting, and varieties classified as midseason maturity (head 85 to 90 days after planting) reach first internode about 8 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 7 to 10 days after the beginning of active cell division at the growing point, an immature panicle about ⅛ 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 (Fig. 4-12). 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 (Fig. 4-13). The growing points of these branches differentiate into florets. Florets form at the

Fig. 4-12. Immature panicle, PD or panicle 2-mm.

Fig. 4-13. Half inch panicle.

uppermost branches first and progress downward. Because there are several panicle branches, development of florets within the panicle as a whole 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 stand point, 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.

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 (Fig. 4-14) 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.

Fig. 4-14. 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

Fig. 4-15. Open floret with floral parts showing.

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.

As heading progresses, flowering begins. During the middle hours of the day, mature florets open, exposing both the stigmas and anthers to air (Fig. 4-15). 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.

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

Fig. 4-16. Milk stage.

Fig. 4-17. Soft dough stage.

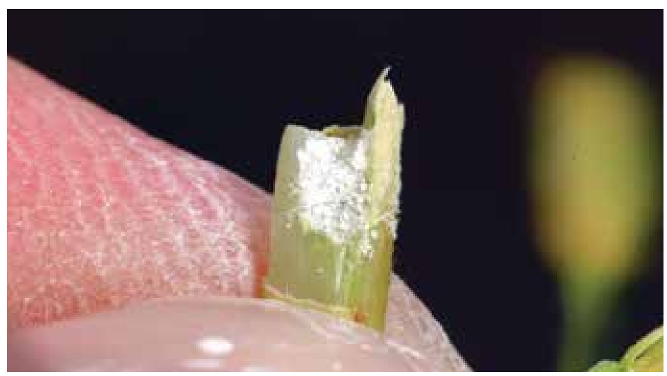


Fig. 4-18. Hard dough stage.

noticeable inside florets on the main stem, the stage is milk stage (Fig. 4-16).

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 (Fig. 4-17).

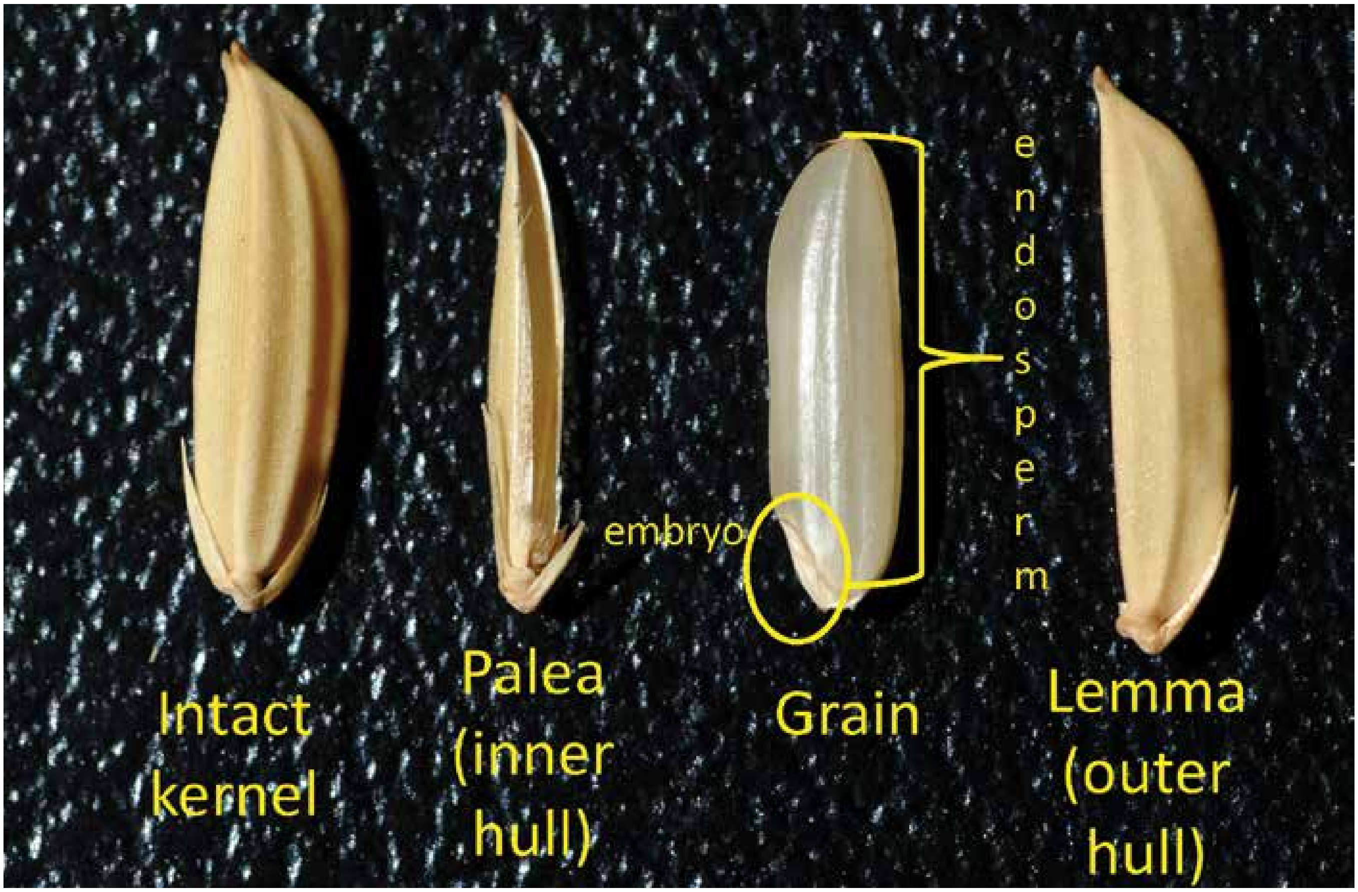


Fig. 4-19. Mature grain, intact and dissected.

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 (Fig. 4-18).

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.

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

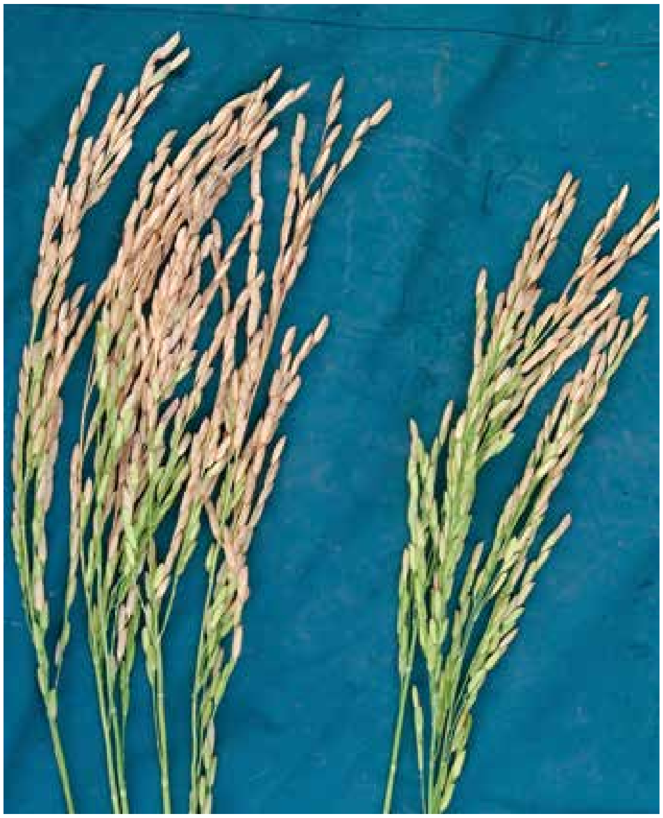


Fig. 4-20. Left panicles are two-thirds ripe. Right panicles are half ripe.

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 (Fig. 4-19).

At this time, 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 (Fig. 4-20). 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 (Fig. 4-21). At each node just above the area of attachment of the leaf sheath to the stem is a bud called an axillary bud.

Fig. 4-21. Axillary bud on stem.

Fig. 4-22. Crown or axillary buds at base of 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 (Fig. 4-22). At the stem nodes on first crop stubble they appear as a small (⅛ 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.

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 5 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 percent). 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 percent 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.

Chapter 5

Weed Management

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 the U. S. rice production. Rice weeds can grow and thrive in aquatic, semi-aquatic 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. Nealy sprangletop and rice cutgrass are grass weeds that have become more widespread over the past few years. These weeds 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 this production system. Ducksalad, grassy arrowhead, common arrowhead, creeping burhead, pickerelweed and roundleaf mudplantain require high moisture to germinate and are much more aggressive in aquatic situations. Perennial grasses such as creeping rivergrass, knotgrass, brook paspalum and water paspalum are becoming more of a problem in Louisiana rice production due to a rice-crawfish rotation.

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 number 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.

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. With the development of Clearfield rice, producers have an option to plant rice that is resistant to the imidazolinone family of herbicides. 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 Beyond (imazamox) 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 Newpath application. This technology continues to be the best option for managing red rice in production rice. Producers are moving to a Clearfield production system to take advantage of the overall weed control program available with this system.

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 percent of the plant above the water line. An 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 herbicide can deliver.

Burndown Herbicide Application

Based on Louisiana State University AgCenter recommendations, burndown herbicides should be applied no earlier than 6 to 8 weeks prior to planting and no later than 3 to 4 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 rice, the use of PPI treatments has been reduced. The Clearfield rice system does have the option of a PPI application of imazethapyr (Newpath). 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 applied to the flooded field. 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 a preemergence application on a portion of the operation to allow postemergence applications over a longer period of time during the growing season. 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 4 to 7 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 4- to 7-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 stand point 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 help 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 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 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. In this system, 4 to 6 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, the permanent flood may not be established until rice is in the five-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.

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 organosilicone 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 mid-South 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 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

- Rice flatsedge *Cyperus iria*
- Yellow nutsedge *Cyperus esculentus*
- Bog bulrush *Schoenoplectus mucronatus*
- Spikerush *Eleocharis* spp.

Grasses

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.

Grasses

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; seed-head 2-6 long racemes, distinctive

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




Fall Panicum

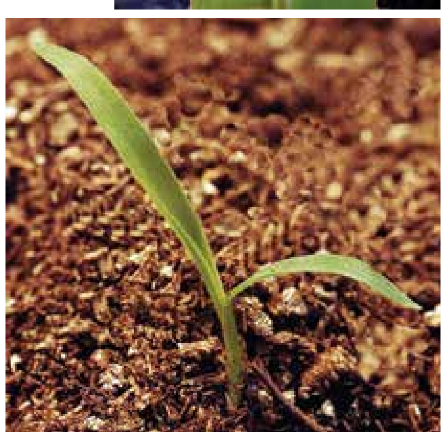
Panicum dichotomiflorum

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.



Grasses

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.

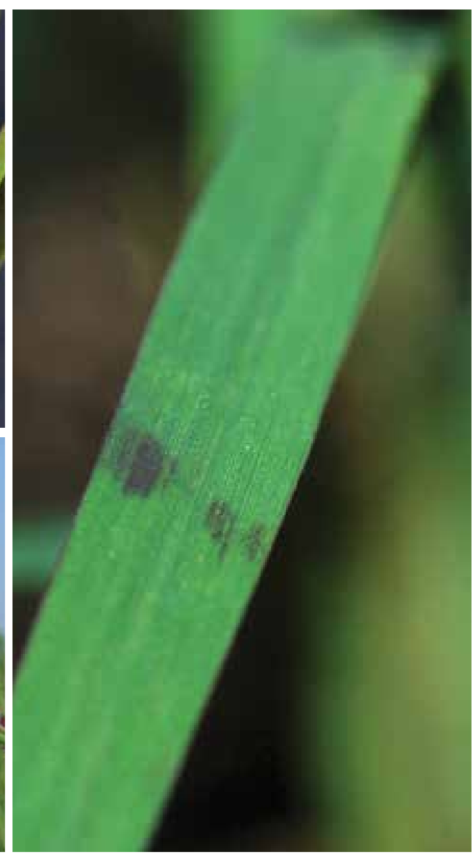
Distribution: All Louisiana parishes.

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.



Grasses

Nealley's Sprangletop

Leptochloa nealleyi

Keys to Identification: Erect annual 3-5 ft tall; small hairs on leaf sheath up to 4 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 paricle.

Distribution: All Louisiana parishes.

Grasses

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.



Grasses

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.

Grasses

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.

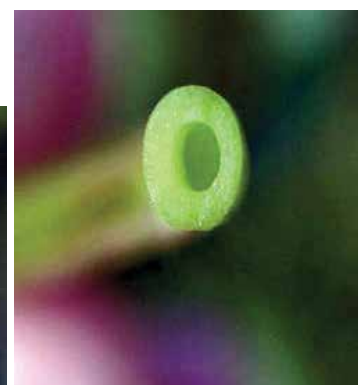
Water Paspalum

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.



Grasses

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.

Broadleaf Weeds

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.

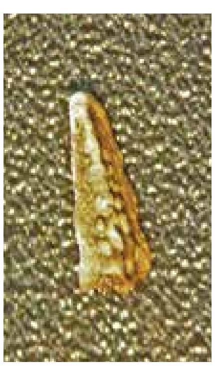
Eclipta

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.



Broadleaf Weeds

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.

Broadleaf Weeds

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.

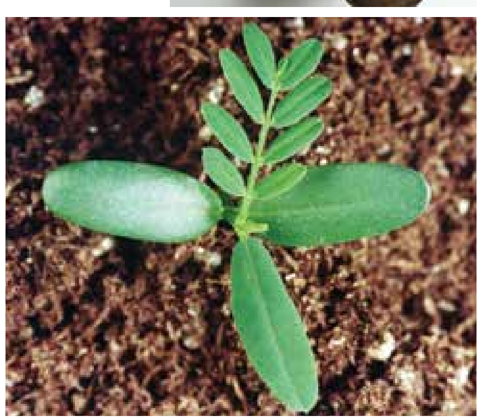
Hemp Sesbania

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 compund; 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.

Broadleaf Weeds

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.

Broadleaf Weeds

Purple Ammannia

Ammannia coccinea

Annual

Keys to Identification: Erect, herbaceous annual; reddish glabrous linear to linear-lanceolate cotyledons; leaves opposte, 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.

Broadleaf Weeds

Spreading dayflower

Commelina diffusa

Annual

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

Distribution: All Louisiana parishes.

