Chapter

9

Soil Fertility

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Nutrient management represents one of the most expensive inputs to a successful rice crop. Because of the large investment required, optimum management is critical to ensuring no more than what is economical is applied but, at the same time, sufficient amounts are applied to ensure profitable and sustainable yields. Many nutrients are necessary for optimum plant growth. Determining which are in sufficient quantity in the soil and which should be supplemented by fertilizer is the key to nutrient management. Either too much or too little is undesirable because the crop could be adversely affected. Therefore, research has focused on providing fertilizer recommendations that are economically, environmentally and agronomically sound. The following sections describe the recommendations and provide some of the research data that supports those recommendations.

Nitrogen

Nitrogen (N) is required by rice in the largest quantities of any nutrient, and it is typically not only the largest fertilizer input cost but the largest input cost for rice producers. Profitable rice grain yields are very dependent on proper and effective N fertilizer management. No other fertilizer nutrient presents a greater challenge to the rice producer than does the effective management of N fertilizer, and no other fertilizer nutrient can provide greater returns in increased rice yield for effective management. Nitrogen fertilizer is subjected to many N loss processes when it is applied to rice, and these N loss processes that operate in the soil-water environment can compete quite successfully with the young rice plant for the N fertilizer. Consequently, the appropriate N fertilizer management options available to the rice producer are based on our current understanding of the N behavior in the soil, before and after flooding, and the N uptake characteristics of the rice plant.

Nitrogen Fertilizer Rates

Two methods now exist to determine the proper N fertilizer rate for rice, the **Standard Method** and the **N-Soil Test for Rice (N-STaR)**. The Standard Method recommendation is based on cultivar, soil texture and previous crop. The Standard Method has worked well over the last four decades, but because it assumes all soils of a given textural class (i.e., clay or silt loam) require the same N rate, its use can result in under- or over-fertilization with N, even when the previous crop is taken into account. To improve N fertilizer rate recommendations for rice producers, the soil test N-STaR was developed that can measure the soil's ability to supply N and enable a prescription N fertilizer rate on a field-by-field basis. N-STaR is accurate and precise enough to allow for prescription N rates for different management or soil texture areas within a single field when grid-sampled properly.

Standard Method

Rice cultivars differ in the amount of N fertilizer required to produce optimum grain yields. The N rates listed in Table 9-1 are for a) rice grown in rotation after soybeans, b) rice grown on silt loam or sandy loam soil, c) optimum stand density and d) land that has been in cultivation for longer than five years.

If all four listed criteria have not been met, an adjustment of the early or preflood N rate is required.

Table 9-1. **Recommended nitrogen rates and distribution for rice cultivars grown in Arkansas.**

Cultivars	Single Preflood N Rate†	Rates and Distribution for Two-Way Split Application			
		Total N Rate	Preflood N Rate‡	Mid season N Rate††	Late Boot N Rate‡‡
		Lbs N/Acre			
CL151	100	**120**	75	45	--
Caffey, Della-2, Jazzman-2, Roy J	115	**135**	90	45	--
Cheniere, CL111, CL153, CL163, CL172, CL272, Cocodrie, Diamond, Francis, Jupiter, LaKast, Mermentau, PVL01, Taggart, Titan, Wells	130	**150**	105	45	--
RT CLXL4534, RT CLXL729, RT XL723	--	**120**	90	--	30
RT 7311 CL, RT CLXL745, RT Gemini 214 CL, RT XP753, RT XP760	--	**150**	120	--	30

† Conditions required for use of optimum single preflood N rate:) field can be flooded timely (<7 days); 2) preflood urea is treated with a recommended urease inhibitor that includes NBPT; or ammonium sulfate is used as the N source; 3) can maintain a 2- to 4-inch flood depth for at least 3 weeks following flood establishment, and 4) the preflood N must be applied uniformly across the field (no streaking).

‡ N rate for rice on silt loam soils following soybean in rotation. Rates may need adjustment based on factors below.

†† Apply midseason N in one application a minimum of 3 weeks after the preflood N application AND internode elongation has started; both conditions must be met to receive maximum benefit from the midseason N.

‡‡ Hybrids receive additional N at late boot rather than midseason. Refer to DD50 for proper timing of this application.

Management Key

Use the N rate adjustment rules for the **standard two-way split and optimum preflood** (formerly referred to as single preflood) application methods.

Adjustments in the preflood N rate will be needed for the following situations and are additive if more than one applies:

1. Increase early N by 30 pounds per acre if:
   - rice is grown on clay soils.
2. Increase early N rate by 20 pounds per acre if:
   - rice follows RICE in rotation.
   - rice follows COTTON in rotation
   - stand density for conventional cultivars is < 10 plants per square foot or hybrids is < 3 plants per square foot.
3. Increase early N rate by 10 pounds per acre if:
   - rice follows GRAIN SORGHUM in rotation.
   - rice follows WHEAT in rotation (double-crop).
   - rice follows CORN in rotation.
4. Decrease early N rate by 10 pounds per acre if:
   - rice follows SET-ASIDE or FALLOW that is not continuously tilled during the fallow period.
5. Use N-STaR or omit early N if:
   - rice follows FISH, LONG-TERM PASTURE or FIRST YEAR AFTER CLEARING in rotation. If N-STaR is not used, then continuously monitor the rice crop after flooding for signs of N deficiency and apply N fertilizer promptly if an N deficiency appears. No more than 45 pounds N acre should be applied into the floodwater during vegetative growth in any single application. Occasionally, a rice crop in these situations requires an N application at midseason of 45 pounds N per acre that should be applied between beginning internode elongation (panicle initiation) and ½ inch internode elongation (panicle differentiation). Beginning internode elongation and ½ inch internode elongation growth stages are indicated on the DD50 printout.

Nitrogen-Soil Test for Rice (N-STaR)

Different soils or fields have different levels of native soil N fertility and require different amounts of supplemental N fertilizer to optimize rice grain yields. The soil-based N test for rice, N-STaR, can measure a soil's ability to mineralize or supply N to the rice crop and prescribe an N fertilizer rate for the different cultivars of rice. N-STaR is a soil-based N test that quantifies the amount of N that will become available to the rice crop during the growing season. A unique attribute of N-STaR is that it measures a combination of simple organic-N compounds and NH_4-N contained in the soil. Organic-N is relatively stable in the soil and is not prone to the loss mechanisms of leaching and denitrification, but must be mineralized into NH_4-N prior to uptake and assimilation by plants. The two primary types of organic-N in the soil quantified by N-STaR are amino acids, such as glutamine, and amino sugars, such as glucosamine. These organic-N compounds reside in the soil and are found in the tissue of plant residues and soil microbes. Thus, N-STaR is site or field specific and is not influenced by the previous crop. However, even with N-STaR the cultivar being grown must be known for a recommendation because different rice cultivars require different amounts of N to maximize yield.

Three things have to be known and supplied for each field to use N-STaR: i) soil texture, ii) the cultivar being grown and iii) a soil sample taken to the proper depth. Accurate soil sampling is critical for N-STaR to give a proper N fertilizer recommendation. The soil sample must be taken from the effective rooting depth or nutrient uptake depth of the rice plant. Proper soil sampling depth is a key component of N-STaR's success and can be attributed to the effective rooting depth of rice. Arkansas research has shown rice roots may grow to a depth of 24 inches, suggesting that roots may take up nutrients present in the subsoil. The proper depth to sample is 0 to 18 inches for loamy soils and 0 to 12 inches for clayey soils using a proper soil sampling implement. Soil samples that are taken at less than the recommended depth for each soil texture will usually result in under-application of N fertilizer (Table 9-2) and less than optimal rice yields. Conversely, soil samples that are deeper than the recommended sampling depth will most likely result in N fertilizer recommendations that are greater than what is actually required to maximize yield, resulting in over-application of N fertilizer.

The N-STaR Soil Sample Bucket (Photo 9-1) is an essential component required to collect soil samples to the proper depth based on soil texture. This mechanized approach is a drastic improvement over the slide hammers used to take deep soil samples for nitrate-N in cotton and corn. It is imperative that the entire soil core be collected and packaged for analysis in order to get an accurate estimate of the potentially available soil N and a reliable N fertilizer recommendation. The N-STaR Soil Sample Bucket has several distinct advantages over the slide hammer, including: i) the use of a cordless drill rather than manpower, ii) the entire sample can be taken in a single core, iii) the ability to soil sample in a variety of soil moisture conditions and iv) the ease with which the soil can be collected and transferred to a 1 quart Ziploc® or similar quality sealable bag. Removal of soil from the probe is often difficult when using a slide hammer due to compaction and the risk of soil spillage. Refer to Arkansas Cooperative Extension Service fact sheet FSA2168, *N-STaR Soil Sample Bucket*, to obtain a detailed list of instructions on how to fabricate or purchase an N-STaR Sample Bucket.

Table 9-2. **N-STaR soil test values, predicted nitrogen fertilizer rates and the associated application errors as influenced by soil sampling depth for a silt loam soil.**

Sample Depth	Category	N-STaR Value	N Rate Recommendation	Application Error†
inches		mg N kg soil $^{-1}$	N fertilizer rate (lbs N/A)	
0-18	Correct Depth	100	115	0
0-12	Too Shallow	135	50	-65
0-6	Too Shallow	150	20	-95
0-24	Too Deep	80	150	+35

† Application error refers to the amount of nitrogen fertilizer either under-applied or over-applied when compared to the nitrogen fertilizer recommendation from the correct sampling depth.

Photo 9-1. **N-STaR soil sample bucket, soil auger and drill.**

After collecting soil samples in the field, the second and equally important part of submitting a quality soil sample is proper packaging prior to shipment. Current recommendations require 10 samples per field, which should be collected and placed in 10 individual 1-quart sealable bags and then grouped in either a larger sealable bag or grocery sack. Proper packaging and grouping of soil samples by field can eliminate some shifting during shipment and also allows identification of samples if the writing on bags is smeared or removed. When preparing samples for shipment, do not place more than 40 samples in a single box as the weight can cause damage to the box and soil samples. Please remember to package samples tightly and fill in any extra space with newspaper or packing material. If samples are not secure during shipment, shifting and sliding can cause bags to split. Do not use soil sample boxes to aid in packing and shipping as they often result in soil spillage. Spilled samples will not be analyzed because they could lead to an erroneous soil test and incorrect fertilizer recommendation. Send samples to the N-STaR Laboratory, 1366 W. Altheimer Drive, Fayetteville, Arkansas 72704. For more information, contact the lab at 479-575-6752 or nstarlab@uark.edu.

The purpose of N-STaR is to provide field-specific N rates that will ensure the proper N rate is being applied on a field-by-field basis to achieve optimum rice yields. Nitrogen fertilizer rate recommendations with N-STaR will come from relative grain yield (RGY) goal calibration curves, as shown in Figure 9-1 and Table 9-3, and give the rice grower options as to how much N fertilizer to apply based on the grower's available finances and fertilization philosophy.

Management Key

Correct identification of the soil texture and soil sampling depth are important to ensure the proper N-STaR N rate recommendation is provided. Remember that the recommended sample depth is 0-12 inches for clay soils and 0-18 inches for loamy soils.

The success of N-STaR for rice has been largely influenced by the high and consistent N uptake efficiency, which is directly tied to proper flood management. **Conditions critical for use of the N-STaR technology are: the field can be flooded timely, the urea is treated with the urease inhibitor NBPT (N-(n-butyl) thiophosphoric triamide) or ammonium sulfate is used, unless the field can be flooded in two days or less for silt loam soils and seven days or less for clay soils, and a 2- to 4-inch flood depth is maintained for at least three weeks following flood establishment.**

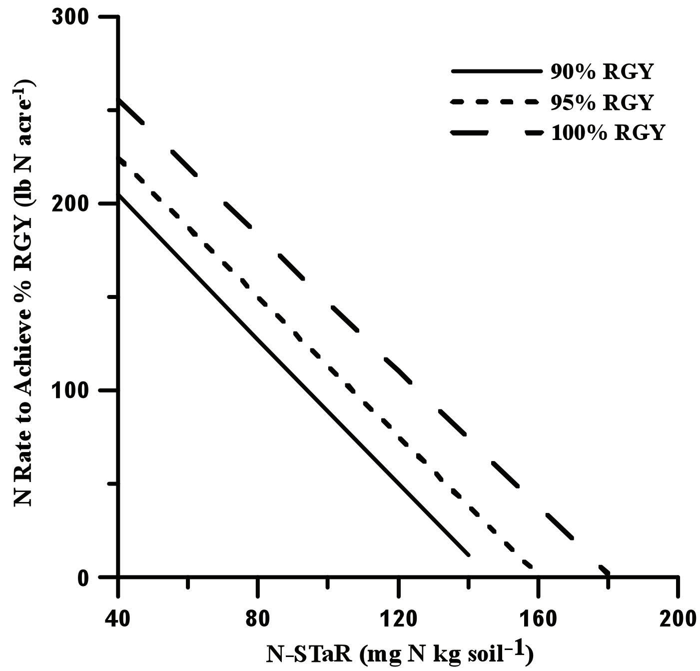


Figure 9-1. Nitrogen fertilizer calibration curves for rice grown on silt loam soils based on relative grain yield (RGY) goal.

Table 9-3. N-STaR soil test values and predicted nitrogen fertilizer rates to achieve 90, 95 and 100% relative grain yield (RGY) goal for various fields with loamy soils.

Field	N-STaR Soil Test Value	Yield Goal (% RGY) Economic (90%)	Optimum (95%)	Above Optimum (100%)
	mg N kg soil $^{-1}$	N fertilizer rate (lbs N/A)		
1	136	20	45	80
2	118	60	80	115
3	110	70	95	130
4	98	95	120	150
5	80	130	150	185
6	70	150	170	200
7	63	160	180	215

The goal of the N-STaR program is to provide field-specific N rates that will maximize productivity and profitability in regard to one's N-fertilizer program. Routine soil analysis for phosphorus (P), potassium (K), sulfur (S) and zinc (Zn) availability should continue to be a producer priority when using N-STaR. Optimizing N fertilizer inputs and maximizing rice yields using N-STaR can only be accomplished when other nutrients such as P, K, S and Zn are sufficient for optimal rice growth. **N-STaR-based N rate recommendations are for delayed, flood rice only** and have not been evaluated for use on water-seeded continuously flooded rice or furrow-irrigated rice.

Management of N fertilizer for maximum uptake efficiency by the rice crop varies with the cultural system, cultivar, soil texture, soil moisture and several other factors. These factors are discussed in more detail in the following text.

Dry Seeding

Two options are available for applying N fertilizer to rice: the **standard two-way split**, a large early (preflood) N application followed by a midseason or late boot N (hybrids only) application, or the single, **optimum preflood** N application. Several options are available for managing the N in a dry-seeded cultural system, and all options are viable if performed using the defined guidelines. However, correct management of the preflood N is critical since a rice crop's potential grain yield is determined by the preflood N.

The standard **two-way split application** is a very effective application method and may be the most practical N fertilization method for a large percentage of Arkansas rice fields. This method should be used on fields where limited irrigation capacity, large field size or another factor compromises the timeliness of establishing the flood across the field and maintaining it. Conditions critical for use of the **optimum preflood** N application method are: the field can be flooded timely, the urea is treated with the urease inhibitor NBPT or ammonium sulfate used, unless the field can be flooded in two days or less for silt loam soils and seven days or less for clay soils, and a 2- to 4-inch flood depth is maintained for at least three weeks following flood establishment. Research indicates that when the preflood N is improperly managed, resulting in poor plant growth, midseason N applications are not capable of recovering the entire lost yield potential. Regardless of the N management system used (two-way split or optimum preflood) proper management of the preflood N is essential to maximize N fertilizer uptake and minimize N losses. Nitrogen is stored in the plant stem and leaf tissue during vegetative growth following the preflood N application. This stored N is transported and used within the plant later in the season during periods of peak N needs, such as during grain fill. If the preflood N is mismanaged and adequate plant growth during the vegetative growth stage does not occur, crop yield potential suffers. As a general rule, when more than 45 pounds of N per acre is needed at midseason, yield potential has likely been lost.

