Chapter 3

Soils, Plant Nutrition and Fertilization

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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-

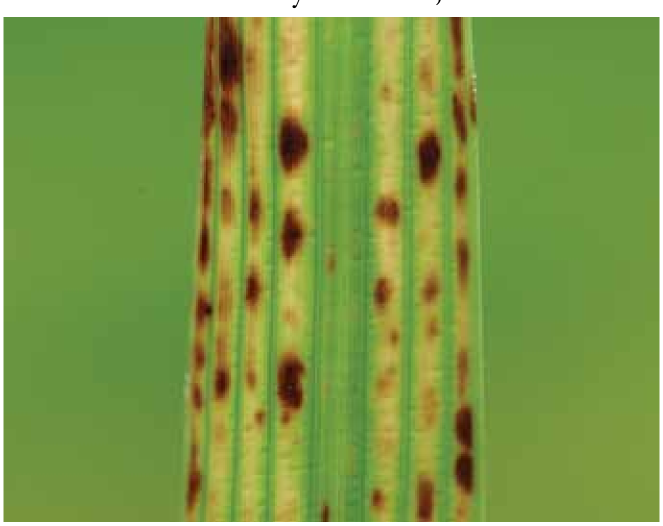

Fig. 3-5. Potassium deficiency symptoms on leaf.

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.