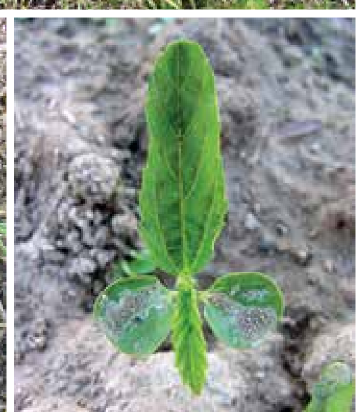
Texasweed

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.



Broadleaf Weeds

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.

Broadleaf Weeds

Common Arrowhead

Sagittaria latifolia

Aquatic Perennial

Keys to Identification: Erect aquatic perennial; leaves variable on long, spongy petioles sagittate, 3-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.

Broadleaf Weeds

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-sagitate; stems short, stout, somewhat succulent; flowers blue or lavender on a spike.

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

Broadleaf Weeds

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.

Sedges and Rushes

Rice Flatsedge

Cyperus iria

Annual

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

Distribution: All Louisiana parishes.

Yellow Nutsedge

Cyperus esculentus

Perennial

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

Distribution: All Louisiana parishes.

Sedges and Rushes

Bog Bulrush

Schoenoplectus mucronatus

Perennial

Keys to Identification: Herbaceous plant; erect, rhizomatous.

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

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.

Chapter 6

Disease Management

Don Groth, Clayton Hollier and Chuck Rush

Disease damage to rice can greatly impair productivity and sometimes destroy a crop. The United States does not have any of the destructive viral diseases present in other rice-growing areas of the world, but fungal diseases are prevalent and very damaging to Louisiana rice. Several bacterial diseases have been found, but significant yield losses have only been associated with bacterial panicle blight.

Direct losses to disease include reduction in plant stands, lodging, spotted kernels, fewer and smaller grains per plant and a general reduction in plant efficiency. Indirect losses include the cost of fungicides used to manage disease, application costs and reduced yields associated with special cultural practices that reduce disease but may not be conducive to producing maximum yields.

The major diseases of rice in the United States are bacterial panicle blight (Figs. 6-2 and 6-3) caused by B*urkholderia glumae* and *Burkholderia gladioli*; fungal diseases including blast, caused by *Pyricularia grisea* (Figs. 6-5 to 6-8); stem rot, caused by *Magnaporthe salvinii (Sclerotium oryzae)* (Figs. 6-33 and 6-34); sheath blight, caused by *Thanatephorus cucumeris* (*Rhizoctonia solani*) (Figs. 6-25 to 6-28); brown spot, caused by *Cochiobolus miyabeanus* (Figs. 6-9 and 6-10); narrow brown spot, caused by *Sphaerulina oryzina* (*Cercospora janseana*) (Figs. 6-20 and 6-21); and kernel smut, caused by *Neovossia horrida* (Fig. 6-16). Seedling diseases caused by species of *Achlya* and *Pythium* (Figs. 6-35, 6-36 and 6-37) also are important in water-seeded rice.

Minor diseases include crown rot (Fig. 6-11), causal agent believed to be an *Erwinia* sp.; leaf scald, caused by *Gerlachia oryzae* (Figs. 6-17 and 6-18); leaf smut, caused by *Entyloma oryzae* (Fig. 6-19); sheath rot, caused by *Sarocladium oryzae* (Fig. 6-30); stackburn disease, caused by *Alternaria padwickii* (Fig. 32); white leaf streak, caused by *Mycovellosiella oryzae* (*Ramularia oryzae*) (Fig. 6-38); sheath blotch, caused by *Pyrenochaeta oryzae* (Fig. 6-29); sheath spot, caused by *Rhizoctonia oryzae* (Fig. 6-31); crown sheath rot, caused by *Gaeumannomyces graminis* var. *graminis* (Fig.s 6-12 and 6-13); black kernel, caused by *Curvularia lunata* (Fig. 6-4); seedling blights, caused by various fungi (Fig. 6-24); bacterial leaf blight (Fig. 6-1); false smut, caused by *Ustilaginoidea virens* (Fig. 6-14); root rots, caused by several fungi (Fig. 6-23); and several miscellaneous leaf, stem and glume spotting diseases. Several diseases caused by other sclerotial fungi are also found in Louisiana but are not significant. An undefined pathogen complex acting alone or with insect damage (feeding) also causes the grain and kernel discoloration called "pecky" rice (Fig. 6-15).

The physiological disorders straighthead (Fig. 3-2) and bronzing or zinc (Zn) deficiency (Fig. 3-6) occur throughout the southern rice area and are locally severe. Cold injury, salt damage and nutrient deficiencies can be confused with disease symptoms. Two minor diseases of rice in Louisiana are caused by small parasitic round worms called nematodes. These are white tip, caused by *Aphelenchoides besseyi* (Fig. 6-39), and root knot, caused by *Meloidogyne* species (Fig. 6-22).

The first step toward disease management is identification followed by careful field scouting to determine the extent of disease. Diseases known to occur in Louisiana and their causal agents are listed in Table 6-1. A guide for rapid identification of the major diseases is given in the following section (Table 6-2). Knowing the level of resistance of the variety to major diseases can be useful in determining the probability of having problems warranting preventive management measures. The list of available variety resistance can change over time, so consult LSU AgCenter publication 2270, "Rice Varieties and Management Tips." Scouting information or disease thresholds and management information are summarized for the major diseases in the last section of this chapter.

Use of foliar fungicides to manage rice diseases is often justified under conditions where environmental factors favor development of severe disease. Some factors that affect the probability of fungicide use being warranted include disease history in the field, the resistance of the variety, the yield potential, intended use (seed or grain), date of planting and ratoon crop potential. Always follow label directions. As the list of labeled fungicides may change, contact your LSU AgCenter extension agent for current information on fungicides available for rice disease management. A rice disease content oriented webpage www.lsuagcenter.com/en/crops_livestock/rice/diseases has been setup to provide up to date rice disease control information and additional resources not available in this publication.

Rice Disease Identification

Each year, the Louisiana rice crop is affected by many diseases. Severity of symptoms often varies because of varietal resistance, environmental conditions and plant growth stage. Also, not all symptoms typical of a disease occur on a single plant. It is important to look at several plants, from several areas of the field, to establish an accurate diagnosis. In the text, all symptoms known to occur are described but not all will be expressed. Use the guide for identification of rice diseases present in Louisiana to decide which diseases are present. The diseases are divided into sections based on what plant part is affected. Several diseases, however, may affect more than one part of a rice plant. When a disease is identified, information is provided in the text for managing the disease.

Table 6-1. Rice diseases and disorders in Louisiana.

Common Name	Pathogen Name or Cause
Bacterial diseases	
Bacterial blight like disease	*Xanthomonas oryzae* pv. *oryzae* (Ishiyama) Swings et al. = X. *campestris* pv. *oryzae* (Ishiyama) Dye
Bacterial panicle blight	*Burkholderia glumae* and *Burkholderia gladioli (Severin) Yabuchi, et al.*)
Crown rot	*Erwinia chrysanthemi* Burkholder et al.
Pecky rice (kernel spotting)	Damage by bacteria (see also under fungal and miscellaneous diseases)
Fungal diseases	
Black kernel	*Curvularia lunata* (Wakk.) Boedijn (teleomorph: *Cochiobolus lunatus* R.R. Nelson & Haasis)
Blast (leaf, rotten neck)	*Pyricularia grisea* Sacc.=P. *oryzae* Cavara (teleomorph: neck, nodal and collar) *Magnaporthe grisea* (Hebert) Barr)
Brown spot	*Cochliobolus miyabeanus* (Ito & Kuribayashi) Drechs. ex Dastur (anamorph: *Bipolaris oryzae* (Breda de Haan) Shoemaker)
Crown sheath rot	*Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier
Downy mildew	*Sclerophthora macrospora* (Sacc.) *Thirumalachar* et al.
False smut	*Ustilaginoidea virens* (Cooke) Takah.
Kernel smut	*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc. = Neovossia horrida (Takah.) Padwick & A. Khan
Leaf smut	*Entyloma oryzae* Syd. & P. Syd.

Common Name	Pathogen Name or Cause
Fungal diseases continued	
Leaf scald	*Microdochium oryzae* (Hashioka & Yokogi) Samuels & I.C. Hallett = Rhynchosporium oryzae Hashioka & Yokogi
Narrow brown leaf spot	*Cercospora janseana* (Racib.) O. Const = *C. oryzae* Miyake (teleomorph: *Sphaerulina oryzina* K. Hara)
Pecky rice (kernel spotting)	Damage by many fungi including *Cochliobolus miyabeanus* (Ito & Kuribayashi) Drechs. ex Dastur, *Curvularia* spp., *Fusarium* spp., *Microdochium oryzae* (Hashioka & Yokogi) Samuels & I.C. Halett, *Sarocladium oryzae* (Sawada) W. Gams & D. Hawksworth and other fungi
Root rots	*Fusarium* spp., *Pythium* spp., *P. dissotocum* Drechs., *P. spinosum* Sawada
Seedling blight	*Cochliobolus miyabeanus* (Ito & Kuribayashi) Drechs. ex Dastur, Curvularia spp., *Fusarium* spp., *Rhizoctonia solani* Kuhn, *Sclerotium rolfsii* Sacc. (teleomorph: *Athelia rolfsii* (Curzi) Tu & Kimbrough), and other pathogenic fungi.
Sheath blight	*Thanatephorus cucumeris* (A.B. Frank) Donk (anamorph: *Rhizoctonia solani* Kuhn)
Sheath blotch	*Pyrenochaeta oryzae* Shirai ex Miyake
Sheath rot	*Sarocladium oryzae* (Sawada) W. Gams & D. Hawksworth = *Acrocylindrium oryzae* Sawada
Sheath spot	*Rhizoctonia oryzae* Ryker & Gooch
Stackburn	*Alternaria padwickii* (Ganguly) M.B. Ellis leaf spot) (Alternaria leaf spot)
Stem rot	*Magnaporthe salvinii* (Cattaneo) R. Krause & Webster (synanamorphs: *Sclerotium oryzae* Cattaneo, *Nakataea sigmoidae* (Cavara) K. Hara)
Water-mold (seed-rot and seedling disease)	*Achlya conspicua* Coker, A. *klebsiana* Pieters, *Fusarium* spp., *Pythium* spp., *P. dissotocum* Drechs., *P. spinosum* Sawada
White leaf streak	*Mycovellosiella oryzae* (Deighton & Shaw) Deighton
Disorders	
Bronzing	Zinc deficiency
Cold injury	Low temperatures
Panicle blight	Several causes – Wind damage, insect feeding, undetermined physiological factors
Pecky rice (kernel spotting)	Feeding injury by rice stink bug
Straighthead	Arsenic induced, unknown physiological disorder
Nematodes	
Root-knot	*Meloidogyne* spp.
White tip	*Aphelenchoides besseyi* Christie

Table 6-2. A guide to the identification of rice diseases present in Louisiana.

For identification of the major diseases, determine the part of the plant affected by the disease then refer to that section of Table 6-2. A list of the causal agents of all rice diseases known to occur in Louisiana is in Table 6-1.

I. Planted Seeds and Seedlings

Water-seeded rice

Seeds rotted after draining water from field; copper or greenish-brown spots on soil surfaces around or above rotted seeds; coarse, bristly mycelium radiating from seed (*Achlya* spp.) (Fig. 6-36) or gelatinous matrix surrounding each affected seed (*Pythium* spp.) (Fig. 6-37).	**Water Mold**
Seedlings 1-4 inches tall dying in seedling flood or after flushing seeded field.	**Pythium Seedling Blight**
Drill-seeded or dry broadcast rice: seedlings 1-4 inches tall dying: Brown spot on coleoptile or growing point (Fig. 6-24), seedlings suddenly dying.	**Seedling Blight**
Seedlings dying or turning white in patches or in short strips of drill row; fluffy white mycelium and small, round sclerotia (tan) may be present on soil surface at the base of affected seedlings after flushing seeded field.	**Sclerotium Seedling Blight**
Seedlings at the three- to five-leaf stage dying, often in patches, may have linear reddish-brown lesion on sheath of small seedlings, older seedlings with purple-brown blotches made up of small spots aggregating, leaves yellow or bronze (Fig. 3-6), lower leaves floating on surface of flood water, seedlings dying in deeper water and disappearing below surface of water.	**Bronzing** See also Salinity and Cold Injury.

II. Roots and Crown (Root-Stem Interface)

Crown area decayed with soft rot, black or dark brown with streaks extending to the lower internodes of culms (Fig. 6-11), fetid odor of bacterial soft rot, tillers dying one at a time; roots dying and turning black, adventitious roots produced at node above crown area. A similar discoloration of the crown may be caused by applying hormonal herbicide such as 2,4-D too early.	**Crown Rot**
Roots turning black or brown, decayed, reduced root volume, roots dying (Fig. 6-23).	**Root Rot**
Roots with swollen areas, found only under dryland conditions (Fig. 6-22).	**Root Knot**

III. Leaf Blades

Lesions varying from small round, dark brown spots, to oval spots with narrow reddish-brown margin and gray or white center with dark circular line (Fig. 6-5). Spots elongated, diamond-shaped or linear with gray dead area in center surrounded by narrow reddish-brown margin.	**Leaf Blast**

Round to oval, dark brown lesions with yellow or gold halo (Fig. 6-10); as lesions enlarge, they remain round, with center area necrotic, gray and lesion margin reddish-brown to dark brown.	**Brown Spot**
Long, narrow brown or reddish-brown lesion (Fig. 6-20, 6-21); lesions 0.5 to 3 cm long, parallel with leaf veins and usually restricted to the area between veins; lesions may occur on leaf sheaths.	**Narrow Brown Leaf Spot**
Lesions similar to narrow brown leaf spot, but wider and white in the center (Fig. 6-38).	**White Leaf Streak**
Lesions begin at base of blade, spreading from leaf sheath or from infection point on leaf blade (Fig. 6-27). Lesions consist of alternating wide bands of cream-colored, greenish-gray or tan with narrow bands of reddish-brown or brown.	**Sheath Blight**
Lesions consist of wide bands of gray, dying tissue alternating with narrow reddish-orange bands (Fig. 6-17); band pattern in chevrons from leaf tip or edges of the leaf, sometimes lesions are gray blotches at leaf edge with reddish-brown margin, advancing edge of lesion usually has a yellow or gold area (Fig. 6-18) between reddish-brown margin and green, healthy tissues.	**Leaf Scald**
Small 1-2 mm, black linear lesions on leaf blade (Fig. 6-19), usually more lesions on tip half of the leaf blade, lesions may have dark gold or light brown halo, leaf tip dries as plants approach maturity, lesions on sheaths of upper leaves.	**Leaf Smut**
Round or oval white or pale tan spot with a narrow, red or reddish-brown margin (Fig. 6-32); often two adjacent spots coalesce to form an oval double spot; lesions are from 0.5 to 1 cm in diameter, spots with small black fruiting structures in the center.	**Stackburn**
Leaf tips turn white with a yellow area between the white tip and the healthy green area (Fig. 6-39); white areas sometimes occur on leaf edges; flag leaf blade twisted with poor emergence of the panicle; kernels aborted or poorly filled; grain distorted or discolored.	**White Tip**
Symptoms consist of elongated lesions near the leaf tip margin that start out water-soaked in appearance; lesions may reach several inches in length, turn white to yellow and then to gray (Fig. 6-1).	**Bacterial Leaf Blight like disease**