When the standard two-way split N application method is used on hybrids, the second N application should be applied between late boot and beginning heading. Application of N later than beginning heading can damage flowering panicles and lead to yield loss. The 30 pounds of N per acre late boot application is recommended only for hybrids to minimize lodging and occasionally increase grain and milling yields. The greatest benefit of the late boot N application in minimizing lodging of the hybrids has been observed when they are grown on soils that are prone to waterlogging in the fall and, thus, do not allow for a timely harvest. Table 9-1 provides rates for the two-way split application method.

A single, **optimum preflood** N application followed by a visual midseason evaluation is recommended for fields with excellent irrigation capability for the conventional, pure-line varieties, not the hybrids. The optimum preflood method should not be used with the weaker-strawed pure-line varieties. Research has consistently shown that a single application of an optimum amount of N preflood results in equal or better yields than the traditional split application methods and usually requires less total N to achieve maximum yields.

The preflood N is critical for determining potential grain yield regardless of whether split or single applications are used. The number of panicles (heads) and the number of grains per panicle are determined by the preflood N application. The stiff-strawed, early-maturing cultivars do not respond to midseason N applications like their taller, longer-season predecessors and, at best, the midseason N application results in only a 10 to 15 bushel per acre yield increase. Because yield potential is determined prior to midseason, yield cannot be completely recovered with midseason N if the preflood N rate is too low or if the preflood N has been mismanaged due to untimely flood application or loss of flood within three to four weeks of preflood N application.

Milling yield (percent head rice) also benefits from proper N fertilization. In general, the percent head rice is highest when maximum grain yield is produced. The preflood N rate for the optimum preflood method can be calculated for each rice cultivar by simply adding 15 to 25 pounds of N per acre to the preflood rate recommended for the two-way split application method in Table 9-1. Where management practices allow, use the optimum preflood N application since this method has consistently produced the highest grain and milling yields in replicated research.

Early N Application and Management

The early N application (Table 9-1) (65 to 100 percent of the total N rate) should be applied as an ammonium N source (Table 9-4) onto dry soil immediately prior to flooding, termed preflood N, near the 4- to 5-leaf growth stage (Table 9-5 and Figure 9-2). There is not an exact time to apply the early N but actually a window of a couple of weeks that the early N can be applied. The DD50 printout gives the window of dates for early N application. Once the early N is applied, flooding should be completed as quickly as possible, preferably in two days or less for loamy soils and seven days or less for clays. The flood incorporates the N fertilizer into the soil where it is protected against losses via ammonia volatilization and/or nitrification/denitrification as long as a flood is maintained. Maintain the flood for at least three weeks to achieve maximum uptake of the early applied N (Table 9-6).

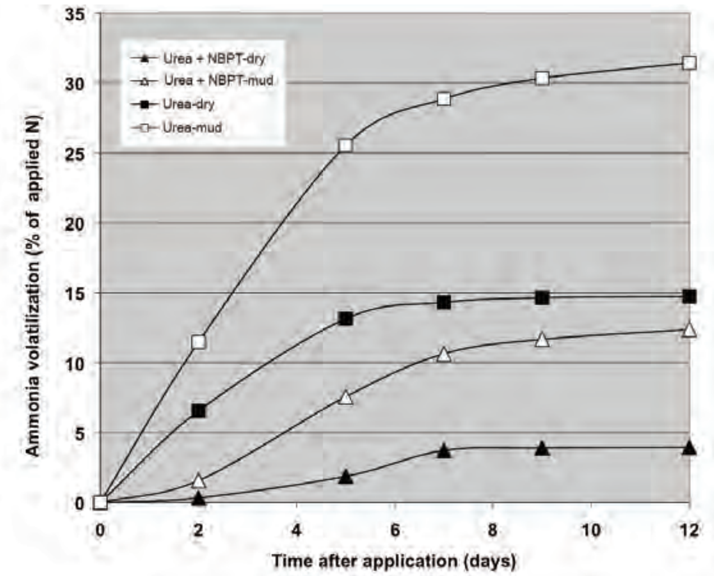
Management Key

The preflood N rate and efficiency of uptake determine overall grain yield potential. Management of the preflood N is critical for achieving maximum yields.

For the preflood N application, an ammonium N source, such as urea, NBPT-treated urea or ammonium sulfate is preferred over an N fertilizer containing nitrates (i.e., N solution) (Table 9-4).

Table 9-4. Nitrogen fertilizer sources.

N Source (in order of preference)	Remarks
Early Season (65% to 75% of total N requirement)	
Urea – 46% N	High N analysis, high N loss via ammonia volatilization if applied to a silt loam soil and not incorporated by floodwater in two days or less or a clay soil and not incorporated in seven days or less.
NBPT treated Urea – 46% N	High N analysis, cost slightly more than urea, minimal N loss via ammonia volatilization if applied to soil.
Ammonium Sulfate – 21% N, 24% S	Low N analysis, high cost, minimal N loss via ammonia volatilization if applied to soil. Good source on soils that also require sulfur (e.g., sandy soils).
Urea ammonium nitrate solution (UAN) – 32% N	Medium N analysis, cost similar to urea, high N loss via ammonia volatilization if applied to soil and not incorporated by floodwater in two days or less and high N loss via denitrification from nitrates in the solution. (Not recommended for preflood N fertilization.)
ESN (Polymer-coated urea) – 44% N	The ESN fertilizer is urea coated with a permeable, plastic coating that allows water to enter, dissolve the urea granule and the urea solution to diffuse back through the coating where it is available for plant uptake. The release rate is affected mostly by temperature. Approximately 40 days is needed for > 80% of the N to be released during the temperatures that are common during April and May. Slightly higher cost per ton than urea. Not recommended for preplant, preflood or postflood N fertilization.
Midseason (25% to 35% of total N requirement)	
Urea – 46% N	High N analysis, widely available, minimal loss at midseason.
UAN Solution – 32% N	Even distribution, cost similar to urea, ammonia volatilization loss greater than urea at midseason.



Source: Norman et al., 2006. p. 290-297. *B.R. Wells Rice Res. Studies 2005*. Ark. Rice Res. Ser. 540.

Figure 9-2. Ammonia volatilization losses when urea and NBPT-treated urea were applied to a dry or muddy soil five days prior to flooding.

Compared to UAN, granular (or prilled) urea applied at preflood results in greater N uptake and grain yield (Table 9-7). Nitrogen solution or UAN solution contains 25 percent nitrate, which will be lost after flooding via denitrification; therefore, its use as a preflood N fertilizer is not recommended. Urea or ammonium sulfate are excellent fertilizers for the early preflood N application; however, urea is much cheaper per pound of actual N compared to ammonium sulfate and equal in effectiveness if incorporated with the flood in less than two days for loamy soils and seven days for clay soils.

Greater than 20 percent of the urea-N applied to a dry silt loam soil can be lost via ammonia volatilization in five days (Figure 9-3) and result in a significant loss in rice grain yield (Table 9-8). The use of ammonium sulfate or urea treated with the urease inhibitor NBPT (N-(n-butyl) thiophosphoric triamide) can reduce ammonia volatilization losses and maintain rice grain yields equivalent to when urea is used and a flood obtained across the field in a single day. Consequently, if greater than two days is required to get the floodwater across a silt loam field, then ammonium sulfate or NBPT-treated urea should be used. Ammonia volatilization of urea from clay soils (Figure 9-4) tends to be less than from silt loam soils, and urea (no NBPT) is recommended on clayey fields when seven days or less is required to flood. Ammonium sulfate or NBPT-treated urea should be applied to clay soils when more than seven days is required to establish a flood. Urea treated with NBPT is usually cheaper than ammonium sulfate. The urease inhibitor NBPT is sold under the trade names *Agrotain*® (Koch Agronomic Services LLC), *Arborite*® (Weyerhaeuser and Gavilon Fertilizer LLC), *Factor* (Rosens Chemical Company) *N-FIXX*™ (Helena Chemical Company), *N-Veil*

Table 9-5. Influence of preflood N source and soil moisture conditions on Wells rice grain yields at the Rice Research and Extension Center in 2004.

N Sources†	Dry Soil	Muddy Soil
	Grain Yield (bu/A)	
Urea	195	161
Urea + NBPT	199	182
Ammonium Sulfate	193	180

† All N sources applied two days prior to flooding at the 4- to 5-leaf stage.

Source: Norman et al., 2006. p. 290-297. *B.R. Wells Rice Res. Studies 2005*. Ark. Rice Res. Ser. 540.

Table 9-6. Percent N uptake by rice at different times after N application.

N Application Timing	Sampling Period Days After Application	Plant N Uptake % of Applied N
Preflood†	7	11
	14	27
	21	63
	28	65
Midseason‡	3	70
	7	67
	10	76

† Urea applied on a dry soil surface and flooded immediately.
‡ Urea applied into the flood.

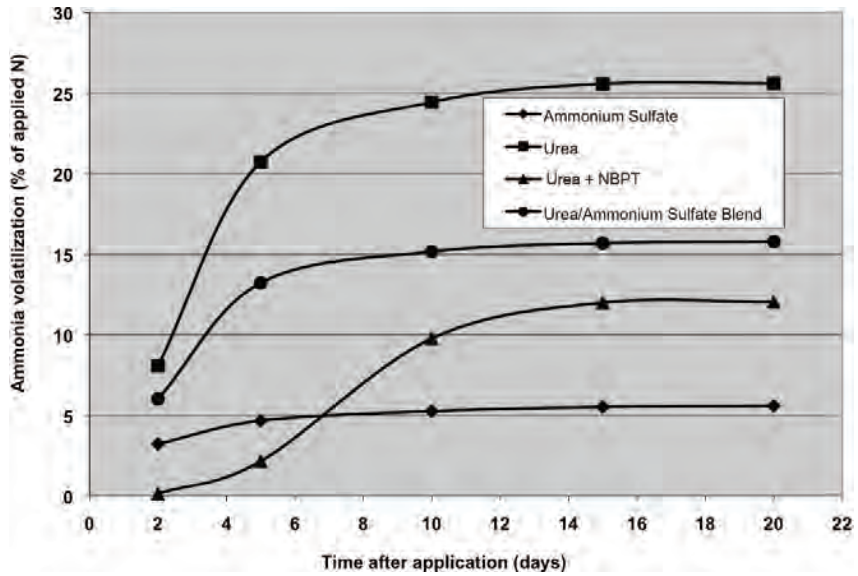
Source: Wilson et al., 1989. *SSSAJ* 53: 1884-1887.

Table 9-7. Comparison of urea and urea ammonium nitrate (UAN) as N sources at three application timings in rice.

N Source	Time of Application: Preflood†	½" IE‡	½" IE + 10d	Grain Yield
	% of applied N			bu/A
Urea	66	77	82	154
UAN	41	64	65	134

† 75 lbs N/A preflood
‡ 30 lbs N/A applied for each midseason [½" IE and ½" IE + 10 days].

Source: Wilson et al., 1994. *SSSAJ* 58:1825-1828.



Source: Norman et al., 2009. *Soil Sci. Soc. Am. J.* 73:2184-2190).

Figure 9-3. Ammonia volatilization losses when several N sources were applied 10 days prior to flooding.

Table 9-8. Influence of N fertilizer sources applied at 1, 5 and 10 days prior to flooding on the grain yields of Wells rice in 2003.

N Sources†	N Rate	Grain Yield		
		Application Time Prior to Flooding		
		1 day	5 days	10 days
	lbs N/A	bu/A		
None	0		96	
Urea	120	187	160	154
Urea + NBPT	120	188	182	175
Ammonium Sulfate	120	181	178	171
Ammonium Sulfate + Urea	120	179	166	161

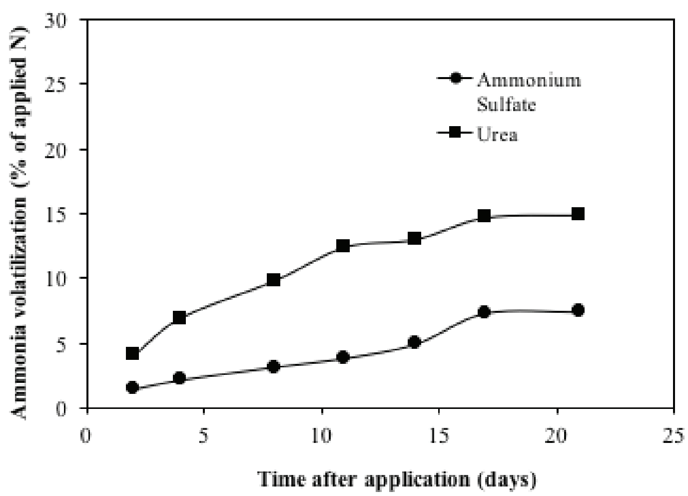
† All N sources applied to a dry soil at the 4- to 5-leaf stage.

Source: Norman et al., 2009. Soil Sci. Soc. Am. J. 73:2184-2190.

(Invictus Crop Care, LLC) and *NitroGain*® (Arclin INC.). (See FSA2169, *Nitrogen Fertilizer Additives*). A typical rate of NBPT treatment on urea prills is 4 quarts per ton of urea of a product that contains ~20 percent NBPT or 3 quarts per ton of a product that contains ~25 percent NBPT. Blending of urea and ammonium sulfate can reduce ammonia volatilization losses and minimize grain yield reductions. However, a urea-ammonium sulfate blend is not as effective as NBPT-treated urea in reducing ammonia volatilization or in maintaining rice grain yields and the blend costs more (i.e., per unit of actual N) than NBPT-treated urea. Ammonium sulfate, urea-ammonium sulfate blends, or other N plus S-containing fertilizers are best utilized when there is the potential for a sulfur (S) deficiency or when rice is grown on permeable soils (sands and sandy loams) that typically suffer from N and S deficiencies.

Management Key

If the urea applied preflood cannot be incorporated with the flood in two days or less for silt loam soils and seven days or less for clay soils, ammonia volatilization loss can be significant (Figure 9-2) and the use of NBPT-treated urea or ammonium sulfate is warranted (Table 9-4).



Source: Griggs et al., 2007. *Soil Sci. Soc. Am. J.* 71:745-751.2007).

Figure 9-4. Ammonia volatilization loss of urea and ammonium sulfate when applied to a Perry clay.

Wet (muddy) soil conditions can prohibit rice farmers from applying the early N onto a dry soil at the 4- to 5-leaf growth stage. Because there is a window of a couple of weeks to apply the preflood N, every effort should be made to apply the early N onto a dry soil surface. However, if wet conditions persist and the preflood N cannot be applied during this window onto a dry soil, use NBPT-treated urea and apply the preflood N onto the muddy soil, but wait until the soil dries before flooding to minimize ammonia volatilization loss (Figure 9-2 and Table 9-5). The flood will not be able to incorporate the urea below the soil surface if the soil is not dry, and ammonia volatilization will not cease when the soil is flooded. **Do not, for any reason, apply the large preflood N into the flood in a single application.**

Application of the large, early N rate into the flood in a single application is very inefficient. Since the N is not incorporated into the soil, most of the N is lost via ammonia volatilization within seven to ten days after application, before the young rice can use it; increasing the N rate will not fully compensate for the amount of N lost. If excessive rainfall has flooded the field at the 4- to 5-leaf stage and the preflood N has to be applied into the floodwater, then it is best to increase the early N rate and split-apply the preflood N every week in increments of 30 to 45 pounds of N per acre per application until internode elongation.