IV. Leaf Sheath and Stem

Water-soaked, gray-green lesions at water line (Fig. 6-28) during tillering or early jointing stages of growth, lesions becoming oval, white or straw-colored in center with reddish-brown edge (Fig. 6-26), lesions 1 to 2 cm wide and 3 to 4 cm long, lesions spreading up leaf sheaths and onto leaf blades, lesions discrete or forming a continuous band on sheath (Fig. 6-26) or leaf (Fig. 6-27) of alternating wide necrotic areas with narrow reddish-brown bands.	**Sheath Blight**

Black, angular lesions on leaf sheaths at water line on plants at tillering or early jointing stages of growth (Fig. 6-33); at later stages outer sheath drying, inner sheath discolored or with black angular lesion; culms discolored with dark brown or black streaks; raised areas of dark fungus mycelium on surface; gray mycelium inside of culm or at maturity culm collapsed with small, round black sclerotia in dead sheath tissues and inside of culm (Fig. 6-34).	**Stem Rot**
Lesions on sheaths midplant, oval, pale green, turning cream or white in the center with a broad dark reddish-brown margin (Fig. 6-31). Lesions remain separate, not forming continuous bands on the sheath.	**Sheath Spot**
Black to brown diffuse lesions on the sheath near the water line (Fig. 6-12). Perithecia necks protruding from upper surface and a thick fungal mat between leaf sheath and culm (Fig. 6-13).	**Crown Sheath Rot**
Reddish- or purple-brown, netlike pattern on sheath below the collar of lower leaf blades (Fig.6-21), lesion oval, 1 to 2 cm wide and 3 to 5 cm long, leaf blades turning yellow and drying. (See Narrow Brown Leaf Spot)	**Cercospora Net Spot**
General reddish-brown discoloration of flag leaf sheath or reddish-brown or yellow-tan spots with dark, irregular ring pattern inside of spots (Fig. 6-30); panicles emerging poorly; stem of panicle twisted; white "frosting" of conidia on inside of leaf sheath, florets of panicles on affected tillers discolored a uniform reddish-brown or dark brown. Grain does not fill or kernels are lightweight.	**Sheath Rot**
Oblong zonate reddish lesions with black fruiting structures (pycnidia) in the center areas of the lesion (Fig. 6-29).	**Sheath Blotch**
Narrow red-brown lesions on flag leaf sheath or penultimate leaf sheath after panicles emerge; lesions 0.5 to 1.5 mm wide and up to 1 to 3 cm long; lesions run parallel with veins in sheaths, affecting the tissues between veins (Fig. 6-21).	**Narrow Brown Leaf Spot**
Collar of flag leaf discolored brown or chocolate brown; leaf blade detaches from sheath as lesion dies and dries (Fig. 6-7).	**Blast on Flag Leaf Collar**
Culm nodes turn black or nodes become shriveled and gray as plants approach maturity (Fig. 6-6); nodes purple to blue-gray with conidia of the pathogen; culms and leaves straw-colored above affected node; culms lodge at affected nodes.	**Node Blast**

V. Panicle, Florets and Grain

Panicle

The panicle may have one to all of the florets blighted with grains not filling or aborted. Florets are initially white or light gray on the basal third with a reddish-brown margin separating this area from the rest of the floret, which becomes straw colored (Fig. 6-3). The florets eventually become gray with growth of saprophytic fungi on the surface. Floret stems (panicle branches) stay green after the unaffected grain matures.	**Bacterial Panicle Blight**

Node and surrounding area at base of panicle discolored brown or chocolate brown (Fig. 6-8); stem of panicle shrivels and may break; node purplish or blue-gray with conidia of the fungal pathogen; panicle white or gray; florets do not fill and turn gray; panicle branches and stems of florets with gray-brown lesions. **Rotten Neck Blast**

Panicles upright, not falling over or slightly bent over because of sterility. Hulls distorted, parrot beak-shaped. Plants may not head at all (Fig. 3-1). **Straighthead**

Internodal area above or below node at the base of the panicle turns light brown or tan-brown; affected area dies and shrivels; kernels in florets of lower portion of the panicle do not fill. (See Brown Spot and Narrow Brown Leaf Spot for more information.) **Cercospora Neck Blight**

Single florets or several florets on a panicle branch turn light brown or straw-colored; floret stem with brown lesion; grain stops developing; florets turn gray. **Panicle Blast**

Panicles twisted and deformed, unable to emerge from the leaf sheath and becoming twisted; the panicle is small, normally remaining green longer than usual; no seeds produced. **Downy Mildew**

Panicles small, reduced number of spikelets and lemmas and paleas often absent on terminal portions of panicles. **White Tip**

Florets and Grain

Single florets or several florets per panicle with brown, reddish-brown, purple or white surrounded by purple-brown spots (Fig. 6-15). **Grain Spotting or Pecky Rice**

Maturing grain partially filled with or without grayish cast; powdery black mass on surface of the kernel and at seam between palea and lemma (Fig. 6-16) (rubs off easily onto fingers). (See Black Kernel) **Kernel Smut**

Single florets or more commonly several florets in a panicle turn reddish-brown to dark brown (Fig. 6-30). **Sheath Rot**

Single florets or several florets on a panicle straw colored, branches of panicle remain green (Fig. 6-3). The grain stops developing, and the florets turn gray. **Bacterial Panicle Blight**

Maturing grain partially filled, shriveled, chalky, fuzzy black mass covering surface of the grain or at seam between palea and lemma (will not easily rub off on fingertips). **Brown Spot**

Large orange fruiting structure on one or two grains in maturing panicle. When orange membrane ruptures, a mass of greenish-black spores is exposed (Fig. 6-14). Grain replaced by one or more sclerotia. **False Smut**

Rice Disease in Louisiana

Bacterial Leaf Blight-Like

Bacterial leaf blight is caused by the bacterium *Xanthomonas campestris* pv. *oryzae*. It was first identified in the United States in Texas and Louisiana in 1987. Additional testing proved the bacterium was not the severe Asian strain. 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 damage.

The blight bacterium overwinters in rice debris in the soil and on weed hosts. There is also a slight chance that seed may transmit the pathogen. The pathogen is spread by wind-blown rain, irrigation water, plant contact and probably on plant debris on machinery. High humidity and storms favor disease development. Watersoaked areas appear on the leaf margins near the tips, enlarge and turn white to yellow. As the lesions mature, they expand, turn white and then gray because of growth of saprophytic fungi (Fig. 6-1). The lesion may be several inches long. Contact your LSU AgCenter extension agent if you suspect this disease. Accurate identification is important since the symptoms can be confused with other diseases, especially leaf scald (Fig. 6-17), herbicide damage and other plant stress. Management practices include rotating to nongrass crops, tilling to destroy plant debris and avoiding contaminating the field through infected plant materials or irrigation water.

Fig. 6-1. Bacterial leaf blight.

Bacterial Panicle Blight

Rice produced in the southern United States has a long history of loss to panicle blighting of unknown etiology. Epidemics of panicle blight occurred during the 1995, 1998, 2000 and 2011 seasons, years of record-high night temperatures, with yield losses in some fields estimated to be as high as 40 percent. Earlier panicle blighting was attributed to abiotic factors, including high temperatures, waters stress or toxic chemicals near the root zone, but in 1996-97, the cause of panicle blighting in the southern United States was identified as the bacterial plant pathogen *Burkholderia glumae*. This bacterium was first described in 1967 in Japan as the cause of grain-rotting and seedling blighting. The disease was later reported from other Asian and Latin American countries. The symptoms of bacterial panicle blight include seedling blighting, sheath rot, and panicle blighting with significant yield losses. 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.

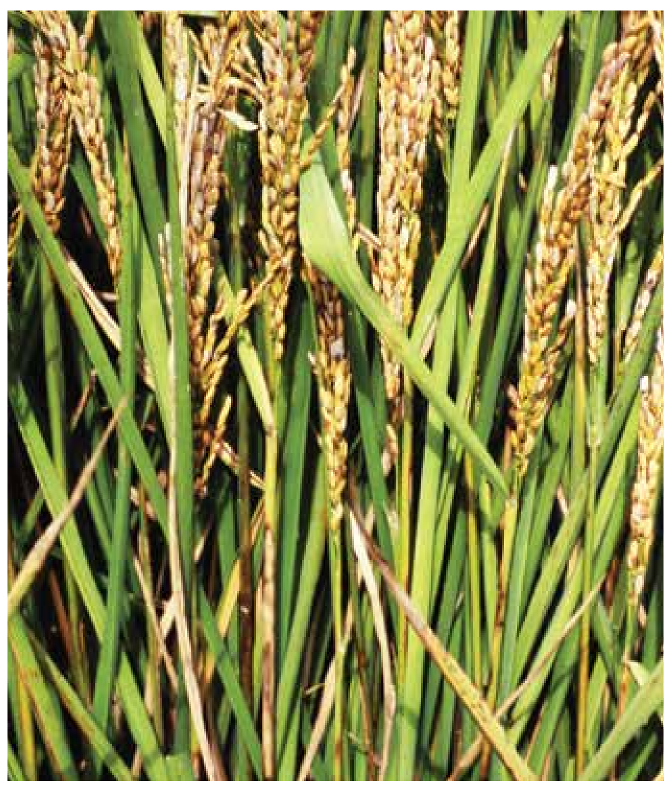


Fig. 6-2. Bacterial panicle blight.

Fig. 6-3. Bacterial panicle blight on kernels.

Affected panicles develop in circular patterns in the field (Fig. 6-2). Florets are initially white or light gray on the basal third with a reddish-brown margin separating this area from the rest of the floret, which becomes straw-colored (Fig. 6-3). The florets eventually become gray with growth of saprophytic fungi on the surface. Floret stems (panicle branches) stay green after the unaffected grain matures. *Burkholderia gladoli* was recently reported as associated with this disease on rice in Japan and the southern United States. This disease can cause severe disease under conditions of extended high temperatures, especially nighttime temperatures, and is ranked with sheath blight and rice blast for its potential to cause loss.

The term "panicle blight" has been used in the United States for more than 50 years, and bacterial panicle blight has been retained as the name of this disease. The bacterium is seed-borne, and rice crops planted with infected seeds can suffer severe losses. The pathogen has also been detected from the soil, but the importance to disease development is not known. Use of pathogen-free seeds is an important practice to reduce or manage the incidence of bacterial panicle blight. A method for testing rice seed-lots with PCR has been developed. 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").

Black Kernel

The fungus *Curvularia lunata* causes black kernel. The fungus causes severe grain discoloration (Fig. 6-4), and after milling, the kernels appear black. When infections are heavy, the fungus can cause seedling blights or weakened seedlings. This disease is rarely severe enough that management practices are recommended. Seed treatments to manage other diseases should reduce seedling damage. No other management measures are warranted.

Fig. 6-4. Black kernel.

Blast

Rice blast is caused by the fungus *Pyricularia grisea*. The disease is also called leaf blast, node blast, panicle blast, collar blast and rotten-neck blast, depending on the portion of the plant affected. Blast has been one of the most important diseases in Louisiana, causing severe yield losses to susceptible varieties under favorable environmental conditions.

Blast can be found on the rice plant from the seedling stage to maturity. The leaf blast phase occurs between the seedling and late tillering stages. Spots on leaves start as small white, gray or blue tinged spots that enlarge quickly under moist conditions to either oval or diamond-shaped spots or linear lesions with pointed ends with gray or white centers and narrow brown borders (Fig. 6-5). Leaves and whole plants are often killed under severe con-

Fig. 6-5. Leaf blast.

Fig. 6-6. Node blast.

ditions. Lesions on resistant plants are small brown specks that do not enlarge.

On stem nodes (Fig. 6-6), the host tissue turns black and becomes shriveled and gray as the plant approaches maturity. 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. Plants lodge or break off at the infected point, or they are connected only by a few vascular strands. Some varieties are infected where the flag leaf attaches to the sheath at the collar (Fig. 6-7). The lesion turns brown or chocolate-brown to gray, and the flag leaf becomes detached from the plant as the lesion area becomes dead and dry.

Rotten-neck symptoms appear at the base of the panicle starting at the node (Fig. 6-8). 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.

Fig. 6-7. Collar blast.

Fig. 6-8. Rotten neck blast.

Scouting a field for blast should begin early in the season during the vegetative phase and continue through the season to heading. Leaf blast will usually appear in the high areas of the field where the flood has been removed, lost or is shallow. Rice is most susceptible to leaf blast at the maximum tillering stage. Areas of heavy N fertilization and edges of the fields are also potential sites of infection. If leaf blast is in the field or has been reported in the same general area and if the variety is susceptible, fungicide applications are advisable to reduce rotten-neck blast.

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. The spores germinate under high humidity and dew conditions and infect the plant. Generally, lesions will appear 4 to 7 days later, and additional spores are produced. Plants of all ages are susceptible. Medium-grain varieties are more susceptible to blast, especially during the leaf phase, than the long-grain varieties grown in Louisiana.

Environmental conditions that favor disease development are long dew periods, high relative humidity and warm days with cool nights. Agronomic practices that favor disease development include excessive N levels, late planting and dry soil (loss of flood). Several physiologic races of *P. grisea* exist, and disease development varies, depending on variety-race interactions.

The disease can be reduced by planting resistant varieties, maintaining a 4- to 6-inch flood, proper N fertilizer, avoiding late planting and by applying a fungicide at the rates and timings recommended by the Louisiana Cooperative Extension Service.

Brown Spot

Brown spot, caused by the fungus *Cochiobolus miyabeanus*, was one of the most prevalent rice diseases in Louisiana. It is also called Helminthosporium leaf spot. When *C. miyabeanus* attacks the plants at emergence, the resulting seedling blight causes sparse or inadequate stands and weakened plants. Leaf spots are present on young rice, but the disease is more prevalent as the plants approach maturity and the leaves begin to senesce.

Fig. 6-9. Brown spot, seedling.

Fig. 6-10. Brown spot.

Yield losses from leaf infection or leaf spots are probably not serious. When the fungus attacks the panicle, including the grain, economic losses occur. Heavy leaf spotting indicates an unfavorable growth factor, usually a soil problem.

The pathogen also attacks the coleoptiles, leaves, leaf sheath, branches of the panicle, glumes and grains. The fungus causes brown, circular to oval spots on the coleoptile leaves of the seedlings (Fig. 6-9). It may cause seedling blight.

Leaf spots are found throughout the season. On young leaves, the spots are smaller than those on older leaves. The spots may vary in size and shape from minute dark spots to large oval to circular spots (Fig. 6-10). The smaller spots are dark brown to reddish-brown. The larger spots have a dark brown margin and a light, reddish-brown or gray center with a gold halo. The spots on the leaf sheath and hulls are similar to those on the leaves.

The fungus attacks the glumes and causes a general black discoloration. It also attacks the immature florets, resulting in no grain development or kernels that are lightweight or chalky.

Brown spot is an indicator of unfavorable growing conditions, including insufficient N, inability of the plants to use N because of rice water weevil injury, root rot or other unfavorable soil conditions. As the plants approach maturity, brown spot becomes more prevalent and the spots are larger on senescing leaves.

Damage from brown spot can be reduced by maintaining good growing conditions for rice by proper fertilization, crop rotation, land leveling, proper soil preparation and water management. Seed-protectant fungicides reduce the severity of seedling blight caused by this seed-borne fungus. Some varieties are less susceptible than others.

Crown Rot

Crown rot is believed to be caused by a bacterial infection (possibly *Erwinia chrysanthemi*). This disease is rarely observed. Symptoms first appear during tillering. The crown area is decayed, with soft rotting, becoming black or dark brown with discolored streaks extending into the lower internodes of culms (Fig. 6-11). There is a fetid or putrid odor characteristic of bacterial soft rots, and tillers start dying one at a time. The roots also die and turn black. Adventitious roots are produced at the node above the crown area. A similar discoloration of the crown can be caused by misapplied herbicides. Control practices are not recommended.

Crown Sheath Rot

Crown sheath rot is caused by the fungus *Gaeumannomyces graminis* var. *graminis*. Other names

Fig. 6-11. Crown rot.

Fig. 6-12. Crown sheath rot.

Fig. 6-13. Crown sheath rot mycelium.

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 severe damage can occur. The pathogen kills lower leaves, thus reducing photosynthetic activity, causing incomplete grain filling, and plants can lodge.

Symptoms appear late in the season, usually after heading. Sheaths on the lower part of the rice plant are discolored brown to black (Fig. 6-12). Reddish-brown mycelial mats are found on the inside of infected sheaths (Fig. 6-13). Dark perithecia are produced within the outside 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 (Fig. 6-33).

The fungus survives as perithecia and mycelia in plant residues. Ascospores are wind-borne in moist conditions. The fungus has been reported to be seed-borne. Management practices have not been worked out for this disease.

Downy Mildew

Downy mildew is caused by the fungus *Sclerophthora macrospora*. In early growth stages, infected seedlings are dwarfed and twisted with chlorotic, yellow to whitish spots. Symptoms are more severe on the head. Because of failure to emerge, panicles are distorted, causing irregular, twisted and spiral heads that remain green longer than normal. This disease is extremely rare. No control measures are recommended.

Fig. 6-14. False smut.

False Smut

False smut, caused by the fungus *Ustilaginoidea virens*, is a minor disease in the United States and is sometimes epidemic in certain areas. The disease is characterized by large orange to brown-green fruiting structures on one or more grains of the mature panicle (Fig. 6-14). When the silver covering ruptures, a mass of greenish-black spores is exposed. The grain is replaced by one or more sclerotia. Most varieties appear to have a high level of resistance, and disease control measures generally are not required. Fungicides used to manage other diseases may be active against this disease.

Grain Spotting and Pecky Rice

Many fungi infect developing grain and cause spots and discoloration on the hulls or kernels. Damage by the rice stink bug, *Oebalus pugnax* F., also causes discoloration of the kernel. Kernels discolored by fungal infections or insect damage are commonly called

Fig. 6-15. Peck rice.

pecky rice (Fig. 6-15). This complex disorder involves many fungi, the white-tip nematode and insect damage. High winds at the early heading stage may cause similar symptoms. Proper insect control and disease management will reduce this problem.

Kernel Smut

This fungal disease is caused by *Neovossia 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 (Fig. 6-16). When this spore mass dries, it is powdery and comes off easily on fingers. Rain washes the black spores over adjacent parts of the panicle. Affected grains are a lighter, slightly grayish color compared with normal grain.

Fig. 6-16. Kernel smut.

Usually, only a few florets may be affected in a panicle, but fields have been observed in Louisiana with 20 to 40 percent of the florets affected on 10 percent or more of the panicles in a field. Smutted grains produce kernels with black streaks or dark areas. Milled rice has a dull or grayish appearance when smutted grains are present in the sample. Because fewer kernels break when parboiled rice is milled, kernel smut can be a severe problem in processed rice. Growers are docked in price for grain with a high incidence of smut.

This disease is usually minor in Louisiana, but it can become epidemic in local areas. Some varieties are more susceptible and should be avoided where smut is a problem. Spores of the fungus are carried on affected seeds and overwinter in the soil of affected fields. The pathogen attacks immature, developing grain and is more severe when rains are frequent during flowering. Fungicide applications at booting can be affective for controlling this disease. Please contact your local LSU AgCenter extension agent for fungicide recommendations.

Leaf Scald

This disease, caused by *Gerlachia oryzae*, is present in the southern rice area of the United States and in Louisiana annually. It affects leaves, panicles and seedlings. The pathogen is seed-borne and survives between crops on infected seeds. The disease usually occurs on maturing leaves. Lesions start on leaf tips or from the edges of leaf blades. The lesions have a chevron pattern of light (tan) and darker reddish-brown areas (Fig. 6-17). The leading edge of the lesion usually is yellow to gold (Fig. 6-18). Fields look yellow or gold. Lesions from the edges of leaf blades have an indistinct, mottled pattern. Affected leaves dry and turn straw-colored.

Fig. 6-17. Leaf scald.

Fig. 6-18. Leaf scald.

Panicle infestations cause a uniform light to dark, reddish-brown discoloration of entire florets or hulls of developing grain. The disease can cause sterility or abortion of developing kernels. Control measures are not recommended, but foliar fungicides used to manage other diseases have activity against this disease.

Leaf Smut

Leaf smut, caused by the fungus *Entyloma oryzae*, is a widely distributed, but somewhat minor, disease

Fig. 6-19. Leaf smut.

of rice. The fungus produces slightly raised black spots (sori) on both sides of the leaves (Fig. 6-19) and on sheaths and stalks. The blackened spots are about 0.5 to 5.0 mm long and 0.5 to 1.5 mm wide. Many spots can be found on the same leaf, but they remain distinct from each other. Heavily infected leaves turn yellow, and leaf tips die and turn gray. The fungus is spread by airborne spores and overwinters on diseased leaf debris in soil. Leaf smut occurs late in the growing season and causes little or no loss. Control measures are not recommended.

Narrow Brown Leaf Spot

Narrow brown leaf spot, caused by the fungus *Cercospora janseana*, varies in severity from year to year and is more severe as rice plants approach maturity. Leaf spotting may become very severe on the more susceptible varieties and causes severe leaf necrosis. Premature ripening, yield reduction and reduced milling can occur. The disease is most severe on ratoon crop rice.

Fig. 6-20. Narrow brown leaf spot.

Symptoms include short, linear, brown lesions most commonly found on leaf blades (Fig. 6-20). Symptoms also occur on leaf sheaths, pedicels and glumes. Leaf lesions are 2 to 10 mm long and about 1 mm wide, tend to be narrower, shorter and darker brown on resistant varieties and wider and lighter brown with gray necrotic centers on susceptible varieties. On upper leaf sheaths, symptoms are similar to those found on the leaf. On lower sheaths, the symptom is a "net blotch" or spot in which cell walls are dark brown and intracellular areas are tan to yellow (Fig. 6-21).

Fig. 6-21. Net blotch phase of narrow brown leaf spot.

The primary factors affecting disease development are (1) susceptibility of varieties to one or more prevalent pathogenic races, (2) prevalence of pathogenic races on leading varieties and (3) growth stage. Although rice plants are susceptible at all stages of growth, the plants are more susceptible from panicle emergence to maturity. Differences in susceptibility among rice varieties are commonly observed, but resistance is an unreliable control method as new races develop readily. Some fungicides used to reduce other diseases also may have activity against narrow brown leaf spot. Low N levels favor development of this disease.

Root Knot

Species of the nematode *Meloidogyne* cause root knot. Symptoms include enlargement of the roots and the

Fig. 6-22. Root knot.

formation of galls or knots (Fig. 6-22). 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.

Root Rot

Root rots are caused by several fungi, including *Pythium spinosum*, *P. dissotocum*, other *Pythium* spp. and several other fungi. The rice plant is predisposed to this disorder by a combination of factors, including physiological disorders, insect feeding, especially feeding of rice water weevil larvae, extreme environmental conditions and various other pathogens.

Symptoms can be noted as early as emergence. Roots show brown to black discoloration and necrosis (Fig. 6-23). As the roots decay, nutrient absorption is disrupted, the leaves turn yellow and the plants lack vigor. With heavy root infections, plants lack support from the roots and lodge, causing harvest problems. Often, plants with root rot show severe brown leaf spot infection. The disease is referred to as feeder root necrosis when the small fine roots and root hairs are destroyed on seedling and young plants. When this happens, no lodging occurs and symptom development is not as apparent on the upper plants.

Fig. 6-23. Root rot.

Fertilizer usually reduces the aboveground symptoms although actual nutrient use is impaired. Rice water weevil control greatly reduces root rots. Draining fields stimulates root growth but can cause problems with blast, weeds or efficiency of nutrient use.

Seedling Blight

Seedling blight, or damping off, is a disease complex caused by several seed-borne and soil-borne fungi, including species of *Cochiobolus*, *Curvularia*, *Sarocladium*, *Fusarium*, *Rhizoctonia* and *Sclerotium*. Typically, the rice seedlings are weakened or killed by the fungi. Environmental conditions are important in disease development. Cold, wet weather is most favorable to disease development.

Seedling blight causes stands of rice to be spotty, irregular and thin. Fungi enter the young seedlings and either kill or injure them. Blighted seedlings that emerge from the soil die soon after emergence. Those that survive generally lack vigor, are yellow or pale green and do not compete well with healthy seedlings.

Severity and incidence of seedling blight depend on three factors: (1) percentage of the seed infested by 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 overcome 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 reduced by treating the seed with fungicides.

Seeds that carry blight fungi frequently have spotted or discolored hulls, but seed can be infected and still appear to be clean. *Cochiobolus miyabeanus*, one

Fig. 6-24. Seedling blight.

of the chief causes of seedling blight, is seed-borne. A seedling attacked by this fungus has dark areas on the basal parts of the first leaf (Fig. 6-24).

If rice seed is sown early in the season, treating the seed is likely to mean the difference between getting a satisfactory stand or having to plant a second time. Little benefit is received from treating rice seed to be sown late in the season, unless unfavorable weather prevails.

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

Treatment of the seed with a fungicide is recommended to improve or ensure stands. Proper cultural methods for rice production, such as proper planting date or shallow seeding of early planted rice, will reduce the damage from seedling blight fungi.

Water- and soil-borne 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 injury is often more visible after the field is drained. It may also occur in drill-seeded rice during prolonged wet, rainy periods.

Seed treatment, planting when temperatures favor rapid growth of seedlings and draining the field are the best management measures for seedling disease control.

Sheath Blight

Sheath blight has been the most economically significant disease in Louisiana since the early 1970s. The disease is caused by *Rhizoctonia solani*, a fungal pathogen of both rice and soybeans. On soybeans, it causes aerial blight.

Several factors have contributed to the development of sheath blight from minor to major disease status. They include the increased acreage planted to susceptible long-grain varieties, the increase in the acreage of rice grown in rotation with soybeans, the increased use of broadcast seeding and the higher rates of N fertilizers used with the modern commercial rice varieties. The disease is favored by dense stands with a heavily developed canopy, warm temperature and high humidity. The fungus survives between crops as structures called sclerotia or as hyphae in plant debris. Sclerotia (Fig. 6-25) or plant debris floating

Fig. 6-25. Sheath blight sclerotia on stem.

Fig. 6-26. Sheath blight lesions on sheath.

Fig. 6-27. Sheath blight lesions on leaves.

on the surface of irrigation water serves as sources of inoculum that attack and infect lower sheaths of rice plants at the waterline.

Sheath blight is characterized by large oval spots on the leaf sheaths (Fig. 6-26) and irregular spots on leaf blades (Fig. 6-27). Infections usually begin during the late tillering-joint elongation stages of growth. Lesions about 0.5 to 1 cm in width and 1 to 3 cm in length are formed a little above the waterline on infected culms (Fig. 6-28). Fungus mycelium grows up the leaf sheath, forms infection structures, infects and causes new lesions. The infection can spread to leaf blades. The lower leaf sheaths and blades are affected during the jointing stages of growth. After the panicle emerges from the boot, the disease progresses rapidly to the flag leaf on susceptible varieties. With very susceptible varieties, the fungus will spread into the culm from early sheath infections. Infected culms are weakened, and the tillers may lodge or collapse.

The fungus can spread in the field by growing from tiller to tiller on an infected plant or across the surface of the water to adjacent plants. The fungus also grows across touching plant parts, for example from leaf to leaf, causing infections on nearby plants. Infected plants are usually found in a circular pattern in the field because the fungus does not produce spores and must grow from plant to plant.

Fig. 6-28. Early, intermediate and late sheath blight lesions.

The lesions have grayish-white or light green centers with a brown or reddish-brown margin. As lesions coalesce on the sheath, the blades turn yellow-orange and eventually die. As areas in the field with dead tillers and plants increase, they may coalesce with other affected areas to cause large areas of lodged, dead and dying plants. Damage is usually most common where wind-blown, floating debris accumulates in the corners of cuts when seedbeds are prepared in the water.

Sheath blight also affects many grasses and weeds other than rice, causing similar symptoms. Sclerotia that survive between crops are formed on the surface of lesions on these weed grasses, as well as on rice and soybeans. The sclerotia are tightly woven masses of fungal mycelium covered by an impervious, hydrophobic coating secreted by the fungus.