Management Key

Do not, for any reason, apply the large preflood N into the floodwater in a single application.

Polymer-coated urea marketed as Environmentally Smart N (ESN) is an excellent N fertilizer for preplant application to upland crops like corn and cotton, but is not currently recommended for use at any growth stage (preplant, flushed in, preflood or postflood applications) in flood-irrigated rice. Research has shown that ESN applied preplant or preflood (3- to 5-leaf stage) to rice grown in the direct-seeded, delayed-flood production system is not a suitable alternative to urea applied preflood and managed properly.

Lab and field studies suggest most of the urea in ESN is released in about 40 days after being incorporated into the soil. As the urea-N is slowly and continuously released from the polymer, the urea is converted to ammonium and eventually to nitrate, which may be lost quite rapidly via denitrification when rice fields become saturated from excessive rainfall, flush irrigation or establishing the permanent flood. Research with water-seeded rice or furrow-irrigated rice has not been conducted, but ESN may be of greater utility in these rice production systems which are used on only a small percentage of the Arkansas rice-producing area.

Table 9-9. **Influence of nonuniform N distribution (streaking) on rice grain yield.**

Preflood N % Distribution	Actual N lbs Distribution	Grain Yield
% : %	lbs N : lbs N	bu/A
100 : 100	75 : 75	170
125 : 75	94 : 56	161
150 : 50	113 : 37	160
175 : 25	131 : 19	146
200 : 0	150 : 0	139

Source: Helms et al., 1987. *Univ. Ark. Farm Res.* 36(2):9.

The large N rates required at the early N application time can be difficult to apply evenly, and streaking may result. Streaking is not only unpleasing to the eye but can cause significant yield loss (Table 9-9). The best way to avoid streaking is to use an aerial applicator who knows exactly how to operate the aircraft when applying heavy rates of fertilizer. All aircraft have a maximum material flow rate that limits their useful swath width. Large aircraft and spreaders may be able to apply heavy rates of materials with little or no sacrifice in distribution uniformity. The usable swath width of all aircraft decreases as the application or flow rate increases. Double flying (using one-half the desired application rate and flying at one-half the optimum swath width for that application rate) may be used for most aircraft applications when the maximum practical flow rate is exceeded. Double flying typically results in more uniform application of N fertilizer.

Management Key

If the urea applied preflood cannot be incorporated with the flood in two days or less for loamy soils and seven days or less for clayey soils, NBPT-treated urea or ammonium sulfate should be used.

An alternative method of reducing the chance of streaking is to split the early N into two applications. Apply about one-third of the early N rate onto dry soil immediately prior to flushing at the 2- to 3-leaf stage and apply the remainder just before flooding. Always incorporate the N with water when N is applied preflush (Table 9-10). The alternative method is only recommended when the early N rate is 90 pounds of N per acre or more. The early split

Table 9-10. **Nitrogen uptake efficiency, using an N-15 tracer, of several N rates and application timings.**

Treatment†	N Use Efficiency		Grain Yield
	lbs N/A	% N	bu/A
30 lbs‡ PPI + 90 lbs PF	12	40	176
30 lbs‡ PFS + 90 lbs PF	17	57	181
30 lbs PPI + 90 lbs‡ PF	72	80	179
60 lbs‡ PPI + 60 lbs PF	20	33	158
60 lbs‡ PFS + 60 lbs PF	32	53	166
60 lbs PPI + 60 lbs‡ PF	47	78	160
120 lbs‡ PPI	32	27	125
120 lbs‡ PF	91	76	177
90 lbs PF + 30 lbs‡ 1 wk POF††	4	13	158
90 lbs PF + 30 lbs‡ 2 wk POF	6	20	163
60 lbs PF + 60 lbs‡ 1 wk POF	8	13	142
60 lbs PF + 60 lbs‡ 2 wk POF	9	15	146

† PPI = Preplant Incorporated; PF = Preflood; PFS = Preflush; POF = Postflood (in water).
‡ Indicates the nitrogen application that was labeled with N15 tracer.
†† Postflood treatments applied into the water one or two weeks (wk) after flooding at the 4-to 5-leaf stage.

Source: Norman et al., 1994. p. 138-145. *Ark. Rice Res. Studies 1993*. Ark. Ag. Exp. Sta. Res. Ser. 439.

application applied a week or two before permanent flooding is at greater risk to nitrification/denitrification loss and ammonia volatilization loss if not flushed in and, therefore, is not used as efficiently as when the N is applied immediately before flooding. Preplant incorporation of all or a portion of the early N to reduce streaking is a poor alternative and is not recommended. Additionally, applications of a portion of the large preflood N into the flood water a week or two after flooding at the 4- to 5-leaf stage is taken up poorly and not recommended.

Nitrogen applied immediately prior to flooding or preflood has resulted in the highest yields and greatest N fertilizer use efficiency in research tests. Therefore, if N fertilizer can be applied evenly, the early N should be applied preflood and not preflush, and most certainly not preplant or postflood during the vegetative stage. However, if rice becomes yellow and deficient of N during the vegetative growth stage, then N fertilizer should be applied immediately and in sufficient amounts to correct the deficiency. Never wait until midseason to correct a deficiency that occurs during the vegetative growth stage or large yield reductions can result. If the rice turns light green or yellow during the reproductive growth stage, there is no need for additional N fertilization because the yield has already been set and this is not unusual.

Management Key

If rice becomes yellow and deficient of N during the vegetative growth stage, N fertilizer should be applied immediately and in sufficient amounts to correct the deficiency, but not if this occurs during reproductive growth after internode elongation.

Midseason N Application and Management

Fertilizer N applied at midseason, at the proper times and in the proper amounts, is taken up with a 65 to 80 percent efficiency (Tables 9-6 and 9-7). Ideally, midseason N rates should not exceed 45 pounds of N per acre. In general, when rates greater than 45 pounds of N per acre are needed, the preflood N rate was considerably inadequate or the preflood N was mismanaged. To take full advantage of the midseason N, the preflood N has to be applied at the correct rate and managed correctly. Notice in Table 9-11 how much better the yield of rice at the NEREC responded to midseason N applied at beginning internode elongation (IE) plus seven days or later when the greater preflood N rate of 90 pounds of N acre was applied compared to a preflood N rate of 45 pounds of N per acre.

Midseason N application should be timed according to plant development (Table 9-1); that is, applied no earlier than beginning IE (Photo 9-2). Recent research has indicated the new varieties do not always respond to midseason N, especially if an adequate rate of preflood N has been applied. Notice in Table 9-11 a negligible yield increase was obtained at PTRS when 90 pounds of N per acre was applied preflood. Results also indicate when there is a response to **midseason N, the application time window appears to be at least two weeks wide** and the application time is later than beginning IE or ½ inch IE (that is, beginning IE + 7 days) depending on when the preflood N fertilizer was applied. Notice in Table 9-11 that the best yield response to midseason N was when the time between the preflood N and midseason N was at least three weeks. **Thus, the first or only**

Photo 9-2. **Rice stems showing internode elongation (IE). The stem on the far left is at the green ring stage (note the green band above the top node), the stem in the middle is at ½ inch IE, and the stem on the far right is at 1 inch IE.**

midseason N application should be applied no earlier than beginning IE and at least three weeks after the preflood N application. Both of these conditions have to be met to obtain the full grain yield benefit of the midseason N application. If a second midseason N application is required, it should be applied seven days after the first.

The DD50 program provides estimated times for midseason applications. Midseason N can be applied into the flood because, by BIE, the plant has developed an extensive root system near the soil surface and is growing rapidly. Research indicates that N applied at midseason is taken up by the rice plant within three days (Table 9-6). The smaller amount of N, coupled with the rapid rate of N uptake by the rice plant at midseason, enables the N to be applied into the flood without the large amount of N loss that is associated with applying the preflood N into the flood during the vegetative growth stage. The standard two-way split application (preflood-midseason) has the midseason N applied at a rate of 45 pounds of N per acre no earlier than beginning IE and three weeks after the preflood N application (Table 9-1).

Application of midseason N rates > 60 pounds of N per acre should be applied in split applications made seven days apart with the first applied no earlier than beginning IE and at least 3 weeks after the preflood N application. When >60 pounds of N per acre are needed at midseason, only a portion of the lost yield can be regained. **Thus, one should apply the correct preflood N rate and manage the preflood N correctly so no more than 0 to 45 pounds of N per acre are needed at midseason to maximize yield.**

To maximize hybrid rice yields and minimize lodging, the N fertilizer should be applied preflood and at the late boot stage (Table 9-1). Consequently, N should not be applied to hybrid rice at midseason unless N deficiency develops prior to late boot. The late boot N application to hybrid rice can, in some instances increase grain and milling yield, but its main purpose is to reduce lodging. Thus, hybrid rice should have the

Table 9-11. **Influence of preflood N rate and midseason (MS) N application time relative to the preflood N application time on rice grain yields.**

MS N Timing†	Grain Yield Location/Preflood N Rate				
	NEREC		PTRS		RREC
	45 lb N /A	90 lb N/A	45 lb N/A	90 lb N/A	
	bu/A				
No MS N	139	170	149	179	192
BIE‡	155	184	152	183	199
BIE + 7 days††	158	203	162	181	196
BIE + 14 days	157	196	163	185	201
BIE + 21 days	162	208	163	182	204

† BIE = beginning internode elongation; 45 lb N/A applied at midseason.

‡ Note: BIE N applied 15, 17 and 14 days after preflood N at the Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS) and the Rice Research and Extension Center (RREC), respectively.

†† BIE + 7 days is analogous to ½ inch IE.

Source: Norman et al., 2014. p. 303-310. B.R Wells Ark. Rice Res. Studies 2013. Ark. Rice Res. Ser. 617.

second N application applied at the late boot stage between full boot and beginning heading. Application of N later than beginning heading can damage flowering panicles and lead to yield loss.

Management Key

Midseason N can be applied in either one or two applications with the first midseason N application made between beginning internode elongation and ½ inch internode elongation.

Determining Midseason N Using Trimble GreenSeeker

The Trimble® GreenSeeker® handheld allows producers and consultants the ability to make objective decisions on midseason N management in rice. This sensor uses NDVI, or Normalized Difference Vegetation Index, which can be used to gauge the relative N fertility of rice (optimal or suboptimal).

To properly use GreenSeeker in rice, you must first establish a Reference Plot (minimum 5' x 5' area) in each field prior to the establishment of the permanent flood. The Reference Plot should have 50 to 100 pounds of N per acre more than the producer's preflood N rate. This is equivalent to 30 to 60 grams of urea over the 5' x 5' area (or ¼ to ⅓ of a standard measuring cup). The Reference Plot provides the user with a GreenSeeker reading from an area with maximum fertilizer-N uptake to compare with the producer practice. The larger the field, the more Reference Plots needed – i.e., a minimum of one Reference Plot per 50 acres.

To determine midseason N needs using the GreenSeeker, readings should be taken after Green Ring AND no earlier than 3 weeks following preflood N incorporation. Take readings from the Reference Plot and divide by the average of readings taken across the field. If the resulting value is greater than 1.15 then there is more than a 50% chance of a response to midseason N and it is recommended to make a midseason N application of 45 pounds N per acre (100 pounds urea per acre).

When taking GreenSeeker readings throughout the field, it is preferred to take a minimum of 10 readings. Each reading should consist of fully depressing the trigger and holding while walking 10 steps. Once the trigger is released, the resulting number on the handheld will be the average of the area covered.

GreenSeeker readings are no longer valid once plants reach the late boot stage of rice development (flag leaves fully exserted). Readings should not be taken from areas with thin stands. In thin stand areas, the resulting GreenSeeker reading will be artificially low due to the sensor reading from areas with no rice.

Table 9-12. Guide to rice midseason N applications using GreenSeeker (GS).

Reference Plot GreenSeeker Average	Apply Midseason N if Field GreenSeeker Reading is Less Than
0.80	0.70
0.75	0.65
0.70	0.61
0.65	0.56

Application recommendation based on greater than 50% chance of response to midseason nitrogen application.
Valid for both varieties and hybrids.

Photo 9-3. Reference plot with additional N showing darker green color compared to surrounding field.

Water Seeding – Pinpoint Flood

The fundamental principles of N fertility are the same regardless of whether rice is dry- or water-seeded, but the methods used to attain efficient uptake of the early N application are quite different. In water-seeding, the early N must be applied as an ammonium-N source onto the dry soil preplant and mechanically incorporated (PPI, 2 to 4 inches). The flood should be established immediately after N application/incorporation to minimize nitrification. Surface application of N followed by flood establishment for water-seeding does not adequately incorporate the N and prevent loss, in contrast to preflood N applications made in the dry-seeded, delayed-flood system. This is because in the dry-seeded, delayed-flood rice system the preflood N is applied at or around the 4- to 5-leaf growth stage and takes only three to four weeks to be taken up, whereas in water-seeded rice the N is applied around seeding and takes seven to eight weeks to be taken up.

Because of this long time period between application and plant uptake, the early N must be stored in the soil for a longer period of time before the rice crop can use the early N. Therefore, it is very important that the early N be incorporated deep and the flood maintained throughout the vegetative growth stage. If the soil does not stay saturated (flooded), the fertilizer N can undergo nitrification during the unsaturated periods and be lost via denitrification upon reflooding. With the pinpoint flooding method, the field must remain saturated when the field is drained for pegdown. One advantage of PPI N application is that early N can be applied with ground equipment, which may potentially reduce streaking and application costs. Two alternative methods of early N application for water-seeded systems include N application: i) when the field is drained for pegdown or ii) after draining at the 5-leaf to early tillering stage. These alternative methods have been used successfully by several Arkansas growers.

Based on field experiences, incorporate only the early preflood N rate recommended for the cultivar (Table 9-1). Regardless of the preflood N rate, supplemental N has usually been required in water-seeded Rice Research Verification Program fields. The need for supplemental N, either during active tillering or at midseason, is highly likely in water-seeded fields. Water-seeded rice should be closely monitored for signs of N deficiency, and if N deficiency occurs, N should be applied immediately.

Conservation or No-Till Systems

No-till dry-seeded, delayed-flood rice should have the N managed in the same manner as conventional-till dry-seeded, delayed-flood rice. Research conducted on silt loam and clay soils found no significant difference between the two tillage systems as concerns the N uptake efficiency of rice. However, if there is a substantial amount of plant residue (previous crop or weedy vegetation), extra N in the amount of 10 pounds of N per acre should be added to the preflood N rate to compensate for N losses due to ammonia volatilization and the extra N required to decompose plant residue.

No-till water-seeded rice is not an efficient N management system. Incorporation of the early N with the flood does not move the N deep enough into the soil to prevent substantial loss for the seven to eight weeks required for water-seeded rice to take up the early N. Spoon feeding the rice with biweekly top-dress N applications typically requires about 25 percent more N fertilizer and may still produce lower than normal yields. One viable alternative for the no-till water-seeded system is to knife anhydrous or aqua ammonia 4- to 6-inches beneath the soil surface prior to planting. This is not a common practice in the southern rice belt but is the standard practice for N fertilization of water-seeded rice in California. Another possible option is to drain and dry the field at the 4- to 5-leaf stage, apply the N fertilizer onto a dry soil and then reflood.

Soil Sampling and Soil Analysis

There are four steps to any soil-testing program including soil sampling, soil analysis, data interpretation and implementation of recommendations and management of soil-test information. Each step is critical in obtaining optimum fertilizer and lime recommendations. However, the most critical step in the process of soil sampling is collecting soil samples that accurately represent the variation of soil properties within fields. **Appropriate use of soil-test results requires that one understand that the soil-test nutrient (e.g., P, K and Zn) values are simply an 'availability index' and not an absolute value of soil nutrient content or plant-available nutrients.**

Soils are inherently variable between and within fields. **The recommendations received from a soil-testing program are no better than the sample that was collected to make those recommendations.** Therefore, correct soil-sampling procedures should be followed so that soil-test results for lime and other nutrient recommendations are representative of the entire field. When using the field-average method, collect composite soil samples from the area near the water inlet, the center and the bottom portions of the field, as well as areas that differ in soil series, soil texture, topography and crop productivity within these locations.

Management Key

One composite soil sample should represent no more than 20 acres.

Composite samples near water inlets should represent only 5 to 10 acres. Each composite sample should contain soil from 15 to 35 individual soil cores taken to a depth of 4 inches while following a zigzag pattern within each sample zone. Individual cores should be placed in a clean plastic bucket and thoroughly mixed. A subsample of this soil represents one composite sample, which will be submitted to the soil-test laboratory. Collecting an inadequate number of soil cores (< 15 to 35) per composite sample may compromise the accuracy of soil-test results by over- or underestimating the true field mean.

Soil samples may also be taken on grids representing 2.5 to 5.0 acre blocks within each field. Grid sampling improves the soil-testing process because composite samples are collected from numerous areas within the field and less area is represented by each sample. Thus, a "picture" can be made that depicts the variability within the field. Grid sampling and variable rate application equipment are highly recommended for lime application to fields with rice in the rotation. When grid sampling is performed, collect eight to ten soil cores per composite sample.

Regardless of whether soil samples are collected using the field-average, zone sampling or grid sampling method, obtaining cores from a uniform sample depth of 4 inches is critical. Soil-test based recommendations for P, K and Zn are based on a 4-inch sample depth. Collecting samples from shallower or deeper soil depths will likely result in over- or under-estimation of soil nutrient availability index values, respectively. Sample depth is highly important because P, K and Zn are relatively immobile nutrients and become stratified such that the concentration is greatest near the soil surface and decreases with increasing soil depth. Stratification of these immobile nutrients is greatest in no- and reduced-tillage systems. The ability to collect soil samples from the appropriate soil depth is influenced by the soil conditions at the time of sample collection. To facilitate uniform and unbiased sampling, soil samples should be collected when the soil is neither too dry nor too wet.

The best time to collect soil samples is considered to be during the winter and early spring (December, January, February, March and April) as soil-test recommendations for P, K and Zn are based on samples collected during this period. Soil-test results may show significant variability across time. Although temporal variability may not always follow a predictable pattern, samples collected in the early fall (October and November) often have different soil-test K values than samples collected in January through April. Soil-test P tends to be more consistent across time than soil-test K. Soil pH may also fluctuate 1.0 pH unit during the year with the tendency to be highest in the winter months and lowest during the summer months. Dry soil conditions during the fall and winter may cause soil pH values to be lower by 0.5 pH units or more. As a general recommendation, soil samples, regardless of collection method, should be collected near the same time of year and following the same crop in attempt to reduce variation in soil-test results caused by time and/or crop and soil management practices. Soil samples should always be collected before (not after) fertilizer, manure or biosolid application.

The second step in the soil-testing process is the chemical analysis of the soil conducted by a soil-testing laboratory. The University of Arkansas Soil Testing Laboratory uses the Mehlich-3 extractant to determine the availability index of nutrients, such as P, K, calcium (Ca) and magnesium (Mg). Some laboratories use different chemical methods to determine the availability of these nutrients. Therefore, soil nutrient concentrations from other labs may not apply to the recommendations that are listed in the following sections. Also, the units in which the nutrient concentration is expressed [e.g., pounds per acre (lb/acre) or parts per million (ppm or mg/kg)] are important for accurate interpretation of soil-test results. For example, 200 pounds of K per acre is the same as 100 ppm K. Soil-test units expressed as ppm can be converted to pounds per acre by multiplying ppm × 2 since units of pounds per acre usually assume that the soil sample represents a plow layer of soil that weighs 2 million pounds. The recommended 4-inch sample depth usually represents an acre-furrow slice that weighs from

900,000 pounds of soil per acre for clayey soils (bulk density ~1.0 g soil/cm^3) to 1,250,000 pounds of soil per acre for sandy loam soils (bulk density ~1.4 g soil/cm^3).

The third step in the soil-testing process is data interpretation and development of recommendations. Once the chemical analysis has been performed by the laboratory, someone must interpret what the numbers mean. Research defines the ranges of soil test values that are considered below optimum, optimum and above optimum for plant growth. Fertilizer recommendations are developed from field research, but may also incorporate different fertilization philosophies. The two most common philosophies that influence P and K fertilizer recommendations are "fertilize the crop" and "fertilize the soil." The idea of "fertilize the crop" is that fertilizer recommendations are based exclusively on crop response at a given soil-test level. The minimum rate of fertilizer that provides adequate growth for the current crop is recommended. If the nutrient availability index is considered sufficient for optimum productivity, no fertilizer is recommended. The second philosophy of "fertilize the soil" is that fertilizer recommendations are based on the needs of the current crop plus an additional amount recommended to 'build and maintain' soil fertility levels. Thus, the fertilize the soil philosophy is often based on a two-part equation that accounts for the amount of fertilizer needed to build the soil test value and the amount of fertilizer nutrient that will be removed by a certain yield. Concepts from both philosophies have been incorporated into research-based fertilizer recommendations for rice to account for factors such as field variability, rotation crop nutrient requirements and nutrient availability under flooded soil conditions.

Management Key

Soil-test results provide an estimate of nutrient availability to the plant and not the total amount of each nutrient that is found in the soil.

The final step in the soil-testing process is implementing the fertilizer recommendations and managing the soil-test information. Fertilizer recommendations represent either the average response to fertilization as determined by a large number of trials or a calculation that accounts for building soil-test values and nutrient removal by the harvested portion of the crop. Therefore, reasonable adjustments to fertilizer recommendations to accommodate specific farm situations and fertilization objectives are appropriate provided that state or federal nutrient management regulations are not broken. For example, one may apply higher fertilizer rates to build and maintain soil-test P and K values on land that is owned but apply lower fertilizer rates on land that is farmed on a short-term lease.

Monitoring field nutrient balances (e.g., nutrient additions minus removals) and field-, grid- or zone-specific, soil-test P, K and Zn values across time are important but often overlooked components of soil fertility management. Specifically, knowledge of crop yields and nutrient additions allows one to determine if soil nutrients are being depleted or accumulating across time. In row-crop production systems, large fluctuations (increases or decreases) in soil-test P and K values are unlikely to occur over a short time if nutrient inputs and removal are balanced. A history of soil-test information for individual fields plus the knowledge of nutrient balances allows one to determine if a particular year's soil test information is reasonably accurate (as compared to past years' results) or is being influenced by variability caused by time, space or field management; potential sample collection errors; laboratory analysis error; or nutrient imbalances. A spreadsheet (e.g., Microsoft Excel) can be used to track a field's soil test, yield and fertilization history. The information included in this chapter can be used to calculate nutrient removal by rice grain.

Sulfur

Rice does not normally require sulfur (S) fertilizer to produce high yields in Arkansas. Generally, adequate amounts of S are provided from soil organic matter, irrigation water and precipitation. The SO_4-S concentrations in irrigation water are highly variable in Arkansas and range from 2 to > 100 mg SO_4-S/liter (3.79 liters/gallon). On average, groundwater tends to contain more SO_4-S than surface water. About 4.5 pounds of SO_4-S is pumped onto fields for each acre-inch (27,154 gallons) of irrigation water that contains 20 mg SO_4-S/L. Thus, in most fields, the rice nutritional requirement for S will be supplied from irrigation water and the decomposition of organic matter. **Sulfur is most likely to be needed on sandy soils due to low organic matter con-**

tent and leaching of plant available SO_4-S. Sulfur may also be needed on soils that are continuously flooded for rice production and winter waterfowl habitat as plant-available S may be reduced to an unavailable form.

Early-season S deficiencies normally occur after establishing the permanent flood on permeable sandy soils. Deficiency symptoms appear similar to those of N deficiency. Sulfur-deficiency symptoms include initial chlorosis (yellowing) of the entire plant starting with the youngest leaves, reduced tillering, delayed maturity and stunted growth. While the chlorosis may start with the younger leaves, prolonged S deficiency eventually results in a uniform yellowing of young plants. Nitrogen-deficiency symptoms begin as a yellowing of the older leaves. Since visual symptoms may be difficult to distinguish from N deficiency, use plant tissue analysis for correct identification (Table 9-13). If S deficiency is verified, ammonium sulfate applied at 50 to 100 pounds per acre will supply sufficient amounts of S.

At maturity, rough rice grain usually contains 0.09% S, and rice straw may average about 0.11% S but will vary depending on S availability and fertilization practices. Based on an average yield of 200 bushels per acre and total aboveground biomass (grain and straw) of 20,000 pounds per acre, aboveground crop uptake and removal of S by harvested grain are approximately 20 and 8 pounds S per acre, respectively. The amount of S removed in the grain comprises approximately 40 percent of the total S taken up by the plant.

Sulfur deficiency may also occur late in the growing season despite no visible early-season S symptoms. Late-season S deficiency is more common than early-season S deficiency, and symptoms include yellowing of the flag leaf that starts at the leaf tip (Photo 9-4), flag leaf size is reduced and rice may be several inches shorter than rice in healthy field areas. Blackish-colored streaks between leaf veins usually develop if the problem is left uncorrected. Normally, the top two or three leaves exhibit these symptoms and lower leaves appear perfectly healthy. Fields showing these symptoms generally have been recently graded, sandy surface soil texture, sandy-textured subsoil (Photo 9-5), and/or may show symptoms each time the field is cropped to rice. Late-season application of ammonium sulfate tends to improve leaf color but may do little to increase yields if applied past the late-boot stage. Midseason application of ammonium sulfate (10 to 20 pounds SO_4-S per acre) may be needed on fields with a history of late-season S deficiency.

Table 9-13. Guide for interpreting nutrient concentrations from plant tissue analysis†.

Nutrient	Plant Part‡	Growth Stage	Nutrient Concentration Required for Adequate Growth††
Phosphorus (P)	Y-Leaf	Mid-tiller	0.14%-0.27%
Phosphorus (P)	Y-Leaf	Panicle Initiation	0.18%-0.29%
Potassium (K)	Y-Leaf	Mid-tiller	1.5%-2.7%
Potassium (K)	Y-Leaf	Panicle Initiation	1.2%-2.5%
Calcium (Ca)	Y-Leaf	Mid-tiller	0.16%-0.39%
Calcium (Ca)	Y-Leaf	Panicle Initiation	0.19%-0.39%
Magnesium (Mg)	Y-Leaf	Mid-tiller	0.12%-0.21%
Magnesium (Mg)	Y-Leaf	Panicle Initiation	0.16%-0.39%
Iron (Fe)	Y-Leaf	Mid-tiller	89-193 ppm
Iron (Fe)	Y-Leaf	Panicle Initiation	74-192 ppm
Manganese (Mn)	Y-Leaf	Mid-tiller	237-744 ppm
Manganese (Mn)	Y-Leaf	Panicle Initiation	252-792 ppm
Zinc (Zn)	Y-Leaf	Mid-tiller	22-161 ppm
Zinc (Zn)	Y-Leaf	Panicle Initiation	33-160 ppm
Sulfur (S)	WS	Mid-tiller	0.17%
Sulfur (S)	WS	Panicle Initiation	0.15%
Sulfur (S)	Flag leaf‡‡	Late Boot to Anthesis	0.15%

† Unless noted otherwise the source of the nutrient-sufficiency values is Reuter, D.J. and J.B. Robinson, 1986. Temperate and sub-tropical crops. p. 38-99. In D.J. Reuter and J.B. Robinson (ed.) *Plant Analysis: An Interpretation Manual.* Inkata Press, Melbourne.

‡ Plant part – Y-leaf is the youngest fully emerged (uppermost) leaf blade on the rice plant; WS – whole shoot – entire aboveground portion of plant.

†† Nutrient concentrations required for adequate growth – the range of concentrations listed for the specific plant parts does not increase nor decrease plant growth or production. Concentrations lower than those listed may limit production and result in visual nutrient deficiency symptoms. ppm = mg\kg.

‡‡ Source: Slaton et al., 2001. p. 388-394. *Ark. Rice Res. Studies 2000.* Ark. Ag. Exp. Sta. Res. Ser. 485.

Management Key

Use ammonium sulfate as part of midseason N needs on fields with a history of late-season S deficiency.

Photo 9-4. Symptoms (on upper leaves) due to late season sulfur deficiency.

Photo 9-5. Sulfur deficiency occurring in sandy area of field.

Applications of elemental S have proven to be effective at reducing soil pH and improving rice productivity on calcareous soils with a history of high pH-related problems (Table 9-14). Application of 500 pounds S^0 per acre (90 percent S) has been required to reduce soil pH enough to affect rice grain yields. Also, different elemental S sources require different lengths of time to effectively lower soil pH (Table 9-15). Some elemental S materials break down in a few weeks while others may require months or years to effectively reduce soil pH to a desirable level. Increased rice growth and yield from elemental S application is attributed to the increased availability of other essential nutrients (e.g., P and Zn) from soil acidification and not from increased S nutrition. Application of ammonium sulfate will also reduce soil pH when applied at very high rates; however, elemental S is over twice as acidic as ammonium sulfate. Elemental S should be applied in the fall or winter to "problem" high pH areas to allow the product to be oxidized (e.g., broken down) and lower pH before seeding. Elemental S is an expensive soil amendment and will lower soil pH only temporarily if groundwater high in Ca and Mg bicarbonates is used. Lowering soil pH with elemental S can be expensive and should be done only after consultation with an Extension rice or soils specialist.

Table 9-14. Rice grain yield, soil pH and electrical conductivity as influenced by an elemental sulfur (S^0) product at two locations†.

S^0 Rate	Grain Yield	Soil pH	Soil EC
lbs/A	bu/A		µS/cm
0	120	7.5	338
223	123	7.4	347
446	130	7.0	490
670	134	6.8	609
893	141	6.8	611
1785	142	6.5	775

† Soil pH and EC measured in a 1:2 soil weight:water volume ratio 34 d after S^0 application.

Source: Slaton et al., 1998. p. 322-325. *B.R. Wells Rice Res. Studies 1998*. Ark. Ag. Exp. Sta. Res. Ser. 460.

Table 9-15. Influence of two elemental sulfur products on rice grain yields and soil pH 34 days after application.

	Grain Yield		Soil pH†	
S^0 Rate	Tiger 90	Wettable S	Tiger 90	Wettable S
lbs/A	bu/A		bu/A	
0	97	97	7.6	7.6
223	109	111	7.4	7.1
446	103	136	7.2	6.6
670	119	127	7.3	6.3
893	123	119	7.4	6.0
1,785	111	141	7.2	5.1

† Soil pH 1 year after 1785 lb S/A application was 6.6 and 5.5 for Tiger 90 and Wettable S, respectively.