Disease severity can be reduced by integrating several management practices. Dense stands and excessive use of fertilizer both tend to increase the damage caused by this disease. Broadcast seeding tends to increase stand and canopy density. Rotation with soybeans or continuous rice increases the amount of inoculum in field soils. Fallow periods, with disking to control growth of grasses, will reduce inoculum in the soil.

The pathogen also is known to infect sorghum, corn and sugarcane when environmental conditions are favorable for disease development.

Medium-grain rice varieties are more resistant to sheath blight than most of the long-grain varieties. Several recently released long-grain varieties are more resistant to sheath blight than the older long-grain varieties (see LSU AgCenter publication 2270, "Rice Varieties and Management Tips").

Fungicides are available for reducing sheath blight. Ask an Extension Agent for the latest information on fungicides for sheath blight management.

Sheath Blotch

This fungal disease affects the leaf sheaths, especially the flag-leaf sheath near the collar. The lesion usually starts at an edge of the sheath and enlarges to form an oblong blotch that may increase in size until it covers the sheath, but the lesion is usually restricted and becomes zonate (Fig. 6-29). This distinguishes it from sheath rot caused by *Sarocladium oryzae*. Many black fruiting structures (pycnidia) are visible in the lesion. This disease is normally not severe or widespread enough to warrant control measures.

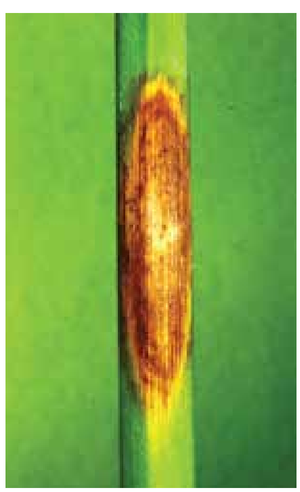


Fig. 6-29. Sheath blotch.

Sheath Rot

This disease is caused by the fungal pathogen *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 (Fig. 6-30), or the lesions may form an irregular target pattern. On U.S. rice varieties, the lesion is usually expressed as a reddish-brown to purple-brown discoloration of the flag leaf sheath. Early or severe infections affect the panicle so that it only partially emerges. The unemerged portion of the panicle rots, turning florets to dark brown. Grains from damaged panicles are discolored reddish-brown to dark brown and may not fill. A powdery white growth consisting of spores and hyphae of the pathogen may be observed on the inside of affected sheaths. Insect or mite damage to the boot or leaf sheaths increases the damage from this disease.

Fig. 6-30. Sheath rot.

This disease affects most rice varieties. The disease is usually minor, affecting scattered tillers in a field. Occasionally, larger areas of a field may have significant damage. Control measures are not recomvmended. Fungicidal sprays used in a general disease management program reduce damage, but recent studies show that several bacterial pathogens commonly cause similar sheath rot symptoms on rice in Louisiana. Fungicides would have little effect on these pathogens.

Sheath Spot

This disease is caused by the fungus *Rhizoctonia oryzae*. The disease resembles sheath blight but is usually less severe. The lesions produced by *R. oryzae* are found on sheaths midway up the tiller or on leaf blades (Fig. 6-31). Lesions are oval, 0.5 to 2 cm long and 0.5 to 1 cm wide. The center is pale green, cream or white with a broad, dark reddish-brown margin (Fig. 6-31). Lesions are separated on the sheath or blade and do not form the large, continuous lesions often found with sheath blight. The pathogen attacks and weakens the culm under the sheath lesion on very susceptible varieties. The weakened culm lodges or breaks over at the point where it was infected. Lodging caused by sheath spot usually occurs midway up the culm. This disease is usually minor on Louisiana rice. Some fungicides used to manage sheath blight also reduce sheath spot.


Fig. 6-31. Sheath spot lesions.

Stackburn

This disease was first observed on rice growing in Louisiana and Texas. Stackburn or Alternaria leaf spot is caused by the fungal pathogen *Alternaria padwickii*. It is common on rice around the world.

The disease is present in most rice fields in Louisiana. Only occasional spots are observed, but the disease may be more severe in restricted areas of a field. The spots are typically large (0.5- to 1-cm in diameter), oval or circular, with a dark brown margin or ring around the spot (Fig. 6-32). 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. These are sclerotia of the fungus. Grain or seeds affected by the disease have tan to white spots with a wide, dark brown border. The disease causes discoloration of kernels or the kernels stop development and grains are shriveled.


Fig. 6-32. Stackburn.

This fungus is the most common seed-borne fungus in Louisiana and may cause seedling blight. It is more common on panicles and grain than on leaves in Louisiana.

No specific control recommendations are available, but seed-protectant fungicides will help reduce the seedling blight caused by this pathogen and will reduce the number of spores available to cause leaf infections.

Stem Rot

Stem rot, caused by the fungus *Sclerotium 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 causes severe lodging, which reduces combine efficiency, increases seed sterility and reduces 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 (Fig. 6-33). 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


Fig. 6-33. Stem rot lesion.

Fig. 6-34. Stem rot scerotia.

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 (Fig. 6-34).

The pathogen overwinters as sclerotia in the top 2 to 4 inches of soil and on plant debris. During water-working and establishment of early floods, the hydrophobic sclerotia float on the surface of the water and often accumulate along the edge of the field and on levees because of wind action.

After a permanent flood is established, the sclerotia float to the surface, contact the plant, germinate and infect the tissues near the waterline. The fungus then penetrates the inner sheaths and culm, often killing the tissues. The fungus continues to develop, forming many sclerotia in the stubble after harvest.

Most commercial varieties of rice are not highly resistant to stem rot. The disease is favored by high N levels. Early maturing varieties are usually less affected by stem rot. In addition, applications of K fertilizer reduce disease severity in soils where K is deficient. Stem rot is more serious in fields that have been in rice production for several years.

Suggested management measures include using early maturing varieties, avoiding very susceptible varieties, burning stubble or destroying by cultivation after harvest to destroy sclerotia, using crop rotation when possible, applying K fertilizer, avoiding excessive N rates and using foliar fungicides recommended by the LSU AgCenter.

Water Mold and Seed Rot

When using the water-seeding method of planting rice, it is difficult to obtain uniform stands of sufficient density to obtain maximum yields. The most important biological factor contributing to this situation is the water mold or seed rot disease caused primarily by fungi in the genera *Achlya* and *Pythium*. Recently, certain *Fusarium* spp. also have been found associated with molded seeds. The disease is caused by a complex of these fungi infecting seeds. The severity of this disease is more pronounced when water temperatures are low or unusually high. Low water temperatures slow the germination and growth of rice seedlings but do not affect growth of these pathogens. In surveys conducted in Louisiana during the 1970s and 1980s, an average of 45 percent of water-planted seeds was lost to water mold.

In addition to the direct cost of the lost seeds and the cost of replanting, water mold also cause indirect losses through the reduced competitiveness of rice with weeds in sparse or irregular stands. Also, replanting or overseeding the field causes the rice to mature late when conditions are less favorable for high yields because of unfavorable weather and high disease pressure.

Fig. 6-35. Water mold.

Fig. 6-36. Water mold caused by Achlya.

Fig. 6-37. Water mold caused by Pythium

Water mold can be observed through clear water as a ball of fungal strands surrounding seeds on the soil surface (Fig. 6-35). After the seeding flood is removed, seeds on the soil surface are typically surrounded by a mass of fungal strands radiating out over the soil surface from the affected seeds. The result is a circular copper-brown or dark green spot about the size of a dime with a rotted seed in the center (Fig. 6-36). The color is caused by bacteria and green algae, which are mixed with the fungal hyphae.

Achlya spp. (Fig. 6-35) normally attack the endosperm of germinating seeds, destroying the food source for the growing embryo and eventually attacking the embryo. *Pythium* spp. (Fig. 6-37) usually attack the developing embryo directly. When the seed is affected by the disease, the endosperm becomes liquified 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 seedling shoot and roots are attacked by *Pythium* spp. after the seedling is established, the plant is stunted, turns yellow and grows poorly. If the weather is favorable for plant growth, seedlings often outgrow the disease and are not severely damaged.

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

Treat seed with a recommended fungicide at the proper rate to reduce water molds and seed diseases. A list of recommended fungicides is available through LSU AgCenter extension agents. Most rice seed is treated by the seedsman and is available to the grower already treated. Seed-protectant fungicides differ in their effectiveness. Information on recent results from seed-protectant fungicide trials can be obtained from an extension agent or the Rice Research Station. In field tests, these fungicides have increased stands over those produced by untreated seeds from 25 to 100 percent.

White Leaf Streak

White leaf streak is caused by the fungal pathogen *Mycovellosiella oryzae*. The symptoms are very similar to the narrow brown leaf spot symptoms caused by *Cercospora janseana* except that the lesions are slightly

Fig. 6-38. White leaf streak symptoms.

wider with white centers (Fig. 6-38). The disease is common on leaf blades some years but is not severe enough to warrant control measures.

White Tip

This disease is caused by the nematode *Aphelenchoides besseyi*. Characteristic symptoms that appear after tillering include the yellowing of leaf tips, white areas in portions of the leaf blade (Fig. 6-39), stunting of affected plants, twisting or distortion of the flag leaf and distortion and discoloration of panicles and florets. Leaf tips change from green to yellow and eventually white. The tip withers above the white area, becoming brown or tan and tattered or twisted. Resistant varieties may show few symptoms and still have yield loss. The nematode infects the developing grain and is seed-borne. This disease is present endemically in Louisiana but is considered a minor rice disease. Fumigation of seeds in storage may reduce the nematode population. No other specific control measures are recommended.

Fig. 6-39 White tip.

Scouting and management practices recommended for major rice diseases

BACTERIAL PANICLE BLIGHT

Scouting and Determining Need

Florets on young panicles become discolored and stay upright as the floret is sterile or aborts. Floret stems (panicle branches) stay green after the unaffected grain matures. Damage may vary from a single floret to all of the florets on a panicle. Damage is most severe during periods of unusually hot weather or unusually hot nights.

Management Practices

Most commercial varieties are susceptible, but some show significant partial resistance. The pathogens are seed-borne and the pathogenic bacteria remain on leaves throughout the vegetative stages of the rice plant without showing symptoms. Panicles become infected as they emerge. No pesticides are currently recommended to control this disease. The best control measure is to not plant seed from fields that were seriously affected the previous year. A procedure has been developed to test seed lots for the pathogen and to quantify the pathogen. This procedure is not yet widely available. Avoiding excessive N rates and early planting can reduce disease.

BLAST

Scouting and Determining Need

Varieties with low levels of resistance should be scouted for leaf blast during the vegetative stages of growth. Leaf blast is more likely when the flood is lost, excessive N is used or rice is planted late in the growing season. Sandy soils and tracts near tree lines are areas where blast is likely to occur. Rotten neck blast has no predictive systems. Since significant damage is already done when rotten neck or panicle blast is first detected, preventive sprays are required on susceptible varieties when blast has been detected in the area.

Management Practices

Plant varieties resistant to blast. Avoid late planting. Plant as early as possible within your recommended planting period. For leaf blast, reflood if field has been drained. Maintain flood at 4 to 6 inches. Do not overfertilize with N. Apply a fungicide if necessary. Contact your parish LSU AgCenter extension agent for the latest information on available fungicides and timing.

SHEATH BLIGHT

Scouting and Determining Need

Fields should be scouted for the presence of sheath blight symptoms at least once a week beginning at midtillering and continuing until heading. The field should be scouted by making periodic random stops throughout the field. Tillers should be examined for the presence of symptoms. When 5 to 10 percent of the tillers of a susceptible variety or 10 to 15 percent of the tillers of a moderately susceptible variety are infected, a fungicide application is justified.

Management Practices

Avoid dense stands and excessive N fertilizer. Most long-grain varieties have little resistance to sheath blight. Medium-grain varieties are more resistant. Timing and rate of fungicide applications are critical for good sheath blight management. Check with your parish LSU AgCenter extension agent for the latest information on fungicides. Fallow periods, with disking to control grasses in the field (which serve as sources of inoculum) and break down crop residue, help reduce disease pressure.

BROWN SPOT

Scouting and Determining Need

Disease is most severe when plants are N deficient or under other stresses. Plants become more susceptible as they approach maturity.

Management Practices

Maintain good growing conditions through proper fertilizer, land leveling, good soil preparation and other cultural practices. Use recommended seed protectant fungicides to reduce inoculum. Correct stress conditions in the field. All varieties are susceptible but some more than others.

NARROW BROWN LEAF SPOT

Scouting and Determining Need

Disease is most severe from panicle emergence to maturity. Several pathogenic races are present, and new races develop to affect resistant varieties.

Management Practices

Some commercial varieties have acceptable levels of resistance to this disease. See LSU AgCenter publication 2270, "Rice Varieties and Management Tips Publication." Check with your parish LSU AgCenter extension agent for latest information on the use of available fungicides. Apply fungicides at the recommended rate and timing.

STEM ROT

Scouting and Determining Need

Most commercial varieties are susceptible. Infection takes place at the water line, and angular black lesions form. The number of infected tillers may reach 100 percent in areas of the field where debris and sclerotia from the previous crop have collected after being windblown on the water surface.

Management Practices

Applying K will reduce disease severity where K is deficient. Early maturing varieties are less affected by stem rot. Destroying the sclerotia in stubble by crop rotation, tillage or burning can reduce disease pressure.

WATER MOLD AND SEED ROT

Scouting and Determining Need

The fungi causing this disease are soil- and waterborne. They occur in most rice fields. The seed rot and water mold diseases are most severe under flooded conditions when the water is cold.

Management Practices

Seed should be treated with recommended fungicides. Check with your parish LSU AgCenter extension agent for recent information on effective seed-protectant fungicides. Draining the seeding flood and flushing as needed helps prevent water mold. The practice of pinpoint flooding helps reduce water mold damage. Seeding should not begin until the mean daily temperature reaches 65 degrees F.

SEEDLING BLIGHT

Scouting and Determining Need

The fungi causing this disease can be seed-borne or soil-borne. They are common and normally are present on seeds or in soil. Seedling blight is common in drill-seeded or dry- broadcast rice.

Management Practices

Treating seed with seed-protectant fungicides effectively reduces seedling blight. Check with your parish LSU AgCenter extension agent for recent information on effective seed-protectant fungicides.

GRAIN SPOTTING AND PECKY RICE

Scouting and Determining Need

Since grain spotting and pecky rice diseases are normally associated with insect damage, scout for the rice stink bug. Monitor fields from immediately after pollination until kernels begin to harden. Sample with a sweep net and count the number of insects collected. Refer to LSU AgCenter publication 2270, "Rice Varieties and Management Tips" for current stinkbug control recommendations.