Source: Slaton et al., 1998. p. 326-329. *B.R. Wells Rice Res. Studies 1998*. Ark. Ag. Exp. Sta. Res. Ser. 460.

Phosphorus and Potassium

Rice response to P and K fertilization is usually not as dramatic as that from N. Fertilization with P and K, when needed, may be accomplished in several ways. If rice is grown in a rotation of two years of soybean followed by one year of rice, addition of P and K, according to soil-test recommendations, to the soybean crop may provide adequate residual P and K for production of near maximal rice yields. If rice is grown continuously or in a 1:1 rotation with soybean, P and/or K fertilizer may need to be added directly to the rice crop to maintain productivity of the soil. Routine soil testing is the best available criteria to establish the necessity of applying P and K to rice and rotational crops.

Phosphorus

Phosphorus fertilizer recommendations for rice are based on soil testing for available P and soil pH (Table 9-16). Phosphorus availability to rice is optimum when the pH is below 6.5. For upland crops, P availability is usually optimal when the soil pH is between 6.0 and 6.5. In acid soils (pH < 6.0), the P is associated ("tied up" or "fixed") with iron (Fe) and aluminum (Al) compounds that are slowly available to most plants. When the soil pH is greater than 6.5, the P is primarily associated with Ca and Mg. Not all Ca and Mg phosphate compounds are slowly available to plants since their availability declines as pH increases. In acid soils, P availability increases following establishment of the permanent flood due to the chemical changes (e.g., reduction) that occur to the Fe phosphate. Thus, more P is usually available for rice uptake and not limited following the flood in soils with a pH < 6.5 than is measured with routine soil-test methods. In contrast, the availability of Ca phosphates tends to be low and may remain low for several weeks after flood establishment in higher pH soils (pH > 6.5). The Mehlich-3 soil test alone does not adequately predict P availability to rice. To improve the soil-test based predictions regarding the soil P availability to rice, both Mehlich-3 extractable P and soil pH are used in making P fertilizer recommendations (Table 9-16).

Table 9-16. Phosphorus fertilizer recommendations for flood-irrigated rice based on soil-test P (Mehlich-3) and soil pH (water pH measured in 1:2 soil:water mixture).

Soil-Test Level	Soil-Test P Range	Soil pH < 6.5	Soil pH ≥ 6.5
		lbs P_2O_5/A	
Very Low	< 9 ppm	50	70
Low	9-16 ppm	40	60
Medium	17-25 ppm	30	50
Optimum	26-50 ppm	0	0
Above Optimum	> 50 ppm	0	0

Soil-test methods currently used by both university and private laboratories are limited in their ability to predict rice response to P fertilization. All soil-P extractants or soil-test methods were developed for crops grown under upland (not flooded) conditions. Use of soil pH and soil-test P more accurately identifies soils that require P fertilization to produce maximal plant growth and yield in Arkansas. Soil pH is not static and can vary by as much as 1.0 pH unit during the year, depending on sample time, environmental conditions and other factors. Recommended P fertilizer rates based on soil-test P (Mehlich 3) and soil pH are listed in Table 9-16. Application of P fertilizer to undisturbed (i.e., nongraded) acid soils that test low in P has failed to show significant yield increases and, in some cases, has increased lodging (especially on lodging-sensitive cultivars), caused rank vegetative growth and/or decreased yield. The yield results in Tables 9-17 and 9-18 highlight the need for caution when applying P to lodging-prone cultivars or hybrids, especially on soils with a pH < 6.5.

Table 9-17. The effect of P fertilizer rate on grain yield and lodging of CL151, a high-yielding, lodging-prone variety.

P Fertilizer Rate	PTRS-2011† Lodging	PTRS-2011† Grain Yield	PTRS-2012‡ Lodging	PTRS-2012‡ Grain Yield
lbs P_2O_5/A	% lodged	bu/A	% lodged	bu/A
0	20	187	1	194
40-45	42	179	15	182
80-90	59	181	9	177
120	--	--	29	186

† 2011 Trial info: Calloway silt loam with an average soil-test P of 6 ppm and soil pH was 6.5 [Slaton et al., (2011) unpublished].

‡ 2012 Trial info: Calloway silt loam with an average soil-test P of 18 ppm and soil pH was 7.4 [Slaton et al., (2012) unpublished].

Table 9-18. Influence of P fertilizer application on whole plant P tissue concentration and grain yield at two locations during 1995†.

P Fertilizer Rate	Cross County pH = 8.0 Tissue P	Cross County pH = 8.0 Grain Yield	Poinsett County pH = 5.8 Tissue P	Poinsett County pH = 5.8 Grain Yield
lbs P_2O_5/A	%	bu/A	%	bu/A
0	0.10	64	0.32	155
40	0.10	119	0.36	143

† Mehlich-3 soil-test P was < 10 ppm for both locations.

Source: Wilson et al., 1996. p. 196-200. *Ark. Rice Res. Studies 1995*. Ark. Ag. Exp. Sta. Res. Ser. 453.

Management Key

Silt loam soils with a soil pH > 6.5 and very low soil-test P levels are most likely to result in yield responses to P fertilizer.

Many growers are concerned about very low soil-test P levels and are interested in raising these to higher values with extra P fertilizer application. Research has found that soil-test P usually declines (from previous soil-test times) when soil samples are taken following rice in the crop rotation, even when extra P fertilizer was applied. This decrease is usually representative of P availability to upland crops like soybean and is due to changes in soil P compounds under alternating aerobic-anaerobic soil conditions. In general, soil-test P slowly increases with time after rice fields are drained for harvest or when soil samples are collected after soybean is grown in the rotation the following year. The application of higher than recommended P fertilizer rates to increase soil-test P levels may be difficult and uneconomical when rice is grown in the rotation. The best strategy to ensure adequate P nutrition to crops is to apply the recommended rate of P fertilizer directly to each crop.

In addition to recommendations based on soil-test results, P fertilizer is also recommended when the soil has been recently precision graded.

For precision-graded soils, 40 pounds P_2O_5 per acre is recommended, unless the soil test calls for a higher amount. Phosphorus content tends to decline with soil depth and is usually needed on fields that have been precision graded. This is in addition to the recommended rate of poultry litter. Blanket P fertilizer applications to precision-leveled soils should be done for three to four years. If soil productivity appears to be restored to normal, applications of poultry litter and P may be discontinued or limited to "problem areas" within the field. Subsequent P applications should be based on soil-test results.

Regardless of the situation where P fertilizer is recommended, several fertilizer sources and application timing options are available to growers. Triple superphosphate (TSP, 0-46-0) is commonly used as the preplant fertilizer source. Diammonium phosphate (DAP, 18-46-0) is often competitive with TSP in price and is frequently used. Mono-ammonium phosphate (MAP, 11-52-0) and MicroEssentials (MESZ, 10-40-0-10S-1Zn) are other commercially available P fertilizers that may be available in Arkansas and suitable for application to rice. Research comparing multiple P sources has consistently shown no difference in rice grain yield or P uptake among P fertilizer sources. If other pre-plant fertilizers are not required, P fertilizer can be blended and applied with N applications made before flooding. Preflood P applications are as effective as preplant P applications and may offer a savings in application costs if applied aerially with preflood urea (Table 9-19). DAP is commonly used in this situation since it also contains some ammonium-N. On soils that have a history of P deficiency or are highly responsive to P fertilization, preflood application is sometimes better than preplant application.

Table 9-19. **Influence of P fertilizer application timing on rice grain yields at four locations.**

Time of Application	Davis Farm 1997	Davis Farm 1998	Wimpy Farm 1997	Wimpy Farm 1998
	bu/A			
Control	126	152	143	138
Pre-emerge	152	163	150	134
Preflood	143	170	156	139
Postflood (7 days)	157	187	156	136
Panicle Differentiation	131	163	147	133
Soil-test P (ppm)	10	17	28	20
Soil pH	7.6	6.8	8.0	7.7

Source: Wilson et al., 1999. p. 310-316. *Ark. Rice Res. Studies 1998*. Ark. Ag. Exp. Sta. Res. Ser. 468.

Recent research has shown no difference in rice P uptake or grain yield between fall- and spring-applied P fertilizer. However, on occasion, we have observed P deficiency of rice in fields that have received fall or spring P fertilization. Thus, there is lower probability of the P fertilizer being fixed into an unavailable form and seedling rice becoming P deficient when the P fertilizer is applied as close to rice planting (preplant or preflood) as possible on responsive soils. In fields, where P deficiency is not expected and P fertilizer is applied to maintain the existing soil-test P level at a Medium or Optimum level, P fertilizer may be applied in the fall or early spring. Situations where we do not recommend fall P fertilization include fields/soils that have low or very low soil-test P levels, will be flooded during the winter for waterfowl habitat and where crop P deficiency has been recently observed.

Management Key

If a high rate (50 to 70 pounds P_2O_5 per acre) of P is recommended, a split application may be useful on highly responsive soils (one-half to two-thirds applied preplant followed by one-third to one-half applied before flooding).

When seedling rice is P deficient, application of P fertilizer as late as panicle differentiation may improve growth and increase yield (Table 9-19). **However, the yield increase from P fertilizer applied at midseason is usually less than that from P fertilizer applied earlier in the growing season.**

Phosphorus deficiency symptoms on seedling rice may include severe stunting; small, very erect and dark green leaves; small diameter stems; lack of tillering and delayed plant development (Photo 9-6). Leaf chlorosis and bronzing may also be present on P-deficient seedlings. These symptoms may be followed by rapid deterioration of the older leaves, especially after the flood is applied. The symptoms have most commonly been observed 7 to 14 days after permanent flooding (mid-tillering). Symptoms may resemble those of zinc (Zn) deficiency and, like Zn deficiency, have been observed primarily on graded fields or alkaline (high pH) silt loam soils. Because of the similarity with Zn deficiency symptoms, plant tissue analysis is the best means for correctly diagnosing which nutrient is causing the poor rice growth (Table 9-13). Arkansas research suggests that at the mid-tillering stage (about two weeks after flooding) rice seedlings (whole aboveground plant) with P concentrations > 0.20 percent P are P sufficient, 0.15 to 0.20 percent P are low, and < 0.15 percent are likely P deficient.

Photo 9-6. Phosphorus deficiency of rice. Notice dark green streak with stunted plants and reduced tillering.

Rough rice grain has an average P concentration of 0.29% P (±0.02%) resulting in removal of 0.30 pound P_2O_5 per bushel of rough rice. An average rice yield of 200 bushels per acre will remove approximately 27 pounds of elemental P per acre, which is equivalent to about 61 pounds P_2O_5 per acre. The amount of P removed in the grain usually comprises 60 to 70 percent of the total aboveground P uptake. A mature rice crop, including grain and straw (all above-ground biomass), may weigh 20,000 pounds per acre (dry weight) and contain on average about 100 pounds P_2O_5 per acre. The rice straw typically contains 0.159% P (±0.06%) with a total content of about 40 pounds P_2O_5 per acre.

Potassium

Potassium fertilizer is recommended on soils that test < 131 ppm K (< 262 pounds K per acre, Table 9-20). Potassium fertilizer recommendations are based solely on soil-test K. The salts added by recommended amounts of K fertilizer are small compared to the amount of salts already in the soil or that are added with irrigation water. In K-deficient soils, rice yields are potentially more limited by inadequate K than by the potential salinity injury resulting from K fertilization. Application of P with K fertilizer may reduce salinity damage aggravated by K fertilizer application. Application of K fertilizer in the fall or several months before seeding also may help reduce the amount of salts in the root zone.

Management Key

Soils that test ≤ 60 ppm K (≤ 120 pounds K per acre) are very susceptible to K deficiency and receive a higher recommended K fertilizer rate to build soil-test K.

Rice grown on soils with a 'Medium' soil-test K level (91-130 ppm) usually will receive only nominal benefit from K fertilization (Table 9-20). However, K is recommended to account for spatial variability in soil-test K within fields, temporal variability in soil test K and to help maintain sufficient soil K levels for future crops. Silt and sandy loam soils in Arkansas have a low buffering capacity (i.e., ability to maintain soil-test K levels without frequent fertilization), and soil-test K can decline rapidly if K fertilizer is omitted for several consecutive crops. Potassium fertilizer should be applied before seeding or before flooding because plant uptake of K is most rapid during the first three or four weeks after flooding. Soils that have 'Very Low' soil-test K and are very sandy may benefit from split applications of K (i.e., preplant or preflood followed by a second application near the beginning internode elongation stage).

Potassium fertilizer is generally recommended when rice shows K deficiency symptoms during the season. Research has shown excellent yield response and prevention of yield loss from K fertilizer applied to rice with mild to moderate K deficiency at midseason (e.g., panicle differentiation) and late boot stage (Table 9-21). However, K fertilizer should be applied as soon as the K deficiency is positively identified since the magnitude of response tends to decline as rice approaches heading. Potassium fertilizer application after panicle exsertion begins has not, to our knowledge, been evaluated, but we speculate that the yield benefit of K fertilization after anthesis would be nominal and is therefore not recommended. Potassium fertilizer is very water soluble and when applied into the flood water or on the soil surface immediately before flooding will result in a significant portion of the applied K being dissolved in the floodwater. Thus, for postflood K applications, the K fertilizer should be applied and the floodwater kept static to prevent K movement within the field (areas with a high elevation to areas with lower elevation) for five to seven days. The recommended K fertilizer application rate for aerial application onto K-deficient rice is 60 pounds K_2O per acre.

Table 9-20. Potassium fertilizer recommendations based on soil-test K (Mehlich-3) in the top four inches of soil.

Soil-Test Level	Soil-Test K Range	K Fertilizer Rate
		lbs K_2O/A
Very Low	≤ 60 ppm	120
Low	61-90 ppm	90
Medium	91-130 ppm	60
Optimum	131-175 ppm	0
Above Optimum	≥ 175 ppm	0

Table 9-21. Rice yield response to K fertilizer (average of 60 and 120 lb K_2O/acre) applied at the 5-leaf stage, beginning internode elongation (BIE), and late-boot stage before panicle exsertion.

K Application Stage	Dry Matter	Grain Yield	Yield Difference
	lbs/A	bu/A	bu/A
No K applied	10,368	154	--
5-leaf or preflood	11,263	171	17
BIE or midseason	11,041	170	16
Late boot	10,679	164	10

Source: Maschmann et al. (2010; *Agronomy Journal* V102:163-170).

Potassium deficiency symptoms seldom appear on rice before the onset of reproductive growth (i.e., internode elongation). During vegetative growth, rice grown on K-deficient soils usually has a normal color with little or no reduction in tillering but may lack vigorous growth, making rice slightly shorter with some mild bronzing on the lower, older leaves. These symptoms are difficult to recognize and attribute to K deficiency in production fields. During reproductive growth, K deficiency symptoms include stunted plants (i.e., reduced height), droopy and dark green upper leaves (seldom seen in Arkansas), yellowing of the interveinal areas of the lower leaves starting from the leaf tip, leaf tips that eventually die and turn brown and development of brown spots on all leaves (Photos 9-7 and 9-8). The symptoms will often appear in and along the barrow ditches first.

Photo 9-7. Potassium-deficient leaf (top) compared to healthy leaf (bottom). Note severe brown spot and yellow/brown leaf margins of K-deficient leaf.

Photo 9-8. Potassium-deficient rice at heading. Note brown spot on leaves and panicles.

The deficiency symptoms generally start to appear near midseason and may first be noticed when the plants do not "green up" after midseason N is applied.
As the deficiency progresses, plants may develop severe disease infestation due to the plants' reduced ability to resist infection. Diseases that are normally insignificant, such as brown leaf spot and stem rot, may become severe in addition to diseases such as rice blast. While these diseases are typically more severe in K-deficient areas, they are not, by themselves, indications of K deficiency. Field observation also suggests that the development of severe brown spot is somewhat cultivar dependent. For example, brown spot was a more common symptom of K deficiency of cultivars grown in the 1980s and 1990s than on the currently grown varieties and hybrids. Reasons for this are not clear but may include, among other factors, plant genetics as it - pertains to disease resistance and changes in the efficacy of fungicides applied to rice.

Potassium is highly mobile in the plant, and deficiency symptoms occur first and tend to be most severe on the oldest (lower) leaves. As such, K deficiency symptoms will be worse on the lowest, oldest leaves. When the tips of the upper rice leaves turn yellow and then brown, it suggests that K deficiency is very severe and can be confirmed by examination of more severe symptoms on the older leaves or, in the absence of obvious K-deficiency symptoms on the older leaves, that another problem exists. The symptoms of yellowing and/or browning of leaf tips are not exclusively diagnostic of K deficiency but may be caused by a host of other factors and are often more pronounced on some cultivars and in some years. Application of an excessive N fertilizer rate often causes these symptoms. Plant tissue analysis is an effective means of determining whether K deficiency is the problem. Potassium-deficient plants often accumulate sodium (Na). Whole aboveground rice plant K concentrations > 2.00 percent at midseason (panicle initiation to differentiation stage) and > 1.3 percent at late boot are considered sufficient for the production of high yields. Healthy rice with sufficient K may have whole plant Na concentrations of 1,000 to 2,000 ppm and K-deficient plants usually have much higher Na concentrations of 3,000 to 10,000 ppm at the boot stage.

Potassium deficiency may also result in a situation known as **"hidden hunger."** This is when the plant does not have sufficient amounts of K to make optimum yields but deficiency symptoms are mild or not present. Hidden hunger has been observed in research areas where fertilized and nonfertilized plots look similar but yield differences of 20 to 50 bushels/acre have been measured (Table 9-22). For example, at the Lake Hogue location, severe stem rot was observed during late boot, but no leaf K deficiency symptoms were visible during the growing season. The average soil-test K at this site was considered Medium and K fertilizer would have been recommended, but the large yield response to K fertilization was not expected (Table 9-20). Therefore, it is imperative that fields be soil sampled and fertilized appropriately. Very Low or Low soil-test K levels can result in large yield losses with the plants providing few visible symptoms.

Management Key

Proper soil sampling and K fertilization is critical to avoid major yield losses from K deficiency.

Table 9-22. Influence of potassium rate on rice grain yield at four locations during 2005.

K Fertilizer Rate	Grain Yield: Poinsett	Cross	Lake Hogue	Pine Tree
lbs K_2O/A	bu/A			
0	107	179	133	189
40	150	196	159	193
80	152	195	160	196
120	158	195	163	202
160	157	183	176	197
LSD 0.10	19	10	13	n.s.
Soil Test K (ppm)	64	71	94	99

Source: Slaton et al., 2006. p. 333-340. *B.R. Wells Rice Res. Studies 2005*. Ark. Agr. Exp. Sta. Res. Ser. 540.

The K concentration in rough rice averages 0.28% K (±0.025%) resulting in removal of about 0.15 pounds K_2O per bushel. An average rice yield of 200 bushels per acre will remove approximately 30 pounds K_2O per acre. At maturity, the straw of a well-fertilized rice crop has an average K concentration of 1.40% K (±0.34%) and contains the equivalent of about 180 pounds K_2O per acre. Although in excess of 200 pounds K_2O per acre is contained in the rice grain and straw at maturity, only 10 to 20 percent of the K taken up is removed in the harvested grain. University of Arkansas K fertilizer recommendations are based on soil-test K and should help build soil K levels when soil-test K is below optimum because rice removes a low amount of the total K that is taken up. It should be remembered that immediately after harvest of any crop the K not removed by grain may still be in the stubble. Thus, soil-test K should increase as K leaches from stubble back into the soil with time.

Poultry Litter as a Fertilizer Source on Nongraded Fields

Poultry litter contains appreciable amounts of many nutrients (Table 9-23), including N, P and K, and may be used as an alternative to inorganic P and K fertilizers. The price of P and K fertilizers compared with the price and availability of poultry litter should be used to evaluate the economics/feasibility of using poultry litter or other manures and biosolids as a P and K source. When poultry litter is used as a P and K fertilizer, representative samples should be submitted to a qualified lab for analysis because poultry litter is not a homogeneous or consistent product; differences exist among houses, companies and/or poultry type. On average, one ton of poultry litter contains 65 to 66 pounds P_2O_5 and 46 to 59 pounds K_2O, making it equivalent to 144 pounds of triple superphosphate (0-46-0) and 77 to 98 pounds of muriate of potash (0-0-60). The nutrient content of the litter usually decreases as moisture content increases since litter is analyzed on an 'as is' or moist basis. Research shows that the P and K in poultry litter are plant available and should be applied at rates that supply the recommended P_2O_5 and K_2O rates. Fresh and pelleted forms of poultry litter behave similarly with regards to the plant availability of N, P and K.

Preplant incorporated poultry litter will also contribute some N to the current year's rice crop. Rice and weed growth before flooding is usually quite vigorous on silt loam soils receiving poultry litter. **However, research shows that only about 25 percent of the total N in poultry litter is recovered by rice grown in the delayed-flood system.** Thus, when poultry litter is applied preplant to delayed-flood rice, the preflood-N rate should only be reduced by 25 percent of the total N content of the poultry litter. For example, if 1.5 tons per acre of poultry litter that is 4.0 percent N is incorporated before planting, then 120 pounds of total N per acre has been applied in the poultry litter. To account for the poultry litter N, the preflood urea-N rate would be reduced by 30 pounds N per acre (120 pounds PL-N × 0.25). Much of the N in poultry litter applied preplant to delayed-flood rice becomes plant available (mineralized) within three or four weeks following application and can be rapidly converted to nitrate and eventually lost via denitrification when fields are flush irrigated or flooded. Applying poultry

Table 9-23. Mean and standard deviation of selected chemical and physical properties of moist broiler, hen and turkey litter samples analyzed by the University of Arkansas Fayetteville Agricultural Diagnostic Laboratory from 2005-2009.

Property	Broiler Litter		Hen Manure		Turkey Litter	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Observations	514	--	208	--	38	--
Moisture, %	30.2	8.9	39.7	15.9	29.5	7.9
pH	8.3	0.4	8.7	0.5	8.2	0.5
EC, µmhos cm^{-1}	11,400	2,410	7,734	2,486	8,545	1,769
Total C, %	25.5	3.9	19.4	6.78	26.6	3.3
Total N, %	3.08	0.51	2.06	0.89	3.53	0.76
C:N ratio	8.34	1.11	10.2	4.6	7.7	1.4
Organic N, %	85.2	6.1	82.7	11.4	85.0	5.9
NH_4-N, mg kg^{-1}	3,392	1,517	2,568	1,356	4,956	2,099
NO_3-N, mg kg^{-1}	420	800	365	783	227	319
Total P_2O_5, %	3.28	0.66	3.32	0.94	3.30	0.60
Total K_2O, %	2.96	0.50	2.29	0.55	2.66	0.36
Total Ca, %	2.38	0.71	5.66	1.68	2.40	0.44

litter to the soil surface with no incorporation or far in advance of planting may reduce the amount of N available to the rice crop. Greater amounts of the N present in poultry litter may be recovered by rice produced in water-seeded systems, but because water-seeding is not a common practice in Arkansas, no research has been conducted in this production system.

Growers interested in using poultry litter as a P and K source for rice should have the litter analyzed for its N, P and K content. The type of poultry produced, bedding material, composting and the frequency of house cleanout (number of flocks) influence the nutrient content of poultry litter. Several subsamples of poultry litter should be collected from the source (i.e., house, truck or stack) and divided into at least two or three composite samples. Poultry litter from different stacks or poultry houses requires separate composite samples. Composite samples of manure should be placed into quart-size, sealable bags and submitted to a reputable laboratory for analysis of total nutrient content. Samples can be sent to the University of Arkansas Division of Agriculture Fayetteville Agriculture Diagnostic Laboratory (479-575-3911) for analysis through the county Extension office. A small fee is charged for manure analysis.

Management Key

Poultry litter is an equivalent alternative to inorganic P and K fertilizers applied to rice, but only about 25 percent of the total N in poultry litter is equivalent to preflood urea.

The use of poultry litter as a nutrient source requires some precautionary measures. Poultry litter should not be applied at rates > 2 tons per acre because it contains appreciable amounts of soluble salts that may reduce rice stand density. Likewise, poultry litter contains relatively high amounts of P which can cause soil-test P to increase rapidly when applied repeatedly at high rates. Very high rates of P fertilization may reduce rice yields, increase lodging and induce deficiencies of other nutrients. For soils testing Very Low or Low in K, inorganic K fertilizer may still be required unless litter is applied at rates > 1 ton per acre. Poultry litter also has some liming properties and, when used continuously at moderate to high rates, may help maintain or perhaps increase soil pH.

Poultry litter also contains many micronutrients; however, the concentration of micronutrients (e.g., Zn) in litter is usually quite low, making poultry litter a poor source of micronutrients on deficient soils. For example, one ton of poultry litter usually contains < 0.1 pound B, 0.5 pound Zn, 0.7 pound Cu and 8 to 10 pounds of S. Repeated use of poultry litter or other animal manures may eventually build soil-test micronutrient levels.

Liming

Liming a soil is generally for the benefit of the other crops in the rotation because rice grows well in moderately acidic soil. However, rice yields may also benefit from lime when soil pH is near 5.0 or lower. Rice response to liming is often negative due to uneven lime distribution, excessive application rate and/or application to field areas that do not require lime. Deficiencies of P and Zn may occur in rice fields, especially near well water inlets, that have received recent lime applications. Thus, after liming, P and Zn fertilization of the next rice crop should be considered. Soil samples should be collected the year following lime application in the winter months before rice is grown to monitor changes in soil-test results and obtain updated fertilizer recommendations.

If liming is necessary to optimize the growth and yield of other crops in the rotation, the lime should be applied immediately after the rice crop and prior to the production of the rotation crop, not immediately ahead of the rice crop (Table 9-24). Use of grid soil sampling and variable rate application equipment are highly recommended for lime application to fields with rice in the rotation. If grid soil samples are not

Table 9-24. **Lime rates by soil texture for soils that have rice in the rotation†.**

	Soil pH			
Soil Texture	< 5.0	5.0-5.3‡	5.4-5.7††	5.8-6.2
	lbs ag lime/A			
Sandy loam	2000	2000	0	0
Silt loam	3000	2000	0	0
Clay loam	4000	3000	0	0
Clay	5000	4000	0	0

† Lime upper half of field only when well water calcium concentration is < 3 meq Ca/L and pH of water inlet area < 5.5.
‡ Apply lime to crops grown in rotation with rice in this pH range.
†† Consult soil-test recommendations to determine the lime recommendations for specific crops grown in rotation with rice.

used, take extreme care in soil sampling, especially if the irrigation water source is a well, so that a correct lime recommendation can be made in the appropriate areas of the field.

Follow correct soil sampling procedures so that soil-test results for lime and other nutrient recommendations are representative. If grid samples are not being collected, collect composite soil samples from the area near the water inlet, the center and the bottom portions of the field, as well as areas that differ in soil series or texture within these locations. **One composite soil sample should not represent more than 20 acres.** Composite samples near water inlets should represent no more than 5 acres. To determine the lime contribution of the irrigation source, the irrigation water should be sampled. Water sampling kits may be obtained at the county Extension office. Analysis of irrigation water is performed for a fee by the Arkansas Water Resources Center, Biomass Building Room 106, 2435 North Hatch Avenue, Fayetteville, AR 72704 (479-575-7317).

Zinc

Zinc deficiency normally occurs on silt and sandy loam soils or on precision-graded fields. The availability of native soil Zn is reduced when soil pH is increased either from the use of calcareous irrigation water, over-liming and/or exposure of Zn-deficient subsoils by land leveling. Correction of Zn deficiency requires reduction of soil pH and/or the addition of a suitable Zn source. Zinc deficiency is not commonly observed on clay soils in Arkansas, but it has been documented on a few fields that have been precision graded and/or have high pH.

Zinc deficiency, P deficiency and salinity injury symptoms are easily and often confused. Zinc deficiency symptoms are usually observed after flushing or flooding, whereas problems from salinity may occur prior to flushing or flooding under dry soil conditions or following irrigation if the irrigation water contains excessive salt. Salinity injury, P deficiency and Zn deficiency can all be present in the same field. Phosphorus deficiency is also similar to Zn deficiency in that the symptoms typically occur after flooding. However, leaves are usually more erect and leaf chlorosis (yellowing) at the leaf base (e.g., leaf blade above the collar) is usually not present with P deficiency. Also, Zn deficiency appears much sooner after the flood is established, usually within a few days, whereas it generally takes a week or two after flooding to recognize P deficiency. Plant tissue analysis is the most effective means of correctly distinguishing which nutrient is the cause of the unhealthy rice (Tables 9-13 and 9-25).

Table 9-25. Interpretation of whole plant (seedling) tissue analysis for salt (salinity), Zn and P concentration.

Analysis	Tissue Concentration† Normal	Possible	Probable
	mg/kg or ppm		
Zinc, ppm	> 20	15-20	< 15
Phosphorus, %	> 0.20%	0.15-0.20%	< 0.15%
Chloride, ppm	< 10,000	10,000-12,000	> 12,000
Nitrate, ppm	< 1,600	1,600-2,400	> 2,400

† **Normal** refers to healthy seedling rice tissue concentrations. **Possible** means that injury could be due to concentrations in this range. **Probable** means that injury was very likely due to concentrations in this range.

Zinc deficiency symptoms usually are not observed until shortly after flooding, when they have become severe enough that the flood must be removed in order to salvage the rice. However, rice seedlings are often Zn deficient before the flood is applied. Prior to flooding, the symptoms are usually subtle and difficult to recognize. Seedling rice can obtain sufficient nutrients from the seed for about 10 days after emergence. Therefore, Zn deficiency symptoms may not appear on rice seedlings until the 2- or 3-leaf stage. The Zn deficiency symptoms, whether subtle if observed before flooding or severe if observed after flooding, include:

1. Basal leaf chlorosis – the portion of the leaf nearest the stem becomes light green while the leaf tip remains a darker green. Usually begins in the youngest leaf (Photo 9-9).
2. Bronzing – consists of brown to red splotches starting on the surfaces of the oldest leaves (Photo 9-10). Bronzed leaf tissue may eventually turn brown. The midrib of the lower leaves may be pale green or yellow and be surrounded by the bronzed leaf tissue.
3. Short plants – stacking of leaf sheaths or joints makes the rice appear stunted and shorter than normal.

Photo 9-9. Basal chlorosis of bottom leaf and midrib of Zn-deficient plant.

Photo 9-10. Mottled discoloration due to chlorosis and bronzing of lower rice leaves caused by prolonged Zn deficiency. Note the stacked leaf collars on the plants to the left.