Management Practices

Control of the stink bugs with insecticides is the only management measure for grain spotting and pecky rice.

KERNEL SMUT, FALSE SMUT

Scouting and Determining Need

No scouting is possible since disease does not appear until heading and control is ineffective after this stage.

Management Practices

Excessive N increases diseases. Some varieties have resistance. Boot applications of certain fungicides reduce disease.

LEAF SMUT, SHEATH ROT, SHEATH SPOT, LEAF SCALD, STACKBURN, ROOT ROT, ROOT KNOT, WHITE TIP, PANICLE BLIGHT, DOWNY MILDEW, BACTERIAL LEAF BLIGHT, BLACK KERNEL, CROWN ROT, CROWN SHEATH ROT, SHEATH BLOTCH, WHITE LEAF STREAK

Scouting and Determining Need

These diseases rarely occur with enough severity to warrant control measures or scouting.

Management Practices

Control measures are not available or recommended for these diseases. Varieties differ in their reaction to these diseases, but extensive evaluations have not been conducted.

Fungicides used to manage other major diseases reduce several of these diseases. Check with your parish LSU AgCenter extension agent for the latest information.

Chapter 7

Invertebrate Pest Management

Michael Stout and Thomas E. Reagan

The major invertebrate pests of rice in Louisiana are the rice water weevil and the rice stink bug. In addition, rice stem borers, rice seed midge, the rice leaf miner, the South American rice miner, and armyworms can be important rice pests. The panicle rice mite has recently been reported in rice fields in the state. The panicle rice mite is an arachnid and not an insect. Under heavy infestation levels, all of these pests can cause economic losses. 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 is the integration of a variety of pest control strategies to effectively maintain a pest insect population at densities below the economic threshold for treatment. An effective integrated pest management 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 integrated pest management 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 agro-ecosystem.

Rice Water Weevil

Lissorhoptrus oryzophilus Kuschel

Description and Life Cycle

The rice water weevil is the most important early season insect pest of rice in Louisiana. Adults of this insect emerge from overwintering sites beginning in early April in southern Louisiana (later in northern Louisiana) and 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. 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. After eclosing from eggs, larvae feed under water on rice roots and pass through four larval instars and a pupal stage in approximately 30 days.

Fig. 7-1. Adult rice water weevil.

The rice water weevil is the most injurious insect pest in Louisiana rice production. Yield losses in excess of 25 percent can occur from severe infestations.

Rice water weevil adults are grayish-brown weevils (beetles) about 1/8 inch long with a dark brown V-shaped area on their backs (Fig. 7-1). 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 2 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 laying eggs in rice, adult rice water weevils will oviposit (lay eggs) 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.

White, legless, c-shaped larvae with small brown head capsules emerge from eggs in about 7 days. First instar larvae are about 1/32 inch long and feed in the leaf sheath for a short time before exiting the stem and falling through the water to the soil, where they burrow into the mud and begin feeding on the roots of rice plants (Fig. 7-2). 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. Larvae pupate in oval, watertight cocoons attached to the roots of rice and weed plants. The cocoons are covered with a compacted layer of mud and resemble small mud balls (Fig. 7-3). Peak larval density occurs 3 to 5 weeks after flooding.

Fig. 7-2. Rice water weevil larva (root maggot).

Adults emerge from the cocoons and are able to fly a short time after emerging and may return to overwintering sites or attack a different rice field. Newly emerged adult weevils usually do not re-infest the same field that they emerge from because they prefer to attack young plants. 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.

Fig. 7-3. Rice water weevil pupae.

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 (Fig. 7-4). 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 (Fig. 7-5). This feeding or root pruning results in 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 (Fig. 7-5) may turn yellow and appear to be N deficient. 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 percent 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.

Fig. 7-4. Rice water weevil feeding scars.

Fig.7-5. Heavily pruned roots (left) versus healthy roots (right).

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.

Scouting and Management Using Insecticides

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. 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 publications 1838 ("Pest Management Guide") and 2270 ("Rice Varieties and Management Tips").

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. Oviposition is possible when standing water is present in a field, i.e. when the field has been saturated by rainfall or flushing or when permanent flood has been established. In most fields, the majority of oviposition is likely to occur after the establishment of permanent flood. 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 1 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 7 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.

Applications of granular formulations of adulticides are an alternative method that minimizes insecticide drift into nontarget areas (such as crawfish ponds). These formulations will only control adults and are to be used in a manner identical to that described above for liquid formulations of adulticides. Similarly, pyrethroids impregnated on fertilizer will kill adults but will not kill larvae feeding on roots.

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 3 to 5 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

Fig. 7-7. Rice water weevil sampling bucket.

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 10 to 14 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 (Fig. 7-7). Wash the soil from the plant roots through the screen bottom in the bucket by thoroughly stirring the soil in the water. Push the bucket up and down vigorously in the water several times. 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 7 days. If the average number of larvae per sample is fewer than five, sample the field again 3 to 5 days later. If the average number of larvae per sample is five or more, the field should be treated with available larvacides or drained. Sampling should cease when the field has been treated or when plants have reached the 2-mm panicle stage of development.

Prophylactic Seed Treatments

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. Effectiveness of prophylactic seed treatment, however, should be assessed by monitoring larval populations using the bucket sampling method described above.

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 has multiple advantages. The first advantage is that populations of rice water weevil adults infesting early planted fields are generally smaller than populations that infest later-planted fields. This is true because emergence from overwintering sites occurs over a long window of time and the population is not fully emerged when rice is planted early. More weevils are present in late-planted rice fields because they are infested by weevils both from overwintering sites and surrounding rice fields. The 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.

Fig. 7-8. Rice stink bug adults.

Another cultural control strategy is draining fields to reduce rice water weevil larvae numbers. Soil must dry to the point of cracking. Draining fields is the only rice water weevil control method available for rice grown in rotation with crawfish. 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 percent greater yield losses were observed in early flooded rice plots compared with yield losses in field in which flooding was delayed by 2 weeks.

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 (Fig. 7-8). 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 (Fig. 7-9). As they mature, eggs become black with a red tint. Immature stink bugs (nymphs) emerge from eggs in

Fig. 7-9. Rice stink bug hatchling (first instar nymphs).

Fig. 7-10. Rice stink bug nymph.

4 to 5 days in warm weather or as long as 11 days in cool weather. Nymphs develop through five instars 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 (Fig. 7-9). Nymphs increase in size with successive molts, and the color of later instars becomes tan-green (Fig. 7-10).

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 (Fig. 7-11). Both adult and nymph rice stink bugs feed on developing rice grains, but adults alone 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.

Fig. 7-11. 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. Alternatively, 100 random sweeps may be taken per field. During the first 2 weeks of heading, fields averaging one or more rice stink bugs per three sweeps (30 or more per 100 sweeps) should be treated with an insecticide. After the first 2 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 2 weeks of harvest. Contact your parish LSU AgCenter extension agent for specific treatment recommendations. Please consult LSU AgCenter publications 1838 ("Pest Management

Guide") and 2270 ("Rice Varieties and Management Tips") for the most current list of pesticides registered to control rice stink bugs.

Stem Borers

The rice crop in Louisiana can be attacked by the European corn borer, rice stalk borer, sugarcane borer and Mexican rice borer. The sugarcane borer and the rice stalk borer are increasingly important pests of rice in Louisiana. In addition, the European corn borer has been reported affecting localized rice fields in northern parts of the state. A fourth stem borer, the Mexican rice borer, is present in Texas. Two adult males were trapped in Louisiana in 2008. It is likely this borer will become a pest of rice in Louisiana. Increased adoption of minimum tillage and several years of mild and dry winters contributed to the growth of borer populations. In addition, corn, sorghum and rice fields frequently lie in close proximity to one another and are sequentially planted in the northern half of the state. This creates an array of suitable host crops available for the development and expansion of borer populations throughout the growing season. Rice is susceptible to economic injury from panicle differentiation through the dough stage. Yield loss in rice results from plant tunneling, lodging, "deadhearts," "whiteheads" and "partial whiteheads."

The sugarcane borer and the rice stem borer are distributed statewide. Both species overwinter as last instar larvae in the stalks of rice and other weedy host plants. For this reason, the stubble should be plowed to remove the overwintering habitat. These larvae pupate in the spring, and adult moths emerge during early May.

Sugarcane Borer

Diatrea saccharalis (F.)

Description and Life Cycle

The sugarcane borer is the most aggressive and economically important stem borer that attacks rice in some central and northeastern Louisiana rice areas. 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 rice stem

Fig. 7-12. Sugarcane borer adult.

Fig. 7-13. Sugarcane borer egg mass.

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 (Fig. 7-12). 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 1 to 6 days (Fig. 7-13). Larvae emerge in 3 to 5 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 (Fig. 7-14). Overwintering larvae are a deeper yellow and lack the brown spots. The lack of stripes

Fig. 7-14. Sugarcane borer larva.

Fig. 7-15. Sugarcane borer pupa.

Fig. 7-16. Rice stalk borer adult.

Fig. 7-17. Rice stalk borer larva.

distinguishes sugarcane borer larvae from rice stalk borer larvae, which have stripes in the winter and summer. 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, not smoothly tapered as are rice stalk borer pupae (Fig. 7-15). Overwintering sugarcane borer larvae are usually found closer to the plant crown than rice stalk borer larvae. The pupal stage lasts 7 to 10 days. There are three generations per year.

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 (Fig. 7-16). 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 1 to 6 days. Larvae emerge in 4 to 9 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 two pairs of stripes running the entire length of the body and have a black head capsule (Fig. 7-17). These stripes distinguish rice stalk borer larvae from sugarcane borer larvae, which have no 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 and constructing a silken web in which to pupate. Pupae are about 1 inch long, brown and smoothly tapered. The pupal stage lasts 7 to 10 days. There are two to three generations per year in rice.

Fig. 7-18. European corn borer adult.

Fig. 7-19. European corn borer larva.

European Corn Borer
Ostrinia nubilalis (Hübner)

Description and Life Cycle

The European corn borer may increase their population densities in corn and grain sorghum before migrating to rice fields. They have the potential for severe infestations in rice in central and northern latitudes of Louisiana. Adult European corn borers have delta-shaped wings with wavy dark lines running across them (Fig. 7-18). Adults infest the crop, and the lifecycle is very similar to sugarcane borer or rice stalk borer. Larvae of the European corn borer have a flesh-colored body that may have a grayish, greenish or pinkish tinge (Fig. 7-19). 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.

Fig. 7-20. Mexican rice borer adult.

Fig. 7-21. Mexican rice borer larva.

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 has been studied mainly on sugarcane, which has suffered from severe infestations in Texas. Mexican rice borer moths are light tan with delta-shaped wings (Fig. 7-20). Adult moths lay spherical, cream-colored eggs in groups of five to 100. 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 two pairs of stripes running the length of the body (Fig. 7-21). Pupation takes place inside the rice stem after mature larvae have constructed an emergence window covered by one or two layers of plant tissue.

Fig. 7-22. Dead heart caused by Mexican rice borer.

Fig. 7-23. White head.

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 (Fig. 7-22). 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 white-head condition (Fig. 7-23). The white, empty panicles are light in weight and stand upright.

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 (Fig. 7-24). These lesions are caused by the larva that

Fig. 7-24. Borer damage at collar of leaf.

feeds underneath the leaf sheath during the 2 or 3 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 (Fig. 7-25). In addition, scouts must look for adults, egg masses or fresh feeding scars on the leaves.

Fig. 7-25. Borer feeding on stem behind leaf sheath.

Unfortunately, by the time signs of field infestations (deadhearts, white-heads) 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. Scouting can be conducted for stem borer adults or egg masses. Eggs are laid over an extended period, however, and although some injury may be prevented, satisfactory control using insecticides is difficult and generally has not been successful. Please consult LSU AgCenter publications 1838 ("Pest Management Guide") and 2270 ("Rice Varieties and Management Tips") for the most current list of insecticides labeled to control borers in rice.

Biological control can sometimes be effective to control stem borers. Stem borer eggs and larvae are parasitized by the wasps, *Trichogramma minutum* Riley and *Agathis stigmaterus* (Cresson), respectively. It is believed these parasites play an important role in maintaining stem borer numbers below economic levels.

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. Crop rotation is not an effective tool for managing borers because the field-to-field mobility of moths allows them to infest newer areas. Pheromone traps are useful for monitoring the emergence and movement of the European corn borer and Mexican rice borer, but no pheromone is currently available to monitor sugarcane borer moths. Therefore, plant inspections still are needed to detect sugarcane borer infestations. Early planting is also important for rice grown near corn in areas with a history of borer infestations. Early planting allows those crops to mature before the beginning of moth migration from maturing corn fields. No economic thresholds have been developed for these insects in rice. Please consult your parish LSU AgCenter extension agent for the latest recommendations to control stem borers in rice.

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 (Fig. 7-26). Adult midges resemble small mosquitoes but lack the 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 spaghetti-like tubes constructed from secreted silk, plant debris and algae. The larvae mature through four instars before pupating under water in the tubes (Fig. 7-27). The life cycle from egg to adult requires 10 to 15 days.

Fig. 7-26. Seed midge swarms.

Fig. 7-27. Midge tubes on soil under water.

Fig. 7-28. Seed midge damage.

Injury

Larvae injure rice by feeding on the embryo of germinating seeds (Fig. 7-28) 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. Water-seeded fields should be scouted for midge injury, checking for hollowed out seed within 5 to 7 days after seeding. 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.

Scouting and Management

Rice seed midge is a problem only for rice seeds and seedlings in water-seeded fields. Midges are not a problem in rice more than 2 to 4 inches tall. Scout fields for midges and midge injury within 5 to 7 days after seeding. Repeat scouting at five- 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 (Fig. 7-28). If midge injury is present and plant stand has been reduced to fewer than 15 plants per square foot, treatment may be necessary.

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 2 to 3 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.

Rice Leaf Miner

Hydrellia griseola

Description and Life Cycle

Adult flies have clear wings on a metallic blue-green-to-gray thorax (Fig. 7-29). 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 3 to 6 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 (Fig. 7-30). The larvae feed for 5 to 12 days before pupating. Adults emerge after 5 to 9 days and live 2 to 4 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.

Fig. 7-29. Adult leaf miner.

Fig. 7-30. 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

Fig. 7-31. Rice leaf miner damage in fields where water is more than 6 inches deep.

Fig. 7-32. Bumps in leaves indicate leaf miners.

Fig.7-33. Rice leaf miner pupa.

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 (Fig. 7-31). In Louisiana, rice leaf miner seems to attack fields in the same vicinity year after year.

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 (Fig. 7-32). The larvae or pupae can be found by separating the layers of the leaf (Fig. 7-33). If leaf miners are present and plant numbers are reduced to less than 15 per square foot, treatment is necessary. Rice leaf miner management involves cultural control or insecticide application, perhaps both. 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. Contact your parish LSU AgCenter extension agent for specific control recommendations.

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 (Fig. 7-34). 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 (Fig. 7-35). The puparium is elongate, tapered at both ends and brown (Fig. 7-36).

Fig. 7-34. SARM egg.

Fig. 7-35. SARM maggot.

Fig. 7-36. SARM pupa.

Injury

Economic 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 are more visible (Fig. 7-37). Affected young leaves usually break off or display a ragged appearance. 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

Fig. 7-37. SARM or "whorl maggot" damage.

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 (Fig. 7-38).

Scouting and Management

Scout young rice for large, elongated lesions along the margins of emerging leaves. 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.

Fig. 7-38. SARM field damage.

Fig. 7-39. Chinch bugs on rice.

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 small grains such as wheat, rye, oats and barley. Adults are small, black insects about 1/6 inch long, with white front wings (Fig. 7-39). 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 7 to 10 days. There are five nymphal instars. Early instar nymphs are red with a yellow band on the front part of the abdomen (Fig. 7-40). Last instar nymphs are black and gray with a conspicuous white spot on the back (Fig. 7-41). The

Fig. 7-40. Early instar nymph of Chinch bug on rice.

Fig. 7-41. Late instar nymphs and adult chinch bugs.

life cycle from egg to adult takes 30 to 40 days, and adults may live 2 to 3 weeks.

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 corn, sorghum and wheat fields. As these crops mature and are harvested, large numbers of chinch bugs may move to young plants in nearby rice fields. Serious economic losses have resulted from chinch bug infestations in north and south Louisiana. The trend toward increasing acreage of small grains increases the potential for chinch bug problems. 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 (Fig. 7-42). High numbers of chinch bugs can kill young plants, severely reducing plant stands.

Scouting and Management

Check unflooded rice near small grain fields or recently cut grassy areas every 3 to 5 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, the field should be treated. 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.

Fig. 7-42. Firing of lower leaves from chinch 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 (Fig. 7-43). 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 2 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

Fig. 7-43. Fall armyworm adult.

Fig. 7-44. Fall armyworm larvae.

Fig. 7-45. Mature larvae have a distinctive inverted "Y" on the head capsule.

(Fig. 7-44). Larvae feed for 2 to 3 weeks, developing through four instars. Mature larvae are about 1 inch long and have a distinctive inverted "Y" on the head (Fig. 7-45). 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.

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. 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. 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. When fall armyworm numbers reach threshold levels, cultural or chemical control is needed. 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. Contact your parish LSU AgCenter extension agent for specific recommendations if chemical control is needed.

Panicle Rice Mite

Steneotarsonemus spinki Smiley

Description and Life Cycle

The panicle rice mite (PRM), *Steneotarsonemus spinki* Smiley, has recently been reported in the continental United States. The panicle rice mite is a pest of commercial rice production in Asia, India, Central America and the Caribbean. Significant crop losses have been attributed to this mite, particularly in the presence of sheath rot and bacterial panicle blight. The adult PRM are clear to straw-colored, oval and

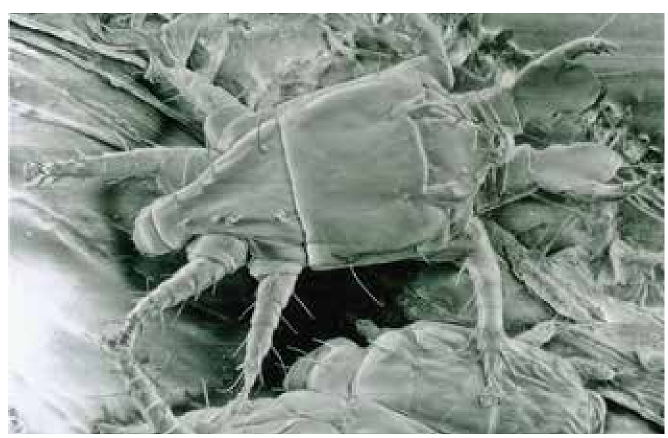


Fig. 7-46. Adult panicle rice mite. (USDA photo)

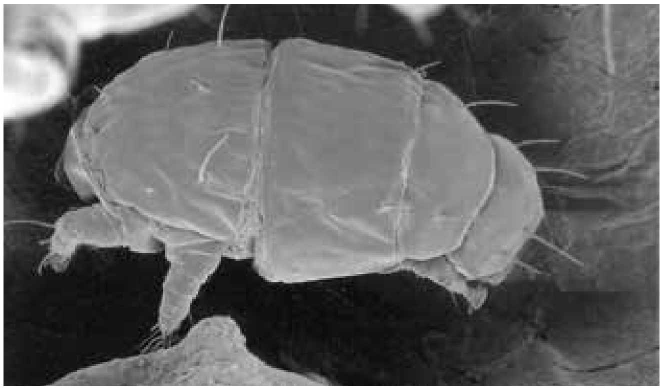


Fig. 7-47. Immature panicle rice mite. (USDA Photo)

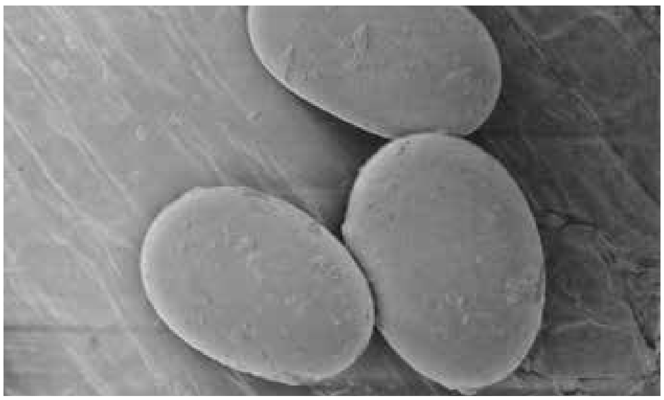


Fig. 7-48. Panicle rice mite eggs. (USDA Photo)

approximately 1/100 of an inch long (Fig. 7-46). Immature PRM are clear to straw-colored and about ½ the size of adults (Fig. 7-47). Eggs are clear in color, oval-shaped and about one-third the size of adults (Fig. 7-48). An entire lifecycle can be completed in 7 to 21 days, depending on temperature.

Injury

The PRM injures rice plants both directly by feeding on cells of rice leaves, stems and kernels and indirectly by vectoring and/or facilitating the establishment of fungal, bacterial and possibly viral pathogens. Feeding damage can result in a sterile grain syndrome, which is described as a loose and brownish flag leaf sheath, a twisted panicle neck, impaired grain development with empty or partially filled grains with brown spots and panicles standing erect. Extensive reports from important rice-producing areas of the world attribute yield losses to the interaction between the PRM and *Burkholderia glumae*, the causal agent of bacterial panicle blight, and the fungus *Sarocladium oryzae*, which is the causal agent of sheath rot and one of the many important contributors to kernel spotting ("pecky" rice). Injury to de-

Fig. 7-49. Panicle rice mite injury.

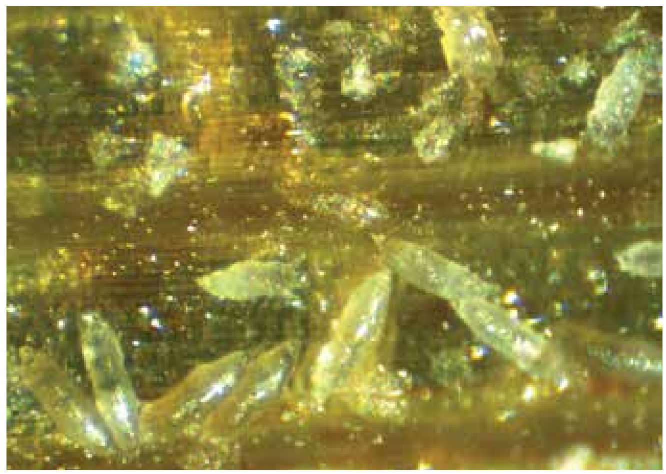


Fig. 7-50. Panicle rice mites on sheath.

veloping grains leads to panicle sterility. Malformed grains sometimes show a curved appearance, often referred to as "parrot-beak" symptom. Damage to the leaf sheath reduces the photosynthetic potential of the plant and can have a negative effect on fertility. The heaviest and most economically damaging populations of PRM are often reported during the second or ratoon crop.

Scouting and Management

Scout for PRM by looking for the symptoms associated with bacterial panicle blight and sheath rot. In affected plants, look for a cinnamon, yellow or chocolate-brown discolored lesion on the leaf sheath that does not have a distinct edge (Fig. 7-49). To find mites, pull the leaf sheath back and examine the underside of the leaf sheath with a minimum 20X hand-lens. The PRM feeds on the plant material on the inside of the flag leaf sheath (Fig. 7-50). Once a new leaf begins to develop, a female PRM will move to the new leaf sheath, produce male offspring and establish a new feeding lesion. Thus, damage will often be observed on interior sheaths when the outer sheath is removed. This continues until the PRM reaches the leaf nearest the stem. They also feed on developing panicles from the boot stage to the milk stage of heading.

Contact your parish LSU AgCenter extension agent if you suspect that this mite may be present in your field and to obtain the latest information on this pest.

Colaspis

Colaspis brunnea and *Colaspis louisianae*

There are two species of colaspis that can be found in Louisiana rice: *Colaspis brunnae* and *Colaspis louisianae*. This pest can be found damaging fields of dry-seeded rice in a soybean-rice rotation. 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.

Description and Life Cycle

Colaspis will complete a single generation in soybeans and lespedeza. This is why they are often called Lespedeza worms. The larvae of colaspis will overwinter in the soil (Fig. 7-51). 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 the plant. Feeding on fine root hair may result in plant death. The larvae will then pupate (Fig. 7-52) and emerge as adults. Adults are oval in shape and about ¼ inch in length. They are a light golden color with white/gold stripes down the back and long antennae (Fig. 7-53). Adults will not lay eggs on rice, but will most likely travel to a nearby soybean field. It is common to find a clumped distribution of larvae in the soil and patches of stand loss (Fig. 7-54).

Fig. 7-51. Colaspis larva.

Fig. 7-52. Colaspis pupa.

Fig. 7-53. Colaspis adult.

Fig. 7-54. Rice field damage caused by colaspis larvae feeding on roots.

Scouting

To scout for this pest, locate plants that are stunted, dying and surrounded by declining plants. The plants will often appear to be withering and drying. Dig around the base of the plants, carefully peeling back the soil and looking for white grubs with brown heads that are a little larger than RWW larvae. You may also find pupae or adults in the soil.

Management

We do not have any insecticides labeled to control colaspis in Louisiana rice. The only thing we can recommend is to apply permanent flood as soon as possible. These insects are not aquatic and so they cannot survive in a permanent flood. This is why they are not reported as a problem in water-seeded rice.

Amaurochrous dubius
(formerly called Black Rice Bugs)

Both nymphs (Fig. 7-55) and adults (Fig. 7-56) 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 (Fig. 7-57). 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.

Fig. 7-55. Amaurochrous dubius nymph

Fig. 7-56. Amaurochrous dubius adult

Fig. 7-57. Amaurochrous dubius rice damage.

Fig. 7-58. Southern green stinkbug.

Fig. 7-59. Billbug grub.

Fig. 7-60. Billbug adults.

Fig. 7-61. Skipper adult.

Fig. 7-62. Skipper larva.

Other Insect Pests of Rice

Several other insects may occasionally attack rice in Louisiana. They include the southern green stink bug, *Nezara viridula* (L.) (Fig. 7-58), rice levee bill bug (Figs. 7-59 and 7-60), several grasshopper species and the larvae of several species of skippers (Figs. 7-61 and 62) and tiger moths. 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.

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 (Fig. 7-63), the rice weevil (Fig. 7-64), the Angoumois grain moth (Fig. 7-65) and the Indian meal moth (Fig. 7-66). 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.

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 2 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 rice is already infested with a grain pest (at the time of harvest), it must be fumigated before storage. 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 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 4 days during fumigation.

Fig. 7-63. Lesser grain borer. (Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org)

Fig. 7-64. Rice weevil. (Joseph Berger, Bugwood.org)

Fig. 7-65. Angumois grain moth. (Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org)

Fig. 7-66. Indian meal moth. (Joseph Berger, Bugwood.org)

Chapter 8

Rice Drying on the Farm

Dennis Gardisser and Johnny Saichuk

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 percent 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 place 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 percent, the grain moisture will eventually reach 12 percent 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 percent 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 percent) 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 hundredweight (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

Fig. 8-1. Axial flow fan.

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 (Fig. 8-1). 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 (Fig. 8-2). 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 (Fig. 8-3).

Fig 8-2. Centrifugal fan.

Fig 8-3. Blades of centrifugal fan.

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 percent or less throughout the bin, the bin filling process may be completed.

Dry grain (moisture content less than 15 percent) should not be mixed with moist grain (moisture content greater than 18 percent). Once a rice kernel is dried to a level below 15 percent, 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

Fig. 8-4. Temperature is critical in drying rice.

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 degrees F (Fig. 8-4). 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.

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 percent.

5. Harvesting rice with a moisture content in excess of 20 percent 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 percent or less and avoid attempting to dry rice on the farm if the moisture at harvest exceeds 20 percent.

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 percent 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 degrees F.

11. Dry high moisture rice in shallow batches until the rice moisture content is 15 percent 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 hundredweight (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 percent 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 percent 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 percent and the air is cool (50 to 60 degrees F).

17. Do not operate fans when ambient temperature is below 32 degrees 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.