4. Flaccid plants or floating leaves – the leaves or plants may lose turgidity and float on the water surface if the rice is flooded or being flushed. Flushing seedling rice can aggravate Zn deficiency, cause the visual symptoms mentioned to become more noticeable and enable visual diagnosis before flooding to avoid a salvage situation. So pay close attention to the young rice when flushing. The loss of leaf turgidity is a difficult symptom to evaluate since deep water may also cause seedlings to elongate and lay on the water. Zinc deficiency symptoms are often noted within 72 hours after flooding and are aggravated by deep and cold water. Environmental factors such as cool temperatures or damage to the rice root system by insects or herbicides may increase the severity of Zn deficiency. Likewise, high P fertilizer rates may aggravate a Zn deficiency. Field history and soil pH combined with soil-test Zn are the two best methods for determining if Zn fertilizer is needed. Zinc deficiency should be documented by plant (Table 9-25) and soil analysis.

Zinc fertilizer recommendations are based on soil texture (silt and sandy loam soils), soil-test Zn (Mehlich-3 Zn ≤ 4.0 ppm) and soil pH (> 6.0, Table 9-26). When all three of these criteria are met, application of Zn fertilizer is recommended. The native soil-test Zn (Mehlich-3 Zn) for most topsoil in Arkansas is generally < 2.5 ppm. Zinc deficiency occurs primarily on soils with moderate to high pH (> 6.0) and low soil-test Zn (< 2.0 ppm). Soil-test Zn (Mehlich-3 Zn) levels greater than 4.0 ppm suggest a history of Zn fertilizer use, and a crop response to Zn fertilization is not likely. If soil-test Zn is high and rice continues to get sick after flooding, another nutrient may be deficient or the field may have a large variation in soil-test Zn within the field.

Table 9-26. Soil-test Zn and soil pH based Zn fertilization recommendations for rice.

Soil Texture	Soil pH	Soil-Test Zn Level and Concentration			
		Very Low	Low	Medium	Optimum
		≤1.5 ppm	1.6-2.5 ppm	2.6-4.0 ppm	≥ 4.1 ppm
		lbs Zn/A			
Sandy Loam and Silt Loam	> 6.0	10	10	1 to 10	0
	≤ 6.0	5 to 10†	0	0	0
Clay Loam and Clay	> 6.0	10	0	0	0
	≤ 6.0	10†	0	0	0

† Recommended for general maintenance of soil-test Zn.

When soil pH is ≤ 6.0 and soil-test Zn is Very Low (≤ 1.5 ppm), Zn fertilization is recommended as a precautionary measure on loamy and clayey-textured soils (Table 9-26). Application of a granular Zn source at 5 to10 pounds Zn per acre for loamy soils or 10 pounds Zn per acre for clayey soils is recommended to increase soil-test Zn, especially if well water is the irrigation source.

Zinc deficiency may be corrected by either acidifying the soil or applying a suitable Zn fertilizer source at the proper rate and timing. Acidification of the soil requires the addition of elemental S at 500 to 1,000 pounds per acre (Table 9-14) but is not likely economical. Repeated broadcast application of lower amounts of elemental S may not be sufficient to lower the pH and benefit the rice crop (Tables 9-14 and 9-15) unless the elemental S is applied in bands.

Zinc fertilizer may be applied on the soil before planting, as a seed treatment, on the soil surface after planting or as a foliar application to seedling rice. The Zn source determines the proper rate and application timing (Tables 9-27 and 9-28). Studies of granular Zn materials show that the degree to which granular Zn fertilizers dissolve in water is an indication of the relative effectiveness at preventing Zn deficiency. Granular Zn sources should have a minimum of 50 percent water solubility for optimum effectiveness. Sources with water soluble Zn concentration < 50 percent should either not be used or be applied at higher (15 to 20 pounds Zn per acre) Zn rates. It is very important that growers know the source/type of granular Zn that they are purchasing. The percent of water-soluble Zn is not always provided on Zn fertilizer labels but can be determined by a qualified laboratory.

Preplant and Delayed-Pre Zn Application

Granular Zn may be blended with P and K fertilizers and applied before planting. Preplant and delayed-preplant surface applications of Zn fertilizer are equally effective for dry-seeded rice. Zinc fertilizers might perform best when surface applied to fields that will be water-seeded. Root development under water-seeded conditions is slow; therefore, Zn fertilizer placement may be more critical for proper plant uptake. Highly water-soluble, granular Zn sources intended for soil application should be applied at 10 pounds Zn per acre. To calculate the total amount of Zn fertilizer required, divide 10 pounds Zn per acre by the guaranteed Zn analysis (i.e., 31 percent = 0.31) of the fertilizer. For example, 10 pounds Zn per acre of a Zn fertilizer having an analysis of 36 percent Zn requires 27.8 pounds of fertilizer to obtain 10 pounds Zn per acre [10 pounds Zn ÷ (36 percent Zn ÷ 100)]. Although the total uptake of Zn in a mature rice crop is less than 1 pound per acre, 10 pounds Zn per acre are required for adequate and uniform distribution of Zn fertilizer granules in the soil. Fertilizers with a lower guaranteed Zn analysis provide better distribution of fertilizer granules compared to higher analysis fertilizers with similar particle size.

Management Key

Granular Zn fertilizers with high water-soluble Zn content should be applied preplant to build soil test Zn when soil pH is > 6.0 and soil test Zn levels are Very Low.

Table 9-27. **Suggested zinc fertilizer sources and rates.**

Fertilizer Source	Actual Zinc lbs/A
Organic chelates EDTA, DPTA, etc.	1.0
Organic complexes ligno-sulfonates, phenols, citrates mixtures, etc.	2.0-2.5
Inorganic sulfates, oxysulfates	10.0
liquids such as nitrates and chlorides	2.0-2.5

Table 9-28. **Approximate Zn content and volume in quarts of liquid Zn fertilizer to supply 1 lb of elemental Zn for solutions with Zn concentrations** (Note this is general guide and the actual Zn content of liquid fertilizers will vary. Always read the fertilizer label to determine the exact composition of a fertilizer.)

Fertilizer Zn Concentration	Fertilizer Zn Content	Volume to Apply 1 lb Zn
% Zn	lbs Zn/gallon	quarts/A
4	0.40	10.0
6	0.62	6.5
8	0.80	5.0
10	1.00	4.0
12	1.14	3.5

Research also suggests that liquid Zn sources (Zn EDTA and Zn sulfate) may also be applied shortly before or after planting (i.e., pre-emergence). Liquid sources offer the advantages of more uniform distribution, lower use rates and, depending on the source, lower fertilizer cost when compared to most granular applications. Liquid Zn sources may be compatible for tank-mixing with most herbicides but the herbicide label should always be checked and a compatibility test performed before mixing. Please refer to Arkansas Cooperative Extension Service fact sheet FSA2166, *Checking for Compatibility of Herbicide-Fertilizer Combinations*. Avoid applying herbicides and/or herbicide Zn mixtures if the rice is stressed at the desired time of application since increased injury may occur. Application of herbicides under stressed conditions may result in a loss or reduction of stand. Inorganic Zn sources (Zn sulfate) applied in the liquid form before planting or emergence should be applied at 2 pounds Zn per acre and chelated Zn sources should be applied at 1 pound Zn per acre. The lower use rates of Zn applied in this manner offer less residual or future benefit of the Zn on future crops and soil-test Zn. Therefore, this approach is recommended only on soils that have Medium soil-test Zn levels (2.6-4.0 ppm Zn).

To calculate the proper volume of a liquid Zn source to apply, determine the amount of Zn contained in each gallon of material. The fertilizer label should provide the weight per gallon of material and the percent Zn in the fertilizer. The product of these two values divided by 100 is the pounds of Zn per gallon of liquid fertilizer. For example, a fertilizer with 6.5% Zn and weighing 11.8 pounds per gallon contains 0.77 pound Zn per gallon [(0.77/100) × 11.8 pounds per gallon)] and requires 5.2 quarts per acre to supply 1 pound elemental Zn per acre.

Zinc seed treatments are also an effective means of Zn fertilization for dry-seeded rice (Table 9-29). The advantages of Zn seed treatments are potential lower cost (depending on the Zn source and rate used to treat the seed) and uniformity of application. Zinc seed treatments require from 0.25 to 0.50 pounds of Zn per hundredweight of seed. Some sources and high rates of Zn applied to rice seed may reduce germination, so caution should be used when selecting new, untested Zn sources for seed treatment. As a rule of thumb, the higher Zn application rate (0.50 pounds Zn hundredweight of seed) should be used when soil pH is > 7.0 and soil-test Zn is relatively low (< 2.6 ppm) and/or when the seeding rate will be very low (< 50 pounds seed per acre).

Table 9-29. **Influence of Zn seed treatments on rice yields on two alkaline silt loam soils.**

	RREC†		PTRS†	
	Yield	Tissue Zn	Yield	Tissue Zn
Zn Rate	bu/A	mg/kg	bu/A	mg/kg
Check	114	17.5	130	17.5
10 lb Zn/A‡	158	31.0	143	19.4
0.10 lb Zn/cwt††	136	16.9	145	20.2
0.22 lb Zn/cwt	146	18.5	142	20.9
0.47 lb Zn/cwt	152	20.9	163	29.7

† RREC, Rice Research & Extension Center, Stuttgart; PTRS, Pine Tree Research Station.
‡ 31% Zn sulfate (> 95% water soluble Zn) preplant incorporated at 32 lb/A.
†† Zn sulfate applied to seed - values are net seed concentration after treatment.

Source: Slaton et al., 2000. *B.R. Wells Rice Res. Studies 1999*. Ark. Ag. Exp. Sta. Res. Ser. 476.

When soil pH is > 6.0 and soil-test Zn is < 2.6 ppm, Zn seed treatments alone may not provide sufficient Zn to prevent Zn deficiency. Another method of Zn fertilization (foliar or soil-applied Zn) should be used in place of or as a supplement to Zn-seed treatments under these conditions. **The amount of Zn retained on the seed after treatment rather than the amount applied is critically important.** Zinc oxide is the form of Zn used to treat seed because it usually has a high Zn analysis and allows for the lowest volume of Zn material to be added to the seed treatment equipment. However, Zn oxide formulations must be well mixed since the Zn can settle in the shipping container and contribute to lower than desired Zn addition. Most laboratories that perform plant and soil analysis can check the Zn concentration of treated seed. Submit a half pint of Zn-treated seed in a sealable bag to a reputable lab to determine the seed Zn concentration.

Management Key

Zinc seed treatments should only be used as the sole source of Zn fertilizer when the soil test Zn is ≥ 2.5 ppm.

The best approach for management of Zn nutrition in rice may be to build soil-test Zn levels above 4.0 ppm (Mehlich-3 soil test) with granular Zn applications and use Zn-treated seed or other low cost Zn fertilization methods for insurance on future crops.

Preflood Applications

Liquid organic chelate or inorganic sources can be applied from the 2-leaf stage to five to seven days prior to flooding. Application of liquid Zn immediately before flooding is discouraged since seedling rice may be Zn deficient before flooding. Application of Zn fertilizer to rice foliage five to seven days before flooding provides time for fertilizer uptake and correction of the Zn deficiency before the seedlings are stressed by flooding. Use of chelated Zn sources is advantageous only when the plants are very small (i.e., small leaf area) and most of the applied Zn solution will contact the soil. Chelated and inorganic Zn are absorbed with equal efficiency when applied to plant leaves. However, chelated Zn sources are mobile in the soil, which aids in Zn movement and uptake by plant roots, and the chelate protects the Zn from becoming fixed (or unavailable) by the soil for a short time. The rate of Zn is very important. The minimum recommended rate for foliar Zn application to rice is 1 pound Zn per acre. Finely granulated or powdered water-soluble forms of Zn sulfate may be dissolved and applied as a solution as an alternative to liquid Zn formulations. Dry formulations of water-soluble Zn sulfate are oftentimes cheaper per pound of Zn than liquid Zn formulations.

Management Key

Granular Zn sources are best for increasing soil test Zn.

Many of the products sold as chelates are not well labeled and are often mixtures that contain a very small portion of the Zn in the chelated form. If in doubt as to the reliability of the Zn source, use the higher rate recommended for the nonchelated organic and inorganic liquids. **The disadvantage of foliar or low-rate soil applications of Zn fertilizer is they benefit only the current rice crop and do not build soil-test Zn to provide residual benefit to future crops.** Application of granular Zn fertilizers a week or two before flooding is not recommended.

Management Key

Use Zn solutions when the application will be made after emergence and before the flood is established.

Salvage Treatment for Zn Deficiency

1. Drain immediately after detecting symptoms. The interval between draining and visual recovery from symptoms is usually 7 to 14 days. Correction of the problem by foliar applying Zn fertilizer while the field is still flooded is not recommended unless the Zn deficiency is detected early, flood depth is shallow, and the Zn deficiency is not severe.
2. When new root and shoot growth are observed, apply 1 pound Zn per acre to rice foliage.
3. 3 to 5 days after Zn application, apply 100 pounds ammonium sulfate per acre and apply shallow flood.

Zinc deficiency may delay plant development by as much as two to three weeks; however, yields approaching 90 percent of normal may be expected if the delay in development does not result in additional losses due to cold weather at heading.

Delaying the initial flood (e.g., past the 5-leaf stage) may help minimize Zn deficiency on high pH soils by allowing further development of the rice root system; however, this may also increase herbicide use to control weeds.

Salinity

Salinity damage occurs mainly on rice during the seedling stage and on larger rice located on levees both prior to and after flooding. Injury results when soluble chloride or nitrate salts (i.e., calcium, magnesium, potassium, sodium, etc.) become concentrated within the root zone of the seedling rice plant. Salt accumulation is often the result of irrigation water containing high quantities of soluble salts. In addition, salinity problems are commonly associated with poor soil drainage, and some soils and subsoils have naturally high levels of soluble salts. The poor soil drainage characteristics that are beneficial for flood maintenance in rice are the same characteristics that increase the likelihood of salinity. Salinity injury occasionally occurs when the field is flushed or flooded due to the irrigation water containing high levels of soluble salts.

When soluble salts are deposited in the soil, the salts may move vertically and horizontally in the soil profile with the water. During periods of high rainfall or irrigation, salts leach downward through the soil profile, the extent of which is determined by the soil's permeability, or salts may move laterally with the flow of water. During dry periods, water is removed from the soil through evaporation and salts move up and accumulate at the soil surface. Salt accumulation at the soil surface can reduce stands in certain areas of the paddy, such as the breaks of ridges, stagnant water areas (low spots) and on the top of levees. Usually salinity damage on levees does not occur until the field is flooded. Salt accumulation on the levee tends to be greatest on the top and deep water side of the paddy. The soil surface on top of the levee may have a black, oily appearance from the accumulation of salt and organic matter that was dissolved in the soil water prior to evaporation.

Research has shown that reduced tillage may enhance salt accumulation during the seedling growth stage on soils that have a history of salinity injury. Yield reductions of as much as 20 percent have been measured as the result of reduced tillage on soils that have a history of salinity damage (Table 9-30). Thus, it may be advantageous to avoid using conservation tillage practices on soils that have a history of salinity injury.

Table 9-30. **Influence of tillage on salinity and rice grain yields.**

Tillage Operation	Grain Yield	Salt in Root Zone at 2-3 Leaf Stage EC†
	bu/A	(μmhos/cm)
Conventional	146	585
Chisel Plow	158	500
Para-till	159	485
No-till	130	775

† EC, Electrical conductivity measured on a 1:2 soil wt: water volume ratio.
Source: Wilson et al. 2000. *SSSAJ* 64 :1771-1776.

Plant symptoms of salinity damage are as follows:

- Plants are usually at the 2- to 5-leaf stage. Rice is relatively tolerant to salinity during germination; however, it becomes quite sensitive to salinity during early seedling development.
- Symptoms include leaf tip die-back, leaf rolling, stunting and rapid death, increased sensitivity to herbicides and reduced stand density. Salt stressed plants may turn chlorotic (yellow), with the chlorosis beginning in the youngest leaves.
- Plant analysis usually indicates an excessive level of chlorides and/or nitrates in the tissue (Table 9-25).

Soil samples taken from the affected area may show an elevated electrical conductivity (EC) along with higher than normal levels of such cations as sodium, calcium, magnesium and potassium or anions such as nitrate and chloride. Salinity problems are difficult to predict from routine soil test results since salt concentrations in the topsoil are greatly influenced by precipitation. Salinity injury may occur on soils having an EC > 400 micromhos per cm (Table 9-31) for a mixture of one part soil to two parts water.

Table 9-31. **Saline and sodic soil identification parameters.**

Soil Condition	All Soil Textures
Saline Soil Condition	**Electrical Conductivity, micromhos/cm†**
Normal	< 150
Excessive	> 400
Sodic Soil Condition	**% Na Saturation‡**
Normal	< 3
Excessive	> 8

† Electrical conductivity as determined in a 1 part dry soil and 2 parts water (volume:volume) mixture.
‡ Exchangeable Sodium Percentage (ESP).

Management of Saline Soils

1. Flush the seedling rice frequently with good quality irrigation water that is low in salts to minimize accumulation of salts within the root zone.
2. Flood the rice as soon as it can tolerate a flood.
3. Have irrigation water tested for quality. When possible, minimize the use of poor quality water by substituting good quality surface water for poor quality groundwater. **CAUTION:** Surface water can also be of poor quality in regards to salt content. Salts are soluble, and water that is relifted from drainage ditches or tailwater recovery systems may actually increase in soluble salt content.

Occasionally, a field may have both a nutrient (Zn or P) deficiency and a salt problem. In this situation, diagnosing both problems is important. Apply the Zn as early as possible; otherwise, flushing the rice may intensify damage from Zn deficiency while attempting to reduce salt damage. In addition, the flush water must be applied and removed in the least possible time. This may require rearranging the flood gates.

Sodic soils are different from saline soils in that they contain very high amounts of exchangeable Na. Precision soil leveling may expose subsoils that are naturally high in Na. Sodic soils have a high pH and very poor physical properties. High amounts of exchangeable Na indirectly affect rice growth by causing poor soil physical properties. Poor physical properties, such as lack of soil structure, may make stand establishment more difficult. Some of the Arkansas soils that are classified as having Natric (sodic) subsoil horizons are the silt loam soils: Foley, Hillemann, Lafe and Stuttgart. The exchangeable Na percentage (ESP) of the topsoil and subsoil test results can be used to identify potential Na problems (Table 9-31).

Diagnostic Soil and Plant Tissue Sampling

In addition to routine soil tests (0 to 4-inch depth), diagnostic soil tests for salt content (EC), sodium, pH and calcium can help determine why seedling rice is dying. Diagnostic soil testing consists of sampling both the affected and unaffected areas at different depths (e.g., 0 to 1, 1 to 2 and 2 to 4 inch depths). Be sure to pay attention to differences in soil texture when sampling. **The likelihood of correctly diagnosing the problem increases when both plant and soil samples are collected.**

Correct diagnosis of nutritional problems is not always easily performed through soil testing and visual identification of deficiency symptoms. This is especially true of precision-graded fields. Plant tissue analysis should be used to help identify the nutritional or salinity problem(s) (Tables 9-13 and 9-25). Tissue analysis is offered through the University of Arkansas for a small fee. For seedling rice, complete plants (without the roots), of both healthy and unhealthy plants, should be submitted for analysis. About 30 to 40 seedlings are needed to provide enough tissue for analysis. Quickly but thoroughly rinse fresh plant tissue with clean water to remove soil contamination. Place the healthy and unhealthy seedlings in separate paper sacks and deliver to the county Extension office. Older plants can either be submitted as entire plants or samples of the affected tissues (i.e., top or bottom leaves). Consult with a specialist to determine which plant tissues might be the best to sample based on plant growth stage and the exhibited symptoms.

Results from plant tissue and soil analysis may not be received quickly enough to salvage a sick crop, but can be used to identify the problem and take corrective measures to avoid problems in future years. A method that frequently identifies and solves nutritional problems is the application of different fertilizers to small plots within the affected area. The nutrient(s) that give a growth response identifies the nutrient(s) that are limiting and should be applied. Usually a growth response from the fertilizer applied in the plots occurs in 3 to 5 days if the field is flooded or if the fertilizer has been watered into the soil. Phosphorus-deficient rice may take longer than 3 to 5 days to respond to P fertilizer.

Fertilization and Management of Precision-Graded Soils

Precision grading of fields for improved water management is continually being performed in eastern Arkansas. A decrease in productivity often results from precision grading of silt and sandy loam soils. Typically, when soils are precision graded, topsoil is removed from areas of higher elevation and deposited in areas of lower elevation. In many cases, the subsoil material that is exposed or moved is unproductive and difficult to manage. In these areas, it is generally true that the deeper the cut, the greater the decline in crop productivity and the more beneficial it will be to invest in soil reclamation. Routine soil testing is often unable to identify the nutrient(s) that are limiting plant growth on the cut areas. The application of poultry litter helps restore lost productivity to graded soils. Realizing that some soils may be graded without a loss of productivity, application of poultry litter to these soils may not be economical unless the soil also requires P and K fertilizer. For example, clay soils do not generally exhibit reduced productivity following grading and seldom require both P and K fertilizer. Graded fields of silt loam soil that have the topsoil removed, stockpiled and replaced after the field is put to grade generally do not have as great of loss of productivity as compared to fields that do not remove/stockpile the top soil prior to grading. The following is a summation of research conducted to refine recommendations for the application of poultry litter and fertility management on precision-graded soils. Suggestions on rice crop management have also been included where appropriate.

General Fertility

Adjust the recommended N rate for the cultivar to be planted by reducing the N rate by 25 percent of the total N in poultry litter (*see previous section on poultry litter as a fertilizer source*). Litter commonly contains 2 to 4 percent N (Table 9-23). However, only about one-half of the total N in poultry litter becomes available during the first growing season and at least half of that is mineralized and nitrified prior to flooding and lost via denitrification after flooding.

Although routine soil testing may not identify specific fertility problems on precision-graded fields, soil samples should be submitted for general recommendations for P, K and Zn and to identify potential problems with pH and Na levels. Refer to the *Rice Production Handbook* sections that discuss P, K, Zn and saline and sodic soils for recommendations.

Application of at least 40 pounds P_2O_5 per acre is recommended on precision-graded soils because the P content of many Delta subsoils is very low. If the soil-test P is high (> 50 ppm) P may not be needed. Rice growing on graded soils frequently responds to P fertilization (Table 9-32). The application of both poultry litter and P fertilizer may produce yields in excess of those obtained when either material is applied alone, especially on deep cuts.

Inorganic fertilizer (P, K, Zn and S) has in some cases increased productivity of precision-graded soils (Table 9-33); however, yield responses to commercial fertilizer applications alone have been inconsistent and are not always as great as those from poultry litter. Trial results also indicate that inorganic fertilizer is less effective on soils with deep cuts (> 6 inches). Apply inorganic fertilizer in amounts recommended by soil-test results, in addition to poultry litter. Diagnostic soil testing and plant tissue analysis may be useful to correctly identify nutritional problems in unproductive field areas during the growing season.

Table 9-32. Rice yield response on precision-graded silt loam soils to poultry litter and P fertilizer.

Treatment	Grain Yield		
	Lewis Farm	Connor1 Farm	Connor2 Farm
rate/A	bu/A		
Control	40	106	88
46 lbs P_2O_5	52	124	121
2000 lbs litter	114	129	142
46 lbs P_2O_5 + 2000 lbs litter	101	135	164

Table 9-33. Rice grain yield response comparing inorganic fertilizers and poultry litter on precision-graded silt loam soils.

Location/Year	Grain Yield		
	Control	Inorganic Fertilizer	Poultry Litter
	bu/A		
Lewis, 1989†	40	73	114
Connor1, 1989†	106	113	129
Connor2, 1989†	88	144	142
Connor, 1990‡	50	80	88
Dunklin East, 1992††	9	32	80
Dunklin West, 1992††	37	93	99

† Litter: 2000 lbs compost/A; Inorganics: 1 lb Zn (Zn EDTA) + 2 tons gypsum + 46 lbs P2O5 (TSP)/A.
‡ Litter: 2000 lbs fresh litter/A; Inorganics: 1 lb Zn (Zn EDTA) + 20 lbs S (elemental S) + 72 lbs K2O (KCl) + 46 lbs P2O5 (TSP)/A.
†† Litter: 2000 lbs fresh litter/A; Inorganics: 300 lbs Rainbow Mix/A (10/14-4-11(S)-2(Zn)).

Management Key

Poultry litter is currently the only soil amendment that is recommended for restoring the productivity of precision-graded soils.

Products sold as soil amendments often claim to restore the productivity of precision-graded soils. The University of Arkansas has compared some of these products to poultry litter in field tests and found that they are not the equivalent of poultry litter and are oftentimes inferior to inorganic fertilizer application. Biosolids and other animal manures may be useful for reclaiming graded soils, but have not been evaluated in replicated research.

Rate of Poultry Litter

Poultry litter is a viable source of P and K on undisturbed soils, but the most unique benefit of litter is restoring lost productivity to subsoil that has been exposed by land leveling. Numerous research studies indicate that poultry litter rates less than 1,000 pounds per acre are inconsistent in producing significant yield increases on precision-graded soils (Table 9-34). Consequently, no less than 1,000 pounds of litter (dry weight basis) per acre should be applied to graded soils. When applying litter, adjust the application rate to compensate for the moisture content of the litter. For example, 1,000 pounds of fresh litter at 30 percent moisture contains about 300 pounds of water and 700 pounds of litter. Poultry litter data included in Tables 9-32 through 936 refer to dry weight litter rates.

Research shows that spring applications of litter produce higher rice yields compared to fall applications of equal amounts (Table 9-35). Results also indicate that pound for pound, fresh, composted and pelletized litter produce equal yield responses (Table 9-36). Since timing of poultry litter influences yield response, the frequency of litter applications is also important to maximize production in future years.

A single application of litter after leveling produces higher yields for several years compared to precision-graded areas which did not receive any litter. Litter has a small residual effect and may increase production for several years. The greatest benefit of litter applications to grain yield occurs the first year (Table 9-37). Grain yields were lower for the second year after litter application when no additional litter was applied.

Table 9-34. Rice grain yield response to various poultry litter rates in 1992 and 2004.

Location	Grain Yield: Poultry Litter Application Rate (dry weight basis)					
	0	250	500	750	1000	2000
	bu/A					
Arkansas County-East†	29	68	65	83	82	103
Arkansas County-West†	9	19	46	57	78	87
Prairie County‡	4	35	44	--	73	114
Poinsett County‡	77	94	109	--	125	137

† Composted poultry litter (Unpublished data, 1992).
‡ Mean of Fresh and Pelleted litter (Unpublished data, 2004).

Table 9-35. Grain yields of fresh poultry litter applied in the spring at five rates on shallow and deep cuts of a precision-graded field near Lodge Corner, Arkansas.

Litter Rate	Grain Yield: Shallow Cut (< 6 inches)		Deep Cut (> 6 inches)	
	Spring†	Fall	Spring	Fall
lbs/A	bu/A‡			
0	37		9	
1000	86	58	45	5
2000	99	79	80	22
4000	111	80	98	47
6000	102	88	107	73

† Fresh litter applied in October (fall) and June (spring) on a dry weight basis.
‡ Field seeded with Lemont rice on June 16, 1992.

Table 9-36. Comparison of rice grain yields when fresh and composted poultry litter were applied in the spring on a precision-graded field†.

Litter Rate	Grain Yield: Litter Source‡	
	Fresh	Composted
lbs/A	bu/A	
0	37	
1000	86	94
2000	99	103
4000	111	110
6000	102	102

† Field seeded in Lemont on June 16, 1992, near Lodge Corner, Arkansas.
‡ Litter applied on a dry weight basis.

Table 9-37. Rice yield response for the second year following fresh poultry litter application for two consecutive years on a precision-graded field compared to one single application at three nitrogen fertilization rates.

Litter Application Time	PF N Rate†	Grain Yield: Litter Application Rate, lbs/A (dry weight basis)				
		0	900	2700	5400	8100
	lbs N/A	bu/A				
1st and 2nd year	0	12	23	54	86	103
1st year only	0	12	--	22	--	31
1st and 2nd year	40	17	36	81	87	115
1st year only	40	17	--	31	--	54
1st and 2nd year	80	29	70	82	92	90
1st year only	80	29	--	70	--	80

† PF = Preflood.

Sequential litter applications may be needed to fully restore lost productivity to graded soils. Usually the deeper the cut, the longer the litter has to be applied. Shallow cuts usually require only a year or two of litter application and the deeper cuts may require three to five years of litter application for full restoration of productivity.

Management Tips

Management of rice on precision-graded fields is difficult since the severity of lost production is unknown and reasons for poor growth are not easily identified. The locations of areas which may have poor growth are often random and unknown prior to planting. Areas of poor growth may be the result of a combination of factors or due to a single nutritional problem. Due to the variability of graded soils, a complete set of management guidelines that would apply to all situations is impossible to assemble, but certain guidelines can be followed to reduce spending large amounts of money to produce a low yield.

Before starting the leveling process, study the county soil survey maps to determine the soil series within the field to be precision-graded. Web (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) soil survey reports provide the physical and chemical properties of the topsoil and the subsoil which may be exposed. This helps pinpoint certain problems that may be present after leveling. Further information can be obtained by soil sampling the topsoil and the subsoil to the depth that the field will be graded. The use of global positioning systems (GPS) and grid soil sampling of both topsoil and subsoil can pinpoint areas in the field that may present problems if the topsoil is removed via precision grading.

Cultivar selection is very important for precision-graded fields. Select a cultivar that has good grain and milling yield potential but has a low cost of production. Semi-dwarf cultivars usually have higher production costs for weed control, N fertilization and sheath blight control compared to taller cultivars. Reduced growth may intensify yield reductions caused by sheath blight and nutritionally stressed plants may also be more susceptible to yield losses from blast infections. Nutritional disorders associated with graded fields often delay maturity; therefore, timely seeding is also important. Poor soil physical properties (i.e., soil structure) regularly occur in graded fields. This may affect seedling emergence and flushing frequency to establish an adequate stand of rice. Consider a cultivar that has excellent seedling vigor and seed treatments that aid in quick, uniform stand establishment. Hybrids are excellent choices for graded fields due to their excellent disease resistance, yield potential, seedling vigor and extensive root systems that allow them to take up nutrients in deficient or problem soils better than conventional varieties; however, ensure an adequate seeding rate and subsequent plant stand to achieve better results.

A preemergence or delayed preemergence residual herbicide may provide effective and economical weed control. However, some residual herbicides are not labeled for use on first year precision-graded fields or caution that increased injury may occur from herbicide application. Always read the entire label. Stressed rice seedlings may also be sensitive to contact herbicide applications, resulting in excessive injury or reduced stands. Observation of winter vegetation growth and previous crops (if any) may help identify field areas that have poor production prior to seeding. If this is the case, application of higher rates of litter to these identifiable areas may be helpful. Diagnostic soil tests may also be submitted as an aid to identify the problem.