Chapter 9

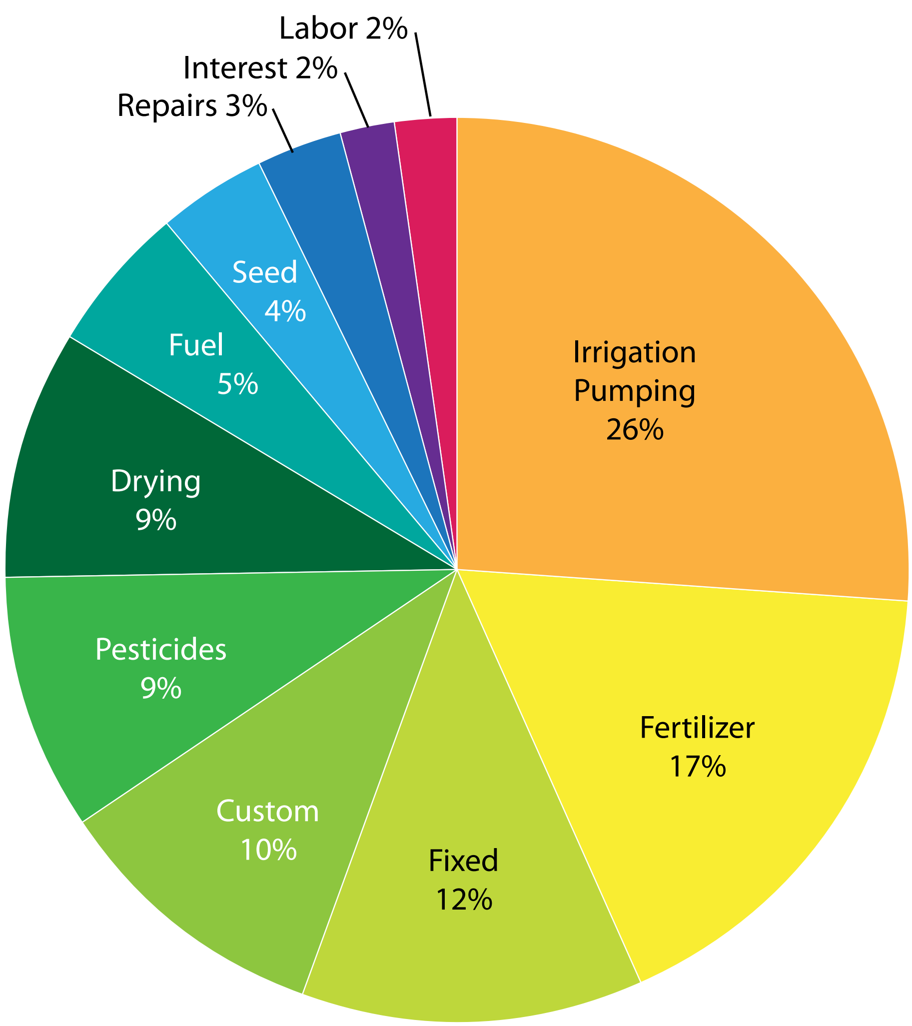
Rice Production Economics

Michael Salassi

Production Costs

Rice is produced in Louisiana under several different types of agronomic production systems. It may be water-seeded by airplane onto a flooded field or drill-seeded by tractor and grain drill on a dry field. It may be produced in a crop rotation, following soybeans, crawfish or some other commodity, or it may be produced following a fallow year. Tillage options include conventional tillage or stale seedbed. Rice variety produced may be conventional, herbicide-resistant or hybrid. Source of irrigation water may be from a deep well groundwater source or a surface canal source. All of these production system options have a direct impact on rice production costs.

The figure below provides a general percentage breakdown of the major production cost items associated with rice production in Louisiana. Irrigation pumping cost (26%), fertilization cost (17%), fixed equipment costs (12%) and custom charges (10%) comprise the major cost items associated with rice production in Southwest Louisiana. Irrigation pumping costs are generally lower for surface water



sources in Southwest Louisiana and for both water sources in Northeast Louisiana. Total variable production costs for rice in Louisiana are in the range of $650 to $750 per planted acre. Total fixed equipment production costs are the range of $80 to $100 per acre. In Southwest 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, 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 on leased land. Share rental arrangements are the most prevalent type of crop lease arrangement being utilized. Under these types of rental arrangements, the producer and the landlord each pay a specified portion of the production expenses. One survey of rice producers 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 government program income and paid all variable production expenses, including irrigation pumping cost, with the exception of 20% of drying expenses paid by the landlord who received 20% of the crop market and government program income and (2) a 60/40 arrangement where the grower received 60% of the crop market and government program income and paid all variable production expenses, excluding irrigation pumping cost and 40% of fertilization, pesticide and drying expenses paid by the landlord who received 40% of the crop market and government program income. Although these two share arrangements are most common, they do not represent the majority of rice share arrangements, as grower-landlord share arrangements for rice can vary greatly. Some rice tracts are leased under a cash rental arrangement. In these cases, the producer generally pays all production expenses and receives 100% of the crop market and government program income. Average rice cash rental rates, based upon the same survey data, and were in the range of $75 to $100 per planted acre.

Marketing

Over the past five years, slightly more than half of the rice produced in the United States (54%) is marketed domestically, with the remainder (46%) being exported to foreign countries. The domestic rice market has more than doubled over the past 25 years. Approximately 97% of domestic rice use is for food use, both directly and in processed foods, and industrial uses. Direct food use of rice accounts for more than half of total use, Use of rice in processed foods (package mixes, cereal and rice cakes) accounts for about 18% of total use. The remaining domestic use of rice is used in pet foods and in beer production.

About 70% of rice exported in milled form and the remaining 30% exported as rough rice. Latin America is the primary export market for U.S. rice, representing about one half of total U.S. rice exports. Specific countries which have are top U.S. rice export markets include Mexico, Japan, South Korea, Iraq, Saudi Arabia, Haiti, Canada, Nicaragua, Costa Rica, Honduras and Venezuela. 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 United States is essentially a price-taker in the world rice market, with Thailand and Vietnam driving world market forces.

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 contracts on the exchange. Price risk management relates to alternative commodity selling or market strategies, including hedging in the futures market, to reduce exposure to market price volatility. Price discovery is the generation of information about "future" cash market prices through futures markets using basic supply and demand factors.

Hedging provides an opportunity to lock in a rough rice price, as gains or losses in the cash market are usually offset by 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. The term "basis" refers to the difference between the local cash price of the commodity and the futures price. The basis can be positive or negative and is influenced by transportation costs and other factors. Contract specifications for the rough rice futures contracts traded on the Chicago Board of Trade are shown in Appendix Tables 3, 4, and 5.

Glossary

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

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

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

Amylographic — Spectrographic analysis of starch.

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

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

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 percent 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.

Green rice — Rough rice from which the excess moisture has not been removed (usually 18.5 to 22.5 percent 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.

GPA — Gallons per acre.

Heading — The period during which panicles exert from the flag leaf sheath.

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.

Head milling yield — Pounds of head rice milled from 100 pounds of rough 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 2mm — 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 percent 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 — *C*ondition when all soil pore spaces are full of water.

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.

Scenescence — The process of aging leading to death after the completion of growth in plants and individual plant parts.

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.

Stubble — Rice stalks and their associated crowns remaining after harvesting.

Straighthead — Physiological disorder characterized by sterile, deformed seeds and upright panicles.

Sun checking — Fissuring.

Susceptibility — The inability of a plant to resist the effect of a pathogen or other damaging factor.

Suppression — The act of reducing or holding back rather than eliminating.

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 4- to 5-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.

Appendix

Table 1. Principle Rice Varieties Released from the LSU AgCenter Rice Research Station.

Variety	Grain Type	Year Released	Breeders Involved
Colusa	Short	1917	Chambliss, Jenkins
Fortuna	Long	1918	Chambliss, Jenkins
Acadia	Short	1918	Chambliss, Jenkins
Delitus	Long (A)*	1918	Chambliss, Jenkins
Tokalon	Long	1918	Chambliss, Jenkins
Evangeline	Long	1918	Chambliss, Jenkins
Rexora	Long	1928	Chambliss, Jenkins
Nira	Long	1932	Chambliss, Jenkins
Magnolia	Medium	1945	Jodon
Lacrosse	Medium	1949	Jodon
Sunbonnet	Long	1953	Jodon
Toro	Long	1955	Jodon
Nato	Medium	1956	Jodon
Saturn	Medium	1964	Jodon
Della	Long (A)	1973	Jodon
Vista	Medium	1973	Jodon, McIlrath
LA 110	Medium	1979	McIlrath, Jodon
Leah	Long	1982	Trahan, Jodon
Toro-2	Long	1984	McKenzie, Jodon
Mercury	Medium	1987	McKenzie
Lacassine	Long	1991	Linscombe, Jodari
Bengal	Medium	1992	Linscombe, Jodari
Cypress	Long	1992	Linscombe, Jodari
Jodon	Long	1994	Linscombe, Jodari
Dellrose	Long (A)	1995	Jodari, Linscombe
Lafitte	Medium	1996	Linscombe, Jodari
Cocodrie	Long	1998	Linscombe
Dellmati	Long (A)	1999	Jodari, Linscombe
Earl	Medium	2000	Linscombe
CL 121	Long	2001	Linscombe, Sha
CL 141	Long	2001	Linscombe, Sha
CL 161	Long	2002	Linscombe, Sha
Cheniere	Long	2003	Linscombe, Sha
Pirogue	Short	2003	Linscombe, Sha

Table 1 continued on next page

* (A)-aromatic

Table 1. continued from page 139

Variety	Grain Type	Year Released	Breeders Involved
Ecrevisse	Short	2004	Linscombe, Sha
CL 131	Long	2005	Linscombe, Sha
Jupiter	Medium	2005	Sha, Linscombe
Trenasse	Long	2005	Linscombe, Sha
CL151	Long	2008	Linscombe, Sha, Blanche
Catahoula	Long	2008	Linscombe, Sha, Blanche
Neptune	Medium	2008	Sha, Linscombe, Blanche
Jazzman	Long (A)	2009	Sha, Linscombe, Blanche
CL111	Long	2010	Linscombe, Sha
CL261	Medium	2010	Linscombe, Sha
Caffey	Medium	2011	Linscombe, Blanche, Sha
CL152	Long	2011	Linscombe, Sha
Jazzman-2	Long (A)	2011	Sha, Linscombe
Della-2	Long (A)	2012	Sha, Linscombe
Mermentau	Long	2012	Linscombe, Sha

* (A)-aromatic

Table 2. Sequence of Events in the Development of the Rice Variety Catahoula-Pedigree 9502008-A/Drew.

STEP	YEAR	GENERATION	ID	STAGE OF DEVELOPMENT
1	1997	F_0	97CR346	Artificial Hybridization
2	1998	F_1	98T027	F_1–Space Plant Nursery
3	1999	F_2	99F7041-7042	F_2–Bulk–Segregation
4	2000	F_3	0028270	F_3–Headrow–Segregation
5	2001	F_4	0116926	F_4–Headrow–Segregation
6	2002	F_5	0202519	F_5–PY Test–Purification
7	2003	F_6	0302082	F_6–URN & CA–Purification
8	2004	F_7	0302082	F_7–URN & CA–Purification
9	2005	F_8	0302082	F_8–URN & CA–Purification
10	2006	F_9	0302082	F_9–URN & CA–Purification
11	2006	F_{10}	0302082	Headrow Increase–Puerto Rico
12	2007	F_{11}	0302082	Foundation Seed Field–RRS
13	2008	F_{12}	Catahoula	Registered Seed Production

Table 3. Rough Rice Futures Contract Specification - CME Group

<table>
<tr><td>Contract Size</td><td>2,000 hundredweight (cwt.)
(~ 91 metric tons)</td><td>Contract Months</td><td>January, March, May, July, September, November</td></tr>
<tr><td rowspan="4">Deliverable Grades</td><td rowspan="4">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.</td><td>Last Trading Day</td><td>Business day prior to the 15th calendar day of the delivery month .</td></tr>
<tr><td>Last Delivery Day</td><td>Seventh business day following the last trading day of the month.</td></tr>
<tr><td>Trading Hours</td><td>Open Auction (trading floor): 9:30 a.m. - 2:00 p.m. Central Time, Monday-Friday
CME Globex (electronic): 5:00 p.m. - 2:00 p.m. Central Time, Sunday-Friday
Trading in expiring contracts closes at noon on the last trading day.</td></tr>
<tr><td>Ticker Symbols</td><td>Open Auction: RR
Electronic: ZR</td></tr>
<tr><td>Tick Size (minimum fluctuation)</td><td>1/2 cent/hundredweight ($10/contract)</td><td rowspan="2">Daily Price Limit</td><td rowspan="2">Fifty cents ($0.50) per hundredweight expandable to $0.75 and then to $1.15 when the market closes at limit bid or limit offer. There shall be no price limits on the current month contract on or after the second business day preceding the first day of the delivery month.</td></tr>
<tr><td>Pricing Unit</td><td>Cents/hundredweight</td></tr>
<tr><td colspan="4">Source: CME Group.</td></tr>
</table>

Table 4. Grades and grade requirements for the classes of long grain, medium grain, short grain and mixed milled rice

Grade	Maximum limits of:											Color requirement	Milling requirement
	Seeds, heat-damaged, and paddy kernels (single or combined)		Red rice and damaged kernels	Chalky kernels		Broken kernels				Other types			
	Total (number in 500 grams)	Heat-damaged kernels and objection-able seeds (number in 500 grams)	(singly or combined percent)	In long grain rice (percent)	In medium or short grain rice (percent)	Total (percent)	Removed by a 5 plate (percent)	Removed by a 6 plate (percent)	Through a 6 sieve (percent)	Whole kernels (percent)	Whole and broken kernels (percent)	(minimum)	(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	Reasonably well 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	Reasonably well milled

U.S. Sample grade:
U.S. Sample grade shall be milled rice of any of these classes which: (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 15.0 percent of moisture; (c.) is musty or sour, or heating; (d.) has any commercially objectionable foreign odor; (e.) contains more than 0.1 percent of foreign material; (f.) contains two or more live or dead weevils or other insects, insect webbing, or insect refuse; or (g.) is otherwise of distinctly low quality.

Source: United States Standards for Rice, Federal Grain Inspection Service , U.S. Department of Agriculture.

Table 5. Grades and Grade Requirements for the Classes of Long-Grain, Medium-Grain, Short-Grain and Mixed Milled-Rice

Grade	Maximum limits of: Seeds, heat-damaged, and paddy kernels (single or combined)		Red rice and damaged kernels (singly or combined %)	Chalky kernels		Broken kernels				Other types		Color requirement (minimum)	Milling requirement (minimum)
	Total (number in 500 grams)	Heat-damaged kernels and objectionable seeds (number in 500 grams)		In long-grain rice (%)	In medium- or short-grain rice (%)	Total (%)	Removed by a 5 plate (%)	Removed by a 6 plate (%)	Through a 6 sieve (%)	Whole kernels (%)	Whole and broken kernels (%)		
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	Reasonably well-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	Reasonably well-milled

U.S. Sample grade:
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 15.0% 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) contains two or more live or dead weevils or other insects, insect webbing, or insect refuse; or (g) is otherwise of distinctly low quality.

Source: *United States Standards for Milled Rice*, U.S. Department of Agriculture.

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Inside Back Cover

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